3. LIMITING FACTORS, THREATS & IMPACTS

This chapter provides a general overview of limiting factors and threats affecting lower Columbia River salmon and steelhead. Limiting factors are described in relation to the biological needs of the species, and the threats are those activities that affect limiting factors. Threats relate directly to the statutory listing factors described in Chapter 4 (Goals, Criteria & Objectives) and guide specific strategies, measures and actions detailed in Chapter 5. Species-specific descriptions of threats are summarized in Chapter 3. This chapter also describes impacts which attempt to quantify the biological effect of each threat on each species and population. These quantitative estimates are the basis for threat-specific impact reduction targets and benchmarks defined in Chapter 6.

3. LIMITING FACTORS, THREATS & IMPACTS

Tables

Figures

3.1. Overview

The acute status of lower Columbia River salmon and steelhead results from the combined effects of habitat degradation, dam building and operation, fishing, hatchery operations, ecological changes, and natural environmental fluctuations. Understanding limiting factors, threats, and impacts is essential to the development of an effective recovery plan that addresses statutory listing factors considered in the ESA determinations for these species. Descriptions and estimates of limiting factors, threats, and impacts in this chapter are based on an extensive review and synthesis of the published and unpublished scientific literature for these species in the lower Columbia River region.

Limiting factors are described in relation to the biological needs of the species and include a wide spectrum of conditions that affect salmon throughout their life cycle and migration from freshwater streams, through the mainstem Columbia River and estuary, into the far reaches of the North Pacific Ocean, and back again (Figure 3-1). These include in-basin and out-of-basin influences as well as human and natural operating factors. Failure to consider all life cycle factors can result in the overlooking of key limitations or changes in one area that potentially offset gains in other areas. It would be of little benefit to improve tributary habitat conditions and productivity if gains there were offset by increased mortality in the mainstem, estuary, and ocean. Conversely, improvements in multiple areas can provide compounding benefits over the course of the life cycle. For instance, benefits from improvements of tributary habitat are enhanced where downstream improvements also improve survival such that the full effects of tributary improvements may be realized.

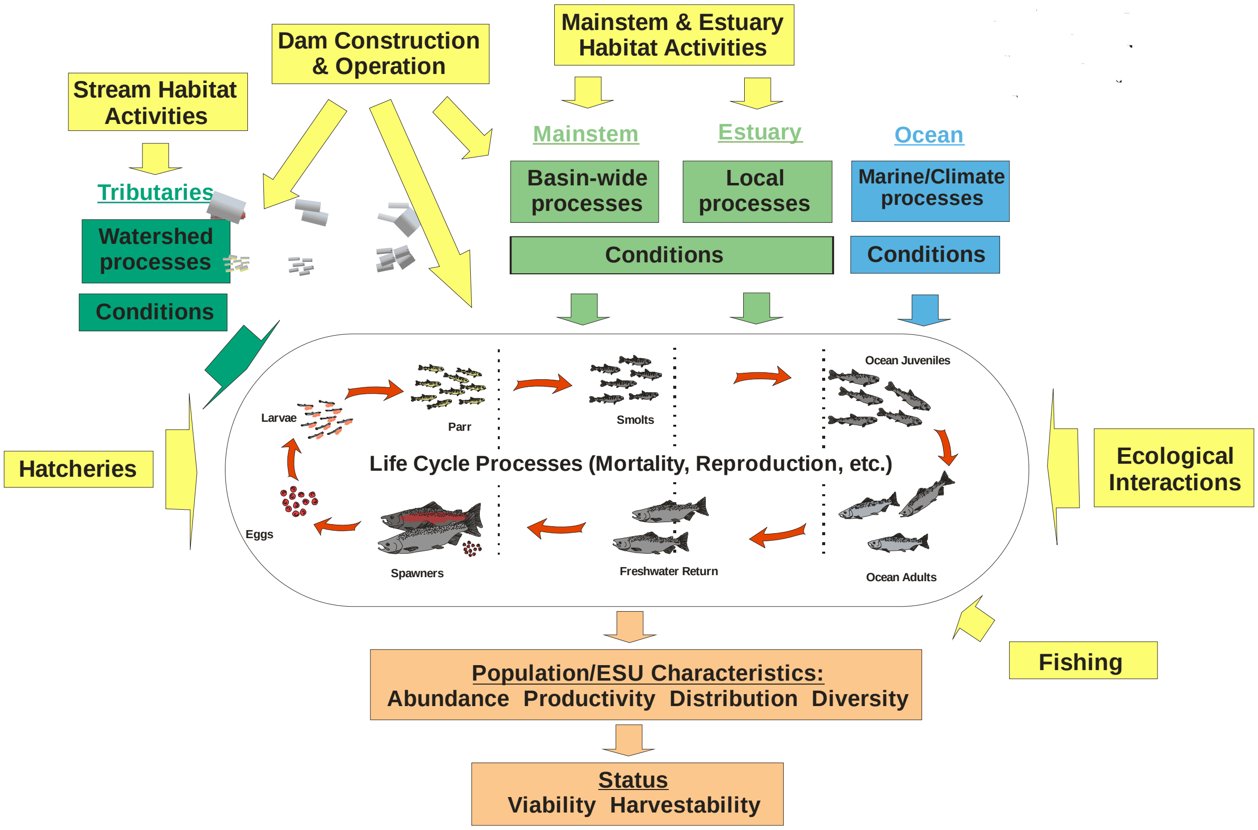

Figure 3-1. Relationship of listing factors, influences on the salmon life cycle, and species status.

Threats describe human activities or other dynamics that affect the limiting factors. This Plan identifies seven categories of threats: 1) stream habitat, 2) Columbia River mainstem and estuary habitat, 3) dams, 4) fisheries, 5) hatcheries, 6) ecological interactions, and 7) climate/ocean. For listed salmon, threats are sometimes categorized and referred to as the ‘4 Hs’ (hatcheries, harvest, hydropower, and habitat) although this label oversimplifies the complexity of direct and indirect relationships and the relative scale of impacts of the different factors that affect fish.

Threats address the statutory listing factors that contribute to low or declining species viability and threaten the probability of long term species persistence. Section 4(a)(1) of the ESA and NMFS’ implementing regulations (50 CFR part 424) state that NMFS must determine whether a species is endangered or threatened because of any one or a combination of the following factors: (1) the present or threatened destruction, modification, or curtailment of its habitat or range; (2) overutilization for commercial, recreational, scientific, or educational purposes; (3) disease or predation; (4) inadequacy of existing regulatory mechanisms; or, (5) other natural or man-made factors affecting its continued existence. Listing factors are discussed in more detail in Chapter 4 (Goals, Criteria & Objectives).

By identifying the threats to recovery, specific recovery strategies and measures can be developed which would guide actions at the subbasin level to mitigate the threats. A comprehensive treatment of all threats helps ensure equitability in balancing the costs of salmon recovery among different stakeholders. Without a systematic treatment for weighing impacts, discussions of site and action-specific recovery actions are easily confounded by counterproductive finger-pointing.

This Plan takes an ecosystem approach to salmon recovery which considers factors and threats that affect every species. This chapter provides a general discussion of limiting factors and threats which serves as an overview or menu for all species. Species-specific assessments of factors and threats are treated in Chapter 6 (Species: recovery strategies and benchmarks). Population-specific limiting factors are detailed for each population at the habitat scale in Volume II. Population-specific threats are identified in this plan based on quantitative estimates of the impact of each threat on each fish population. Impacts are defined as proportional reductions in abundance and productivity due to potentially-manageable threats. Impacts are most intuitively understandable as mortality rates (e.g. fishing, dam passage, and predation) but also include other effects that reduce fish numbers including loss of tributary rearing capacity due to blockage and habitat degradation, reduced estuary survival due to habitat changes, and reduced natural population productivity due to interbreeding with less-fit hatchery fish. Impacts are described in greater detail in Chapter 4 (Goals, Criteria & Objectives).

Impact estimates place each listing factor in context relative to the others by distinguishing factors with large impacts from factors with relatively small impacts. Estimates illustrate the magnitude of effect that needs to be addressed with substantive action and are the basis for strategic impact reduction targets identified to meet viability objectives and population productivity improvement objectives identified for each population in order to meet the recovery scenario described by this Plan.

Impact estimates were developed using a combination of direct empirical estimation, inferences from other populations or areas, indirect analyses (EDT analysis of habitat data for instance), interpretations of our current scientific understanding of fish biology and system dynamics, or working hypotheses that are testable as part of Recovery Plan implementation. The diverse sources and nature of the information makes it difficult to quantify the uncertainty in specific estimates. Clearly the uncertainty in specific point estimates is significant and caveats for their application are in order. In addition, not all human impacts are quantifiable with the available information. Despite these limitations, the results are accurate representations of the available scientific information for the purpose of describing the order-of-magnitude significance of potentially manageable threats. Additional information on definitions and derivation of impact estimates may be found in Appendix E, Chapter 10 (factor analysis). Additional detail on the use of the EDT model may be found in Appendix E, Chapters 6 (EDT application), 7 (EDT documentation), and 9 (EDT comparison).

3.2. Habitat –Streams

3.2.1. Background

Large and pervasive habitat effects resulting from human activities are the primary factor responsible for the decline of lower Columbia River salmon and steelhead. Many of the current threats to the future of listed salmon and steelhead, including harvest and hatchery problems, are the result of unsuccessful attempts to compensate or mitigate for more fundamental habitat problems. Healthy stream habitat, including cool stream flows, clean gravel beds, and deep pools, is critical for sustaining these fish species. These essential habitat features have been almost universally altered or degraded by urbanization, logging, agriculture, road building, gravel mining, channelization, and water withdrawals.

Healthy streams require healthy watersheds and the magnitude of habitat impacts is readily apparent at a watershed scale (Figure 3-2). Large urban and residential zones have been developed in lower elevation valley floor areas along the Columbia River and I-5 corridor from Vancouver to Longview under City, County, and State regulation. Lower elevation valley and foothill areas are typically developed in rural, agricultural, managed forest, or mixed use under County and State regulation. Rain dominated low to mid elevation areas are typically in mixed or managed forest use under Washington Department of Natural Resources regulation. Higher elevation snow-dominated areas are typically forested and managed as Federal and Industrial/Commercial Forest Lands under U. S. Forest Service and Washington Department of Natural Resources regulation.

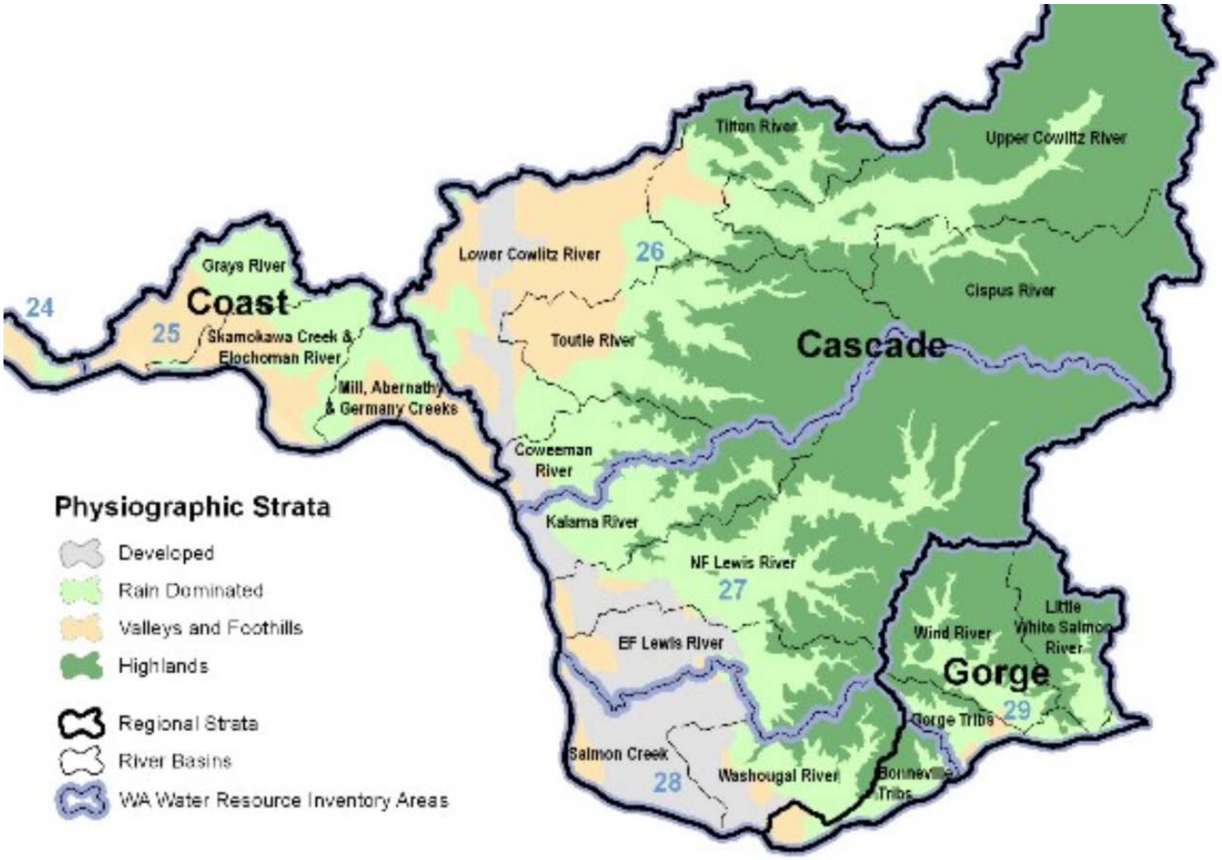

Figure 3-2. Spatial and physiographic strata of the lower Columbia River region reflecting topographic, watershed condition, land use patterns of significance to fish habitat.

3.2.2. Limiting Factors

The habitat limiting factors described below are believed to be impacting healthy life cycles and natural production of salmonids in the lower Columbia region. The information is focused on limiting factors at the stream channel scale.

Passage Obstructions

Processes and Effects—Fish passage barriers that limit habitat connectivity and access to spawning and rearing habitats are a significant factor affecting salmon populations in many Northwest watersheds. Barriers in lower Columbia watersheds primarily include culverts and dams with occasional barriers such as irrigation diversion structures, fish weirs, beaver dams, road crossings, tide gates, channel alterations, and localized temperature increases.

Passage barriers effectively remove habitat from the subbasin, thereby reducing habitat capacity. In situations where a substantial amount of historic spawning or rearing habitat has been blocked, such as in the Cowlitz or Lewis River subbasins, production potential of salmonid populations have been severely reduced. To some degree, depending on the species, formerly unused downstream habitats may compensate for the lost upstream habitat. For example, Chinook or chum salmon may be able to adapt to spawning/rearing in subbasin mainstem habitats below barriers while coho salmon and steelhead are less likely to utilize mainstem habitats because they are more commonly found spawning in headwater portions within the subbasin. However, the degree to which downstream habitats may be utilized after the construction of passage barriers is limited by the downstream effects of those barriers, such as alterations of flow and temperature as a result of hydropower or flood control dam operations.

As early as 1881, Washington enacted legislation to protect fish access to habitat by disallowing the installation of barriers or providing for their removal. Recent efforts include an appropriation by the 1998 state legislature of $5.75 million to inventory and repair barriers throughout the state. Despite these efforts, barriers continue to be a problem in the lower Columbia region.

Box 3-1. Passage Limiting Factors

- Blockages to stream habitats because of structures,
- Blockages to stream habitats because of impaired water quality or channel morphology,
- Blockages to off-channel habitats because of flow alteration, dikes, and levees,
- Blockages to estuarine habitats because of dikes, levees, and tide gates,
- Direct mortality because of structures, and
- Direct mortality because of stranding in diversion channels.

Although dams are responsible for the greatest share of blocked habitat, inadequate culverts make up approximately 86% of all barriers in the lower Columbia region (WDFW 2010). Estimates made from culvert surveys throughout the state indicate that approximately half of culvert problems are related to private and public logging roads (Washington State NRC 1999). The 1950s saw the beginning of extensive road building associated with increased logging activities. Many early logging roads were not outfitted with properly-sized culverts, and despite recent efforts to upgrade critical road crossings, an extensive backlog of passage restoration projects remain.

Current Conditions — The major hydropower systems on the Cowlitz and Lewis rivers are responsible for the greatest share of blocked habitat. Culverts and other barriers are also a concern throughout the region. A region-wide view of barriers to anadromous fish and the extent of upstream blocked habitat are depicted in Figure 3-3.

- In the Lewis River basin alone, the 240-foot high Merwin Dam has blocked 80% of the available steelhead habitat since 1931 (WDFW 1993). The dam blocked the majority of the spring Chinook habitat as well.
- In the Cowlitz basin, the three mainstem dams inundated a total of 48 miles of historical steelhead, Chinook, and coho habitat.
- The Sediment Retention Structure (SRS) on the North Fork Toutle River is a total barrier to salmonids. The Toutle Trap just below the SRS, which is the trapping facility for all salmonids returning to the upper N.F. Toutle River, has been difficult to operate in recent years due to increasing amounts of debris and sediment coming down from the SRS.
- Throughout the region, as many as 800 culverts have been identified that block passage of salmonids. The bulk of these are associated with private and public logging roads.

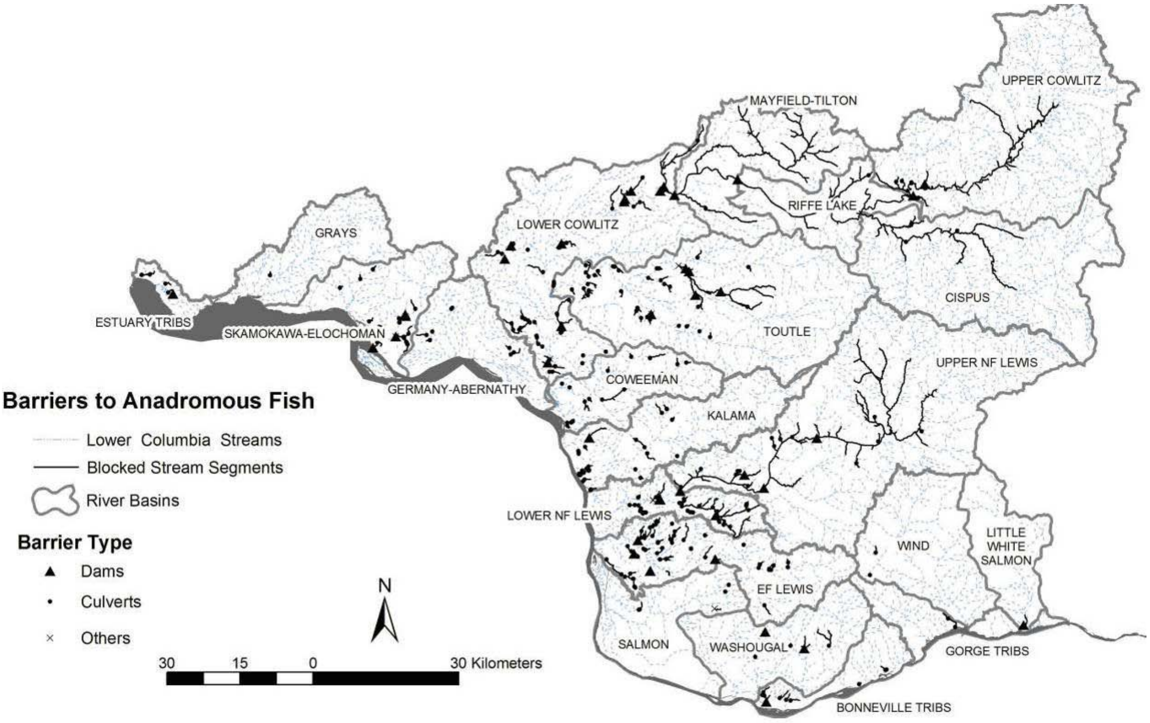

Figure 3-3. Regional map depicting blockages to anadromous fish and the extent of potentially accessible stream segments above blockages. Blockages and potential stream segments are included if passage for any anadromous species is obstructed. The primary source for these data is the Salmon and Steelhead Habitat Inventory and Assessment Project (SSHIAP).

Stream Flow

Processes and Effects — Stream flow patterns are controlled by local climate, geology, basin topography, land cover, and ocean climate patterns. Two annual stream flow patterns dominate in the lower Columbia region. High elevation basins typically experience a flow regime dominated by snowmelt, with peak flows occurring during spring melt conditions, whereas lower elevation basins experience winter peak flows as a result of winter rain storms.

Habitat conditions for fish are created and maintained by natural streamflow regimes including regular seasonal patterns and periodic floods (Poff et al. 1997; Bisson et al. 1997). However, increased flood volume or frequency can increase hillslope sediment delivery and alter channel morphology through bed and bank erosion (Chamberlain et al. 1991). Increased winter and spring flows can also scour fish eggs and alevins from the gravel or displace juveniles from rearing habitats (e.g., Pearsons et al. 1992, Montgomery et al. 1996). Decreased summer low flow volumes can reduce available habitat area and increase stream temperatures. Alterations to summer and fall flows may impact spawner distributions and juvenile rearing success.

Rate, duration, and magnitude of water runoff are affected by land cover. Alterations can decrease soil infiltration, interrupt subsurface flow, and increase snow accumulation and melt rates. Although rainfall is abundant in western Washington, much is lost as evapo-transpiration due to the dense forest cover. Precipitation that is not lost to evapo-transpiration or deep groundwater storage enters streams via three primary methods: surface flow (rapid), shallow subsurface flow (slow), and groundwater flow (very slow). In undisturbed basins, shallow subsurface flow accounts for nearly all of the runoff entering stream channels, except during periods of low flow when groundwater sources dominate (Ziemer and Lisle 1998). The lack of surface runoff in an undisturbed basin is due to the rate of infiltration exceeding precipitation. If the infiltration rate is changed, then precipitation that normally transmits slowly to stream channels as subsurface flow or that contributes to groundwater storage is instead rapidly transported as surface flow. This can decrease the amount of groundwater available to supply flow to streams in dry periods and can increase the magnitude and rate of peak flows during storm events.

Box 3-2. Streamflow Limiting Factors

- Altered magnitude of flows (decreased low flows, increased peak flows),
- Alterations to the duration of flow events,
- Alterations to the rate of change of flow,
- Alterations to the natural temporal pattern of stream flow,
- Channel de-watering,
- Lack of channel forming flows,
- Disrupted sediment transport processes, and
- Increased contaminant transport (urban and agriculture runoff).

These conditions are especially prevalent in urbanizing basins, where native vegetation has been converted to impervious surfaces such as pavement, rooftops, and lawns (Leopold 1968, Fresh and Luchetti 2000). The drainage network in the form of gutters, drains, and storm sewers further increases the magnitude and rate of delivery of storm flows to downstream channels. Previous studies have indicated that 10-20% impervious area in a basin can alter storm flow volumes (Hollis 1975) and severely impact aquatic systems (Booth and Jackson 1997). Infiltration rates are also decreased due to timber harvest operations, forest road building, and conversion of forest land to agriculture. Interception of subsurface flow due to forest road cuts is another major source of runoff manipulation. Excavation of road cuts on hill slopes penetrates the soil mantle, redirecting shallow subsurface flow into road ditches, which accelerates the delivery of water to stream channels.

Streamflow volumes may also be increased due to forest practices that increase snow accumulation and melt rates. Forest canopies naturally intercept snowfall, much of which melts in the canopy and reaches the forest floor as wet snow or melt water (Ziemer and Lisle 1998). Removal of canopy cover increases the amount of snow that accumulates. In addition, melt rates may be increased due to the convective transfer of heat to the snow surface during storm events. In this way, the water available for runoff may be increased during rain-on-snow events (Coffin and Harr 1992).

Current Conditions — Stream flow impairment is difficult to assess without a sufficiently long time series of flow records, and even with such information, it is often difficult to distinguish true flow alterations from natural fluctuations. For this reason, land cover conditions that are known to influence the timing, rate, magnitude, and duration of stream flows are often used as indicators of potential stream flow impairment. These generally include one or more of such metrics as forest seral stage, percentage watershed imperviousness, and road density.

The Integrated Watershed Assessment (IWA) identified hydrologic (runoff) impairments across the study area according to landscape characteristics including impervious surfaces, vegetation cover, and road densities (see Vol. II for presentation of subbasin-level results). IWA hydrology impairment results are depicted for the entire region in Figure 3-4. The greatest impairments are located in lower elevation portions of the basins, which are dominated by private timber lands. Functional conditions are most prevalent in upper watersheds in public land.

Fish habitat modeling suggests that stream flow impairments are limiting fish production in many basins. The most impacted reaches are located in middle and upper basin areas within or downstream of areas with intensive timber harvest and road building activities.

The Vancouver metropolitan area, along with the cities of Camas and Washougal, comprise the largest urban area in Southwest Washington and are located primarily in the Lake River/Salmon Creek and Washougal River basins in WRIA 28. Of land area in WRIA 28, 13% is urban land, with 20% in agricultural uses (Ecology WRIA data). These areas have high degrees of imperviousness with a substantial loss of native forests and wetlands. Urban development plays a relatively minor role throughout the remainder of the region. WRIAs 25 (Grays/Elochoman), 26 (Cowlitz), 27 (Lewis), and 29 (Wind) each have less than 2% of the land area in urban uses.

Forest lands have received significant alteration, particularly those in the western portion of the region and those in lower elevation areas that are in private commercial timber land ownership. In WRIA 25, 79% of land area is forest land, and 83% of the land is private. This WRIA has received intensive timber harvests over the past 50 years. On the whole, WRIAs 26, 27, and 29 have received less alteration to forest lands, attributable to more than 40% of their land area in federal ownership.

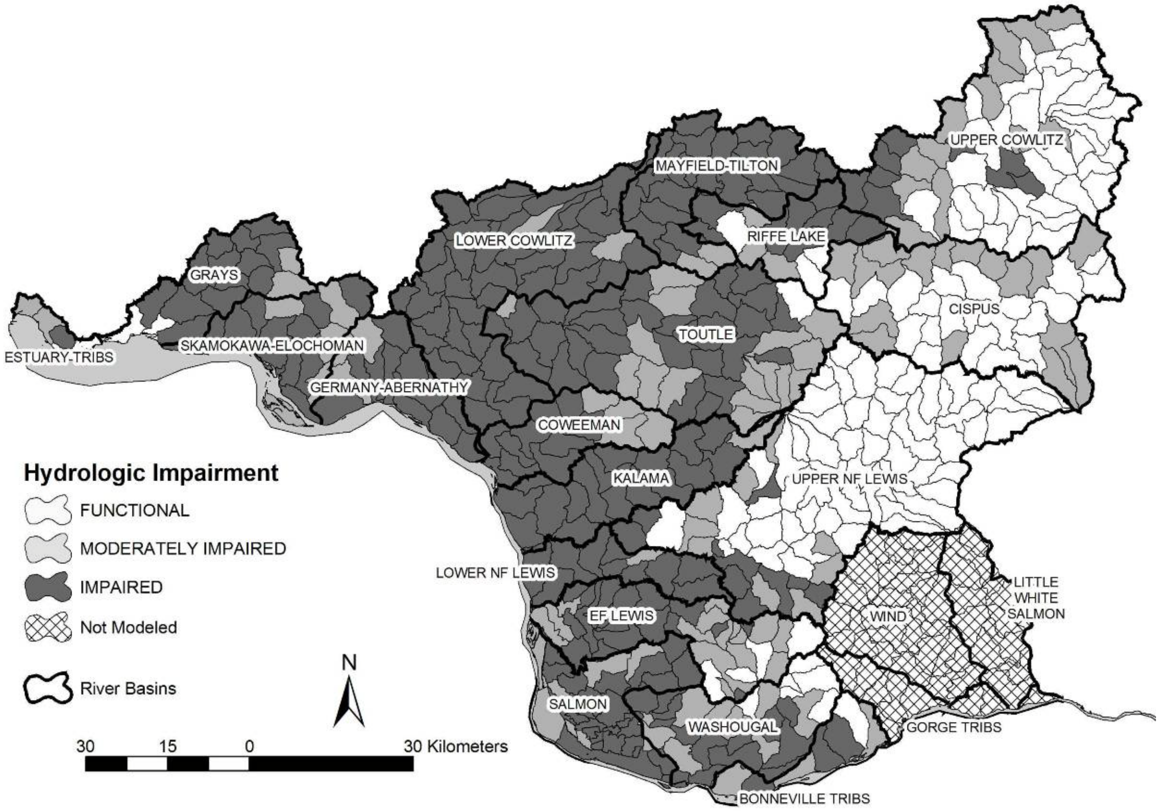

Figure 3-4. Map of hydrologic impairments across the lower Columbia region. Impairment categories were calculated as part of the Integrated Watershed Assessment (IWA) (see Vol. II for presentation of subbasin-level results). These impairment ratings represent local hydrology (runoff) conditions, not including upstream effects.

Many forest stands have been clearcut and are in early seral stages, with over 20 (or 3.5%) of 567 7th-field HUCs having over 20% of forest cover in early seral stages, and a few of these have over 40% in early seral stage conditions.

The preponderance of roads in the region is another major influence on runoff conditions. There are approximately 24,000 miles of roads in the region, and the region has an average road density of 4.15 mi/mi^2. In many basins the forest road density exceeds 7 mi/mi^2.

Analyses by the USFS on national forest lands in many upper basins indicate a risk of increased peak flows for moderate return interval flows (i.e. 2-year flow), attributed primarily to forest practices activities.

Peak flow reductions created by the Cowlitz and Lewis River hydropower systems limit the potential for scour of salmon redds in downstream channels, however, these flow alterations may also limit the occurrence of channel-forming flows that may be important for the maintenance of key habitat types.

Instream flow assessments, primarily the Toe-Width method, were applied to many lower Columbia streams in the fall of 1998 (Caldwell et al. 1999).[1] Most of these analyses indicated sub-optimal flows for both spawning and rearing life stages.

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[1] Toe-width is the distance from the toe of one stream bank to the toe of the other stream bank across the stream channel. This width of the stream is used in a power function equation to derive the flow needed for spawning and rearing salmon and steelhead.

Water Quality

Processes and Effects — Clean, cool, and clear water is essential to salmonids. The health of aquatic habitats declines as temperature, turbidity, nutrients, and other parameters exceed natural ranges and if chemical and biological contaminants are found in significant quantities. Stream temperature is of particular concern in the Northwest due to its importance to fish and its response to land use activities. Brett (1952) found that juvenile Pacific salmonid species generally preferred temperatures in the range of 54-57°F (12°-14°C). Upper lethal limits have been found to be in the 75-81°F (24-27°C) range depending on species and acclimation temperatures (Brett 1952, Hynes 1970, Sullivan et al. 2000).

Stream temperature is readily altered by removing the riparian canopy cover and increasing the channel width. Both canopy cover and channel width are impacted by a variety of land uses. Temperature also has a negative correlation with dissolved oxygen although interactive effects of photosynthesis and groundwater inputs can alter this relationship (Hynes 1970). Current Washington State temperature standards are less than 64°F (18°C) for class A ("excellent") streams and 61°F (16°C) for class AA ("extraordinary") streams. In the lower Columbia region, most streams lying within national forest land are class AA, while most lower basin streams are designated class A. Streams that are monitored according to Department of Ecology protocols and regularly exceed the standards are included on the state's 303(d) list for impaired water bodies.

Turbidity is also a major concern in the Northwest, as it is readily increased by land use practices that produce and deliver fine sediment to stream channels. Turbidity has a strong impact on salmonid feeding success, egg incubation, respiration, and physiological stress.

Box 3-3. Water Quality Limiting Factors

- Altered stream temperature regimes,
- Reduced dissolved oxygen concentrations,
- Excessive turbidity,
- Nutrient over-enrichment,
- Bacteria, and
- Chemical contaminants (from point and non-point sources).

Changes in nutrient dynamics can impact stream productivity. Forestry activities in riparian areas contribute organic debris and increase light availability, which increases primary production and can increase fish productivity. However, these benefits are often offset by detrimental impacts of logging to physical habitat. Increased nutrification also occurs due to agriculture where fertilizers and animal wastes increase the delivery of inorganic and organic compounds. Detrimental impacts from these inputs is seen most in slow-moving river and lake waters where algal blooms result in depleted dissolved oxygen, and anaerobic respiration can pollute waters.

Fecal coliform bacteria is also a concern in many lower Columbia basins and is usually related to livestock wastes and failing septic systems. Other pollutants occur to a lesser degree in lower Columbia basins and are related to mining wastes, urban runoff, and industry.

Current Conditions — The Washington State Department of Ecology 303(d) list of threatened and impaired water bodies represents the most comprehensive and uniform documentation of water quality impairments throughout the region. Water quality-impaired stream segments included on the 303(d) list include streams monitored by Ecology or documented impairments submitted to Ecology by other entities. There are many impairments that are documented by various other organizations that do not appear on to the 303(d) list for a number of reasons. The 303(d) list therefore does not reflect all of the potential water quality concerns in lower Columbia streams. The streams listed on the draft 2002/2004 303(d) list are displayed in Figure 3-5. Only selected parameters are shown. There are also stream segments listed for a variety of other water quality parameters, including DDT, arsenic, lead, sediment bioassay, and others, but they comprise only a small portion of the listed streams.

- The most common water quality concern in the region regards water temperature. Over 150 streams in the lower Columbia region have one or more segments on the 303(d) list for temperature problems. However, many streams with temperature problems are not included on the 303(d) list. Most temperature exceedances have been attributed to reduction in riparian tree canopy cover, increased stream widths, and decreased low flow volumes during the summer. Temperature problems are scattered throughout the forested and developed areas of the region. Dissolved oxygen levels are a related problem and are of most concern in WRIA 28, although most of the listed stream segments for dissolved oxygen are within the Vancouver metropolitan area and are not in significant salmon and steelhead streams.
- Fish habitat modeling indicates that high summer stream temperatures are a major limiting factor for steelhead and coho in many basins (habitat modeling results are presented for each subbasin in Vol. II of the Technical Foundation).
- The presence of fecal coliform bacteria is also considered a problem in the region, with over 30 stream segments on the 303(d) list. Most of the listed segments are within the urban and rural residential areas in WRIA 28 and are likely the result of failing septic systems. Runoff from livestock grazing also has been identified as a contributor to the bacteria problem in many areas.
- There are few sediment-related problems in the lower Columbia region that are on the 303(d) list. Chronic suspended sediment problems (measured by turbidity) are generally not a concern except for portions of the Toutle and Lewis basins that drain Mount St. Helens. Excessive delivery of fine sediment to stream channels during runoff events, however, is a concern throughout the region. This issue is discussed in detail in the Substrate and Sediment section.

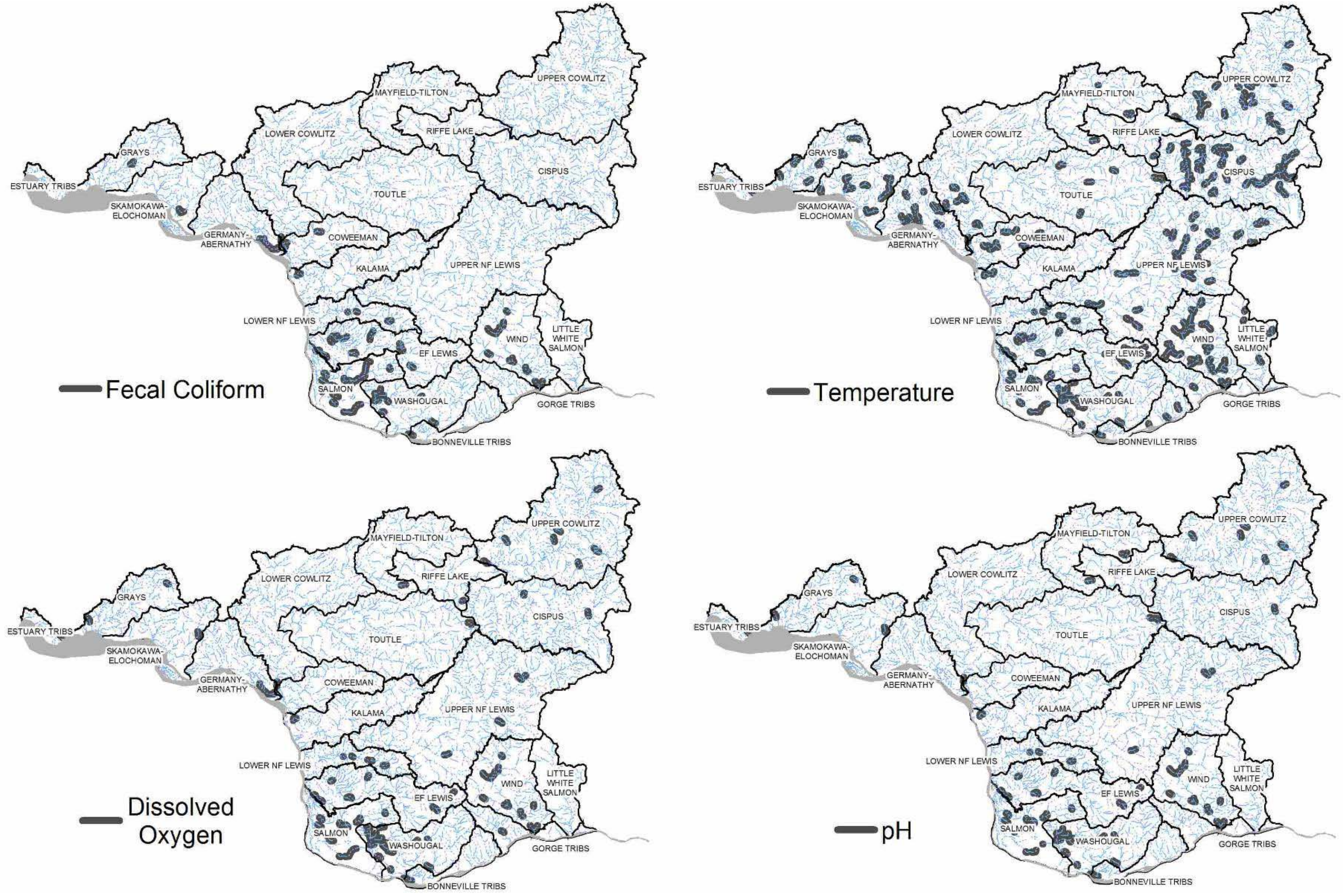

Figure 3-5. **Map of stream segments on the 2002/2004 303(d) list for selected parameters. The selected parameters are the most widespread water quality impairments in the region.**

Important Habitats and Habitat Complexity

Processes and Effects—Salmonids require an array of complex habitat types to carry out freshwater life stages. The distribution, dimensions, and quality of stream channel habitat units greatly affect the health of fish populations (Bjornn and Reiser 1991). Fish use pools, riffles, pocket-water, off-channel backwaters, and other habitat types depending on species, life-stage, activity-level, and stream conditions. Although fish use a variety of habitat types to different degrees depending on their lifestage, pools and backwater habitats are often regarded as the most crucial. For example, spawning often occurs at the downstream end of pools, where the right combinations of substrate and flow conditions are found. Pools also provide important cover and food resources for juvenile fish. Backwater and side channel habitat are especially important for some species, because they are often the site of upwelling, providing cool water in the summer as well as nutrient-rich water important for growth. They also provide refuge from flood flows. For these reasons, pool and side channel availability are commonly used as metrics to assess overall stream habitat condition. Functional connectivity between the various habitats for each life history stage is also critical (Mobrand et al. 1997).

Box 3-4. Habitat Diversity Limiting Factors

- Complete loss of spawning, rearing, and/or migration habitats that normally provide good survival conditions at critical times of the life cycle,
- Lack of stable instream woody debris,
- Altered habitat unit composition,
- Lack of instream cover components,
- Lack of habitat complexity,
- Loss of habitat refugia,
- Loss of access from one habitat to the next in the life cycle, and
- Upland activities that compromise the creation, maintenance, and normal functioning of important habitats.

Structural cover components in the stream channel, including woody debris, boulders, and overhanging banks, contribute to habitat complexity. The creation and maintenance of stream channel habitats is a function of the interaction between the underlying geology and the dynamics of flow, sediment, and large woody debris. Disrupting these physical processes may result in habitat unit types that are outside of natural ranges of quality and quantity. In the lower Columbia region, processes that drive channel conditions have been altered to various degrees by land management activities. The greatest impacts on stream habitat units have been practices that have directly altered stream channels such as splash dam logging, diking, channelization, stream clean-outs, gravel mining, and dam building. Upland and riparian land use practices that alter flow, sediment, and wood recruitment are less direct, but equally important, impacts.

Current Conditions—In many lower Columbia streams, habitat surveys provide information on pool and side channel availability. In other areas, local experts have provided information as part of the limiting factors analysis process, as described in each subbasin chapter in Volume II. Still, there is little information regarding specific stream channel conditions in many areas. In general, the evidence shows an overall decrease in side channel and pool habitats.

The greatest loss of stream habitat has resulted from the Cowlitz and Lewis River hydropower systems, where many miles of stream channel lie beneath a series of reservoirs, and additional miles are blocked from access.

The other major loss of habitat is in the lower reaches of stream systems that have been diked and channelized for agricultural, industrial, and residential uses. Coastal basins have been especially affected; historically, these systems had extensive networks of estuarine side channels that are now isolated or filled. Chum spawning habitat and coho winter rearing habitat have been particularly impacted by loss of off-channel and side channel areas.

Upper basin stream systems have suffered less pool and side channel degradation, though the impacts to some fish populations may be greater because of the concentration of quality spawning and rearing habitat. As in the lower basins, side channels have been lost due primarily to erosion control, diking, and riprap. Some channels are impacted by stream channel incision that has persisted since past splash-damming and riparian timber harvest.

The loss of pool habitat as a result of decreased large wood quantities and degraded riparian areas is also a concern. In most upper forested basins in the region, the quantity of pool habitat is in the low end of the range considered adequate for salmonids.

The presence of good side channel and pool habitats has been identified in some areas. These are most often associated with woody debris. An assessment in the upper Cowlitz basin indicated that streams containing LWD had 15 times the number of pools as streams without large wood (EA 1998 as cited in Wade 2000).

Substrate and Sediment

Processes and Effects—Proper substrate and sediment conditions are necessary for spawning, egg incubation, and early rearing of salmonids. Substrate and sediment are delivered to spawning and rearing areas during natural disturbance events, mediated by LWD and existing habitat complexity (Bisson et al. 1997). However, excessive fine sediment delivered to channels can suffocate salmonid eggs, inhibit emergence of fry from gravels, decrease feeding success, increase physiological stress, and through adsorption, may facilitate the transport and persistence of chemical contaminants (Welch et al. 1998).

The size of substrate preferred by spawning salmon ranges from less than 0.4 in (1 cm) to over 4.7 in (12 cm) in diameter, depending on the species and size of the fish (Bjornn and Reiser 1991, Schuett-Hames et al. 2000). During redd construction, spawning substrates are cleared of fine sediments; however, during the incubation period, redds are susceptible to accumulation of fines.[2] Sediment accumulation can impede intergravel flow necessary to supply embryos with oxygen and carry away wastes. Embryo survival declines as percentage fines increases (Bjornn and Reiser 1991). Fine sediment may also limit the ability of alevins to move around and to ultimately emerge from the gravels. Studies have shown that alevins have trouble emerging when percent fines exceed 30-40% (Bjornn and Reiser 1991). Substrate conditions also are important for juvenile salmonid rearing. Substrates provide cover, protection from high flows, and macro invertebrate production. Juvenile production and densities have been shown to decrease with increased gravel embeddedness (Crouse et al. 1981, Bjornn et al. 1977 [from Bjornn and Reiser 1991]). Embedded substrates may also reduce the availability of macro invertebrate food resources (Bjornn et al. 1977, Hawkins et al. 1983).

Many factors can affect substrate conditions. Scouring of substrates may result from increased flood flows, alterations to channel geometry, loss of channel stability, splash dam logging, and debris flows. Gravel recruitment is reduced by dams, bank armoring, and channel alterations. Direct extraction of substrates has occurred in some areas due to gravel mining operations.

Box 3-5. Substrate and Sediment Limiting Factors

- Embedded substrates,
- Excessive suspended sediment (turbidity),
- Fine sediment in gravels (redd smothering),
- Lack of adequate spawning substrate,
- Excessive build-up of substrate, and
- Lack of boulder cover.

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[2] Fines are typically defined as sediment sizes less than 0.85 mm (0.033 inches) diameter, and percentage fines greater than about 17% are considered not properly functioning according to NMFS (NMFS 1996).

Increased sediment transport and delivery due to upslope land use has a major impact on in-stream habitats. Sediment is contributed to stream channels through surface erosion, gully erosion, and mass wasting (Ward and Elliot 1995). The amount of erosion resulting from these processes is related to climate, soil, slope, and vegetation conditions. Surface erosion primarily occurs as sheet and rill erosion on agricultural, urban, and range lands, but it also may occur on forest road surfaces or areas disturbed during timber harvest. Surface erosion can be extremely high in developing urban areas that are under construction, where erosion may increase from 2 to 40,000 times the preconstruction rate (McCuen 1998). Gully erosion results from concentrated flow and commonly generates sediment volumes an order of magnitude greater than sheet and rill erosion. Gullies are often associated with forest road ditches, where ditch and culvert design and/or maintenance are inadequate to effectively convey runoff volumes.

Mass wasting, in the form of landslides and debris flows, can deliver huge amounts of sediment to stream channels. Landslides may be rapid or slow (slumps) and can occur on shallow or steep slopes. Water saturation, vegetation removal, and human-induced flow concentration (i.e. roads) are often responsible for landslides in forested areas. Debris flows are caused by similar disturbances, though generally involve higher water content, initiate on steeper slopes, and travel farther than landslides. Debris flows are common in steep headwater or tributary channels and can contribute large amounts of sediment and woody debris to salmonid streams.

Current Conditions — Substrate conditions across the lower Columbia region vary with respect to channel types, position within the watershed, and natural and anthropogenic disturbances.

- Fish habitat modeling indicates that fine sediment is one of the primary factors limiting fish production for most salmonid populations in the lower Columbia region.
- Many stream reaches suffer from a lack of adequate spawning gravels and high concentrations of fines. Spawning gravels are often embedded with fines—a particular problem in coastal basins that have sedimentary geology and a high occurrence of mass wasting. Historical chum and Chinook spawning sites on lower river segments are especially susceptible to accumulations of fines. Accumulations of fines near the mouths of streams entering the Columbia River upstream of Bonneville Dam have increased since dam construction.
- High rates of sediment delivery have been a continual problem in the Toutle River watershed and other streams impacted by the Mt. St. Helens eruption, although conditions have been improving. Conditions have improved more quickly in the SF Toutle and Green River than in the NF Toutle, which received the greatest impact.
- The Sediment Retention Structure (SRS) on the mainstem NF Toutle contributes to sediment impairment in the Toutle River. The SRS was constructed after the 1980 Mt. St. Helens eruption in an effort to reduce downstream sediment aggradation and thus improve conveyance of flood waters in the lower Toutle and Cowlitz rivers. The structure has since been overtopped with sediment and has become a chronic source of fine sediment to downstream areas. The SRS is believed to be preventing the recovery of the system (Wade 2000).
- Past and current land use has created upslope land cover conditions that are susceptible to increased sediment production and delivery to streams. The IWA identified sediment supply problems across the study area according to landscape characteristics including topographical slope, soil erodability, and unsurfaced road densities. IWA sediment impairment results are depicted for the entire region in Figure 3-6 (see Vol. II for a presentation of subbasin-level results).

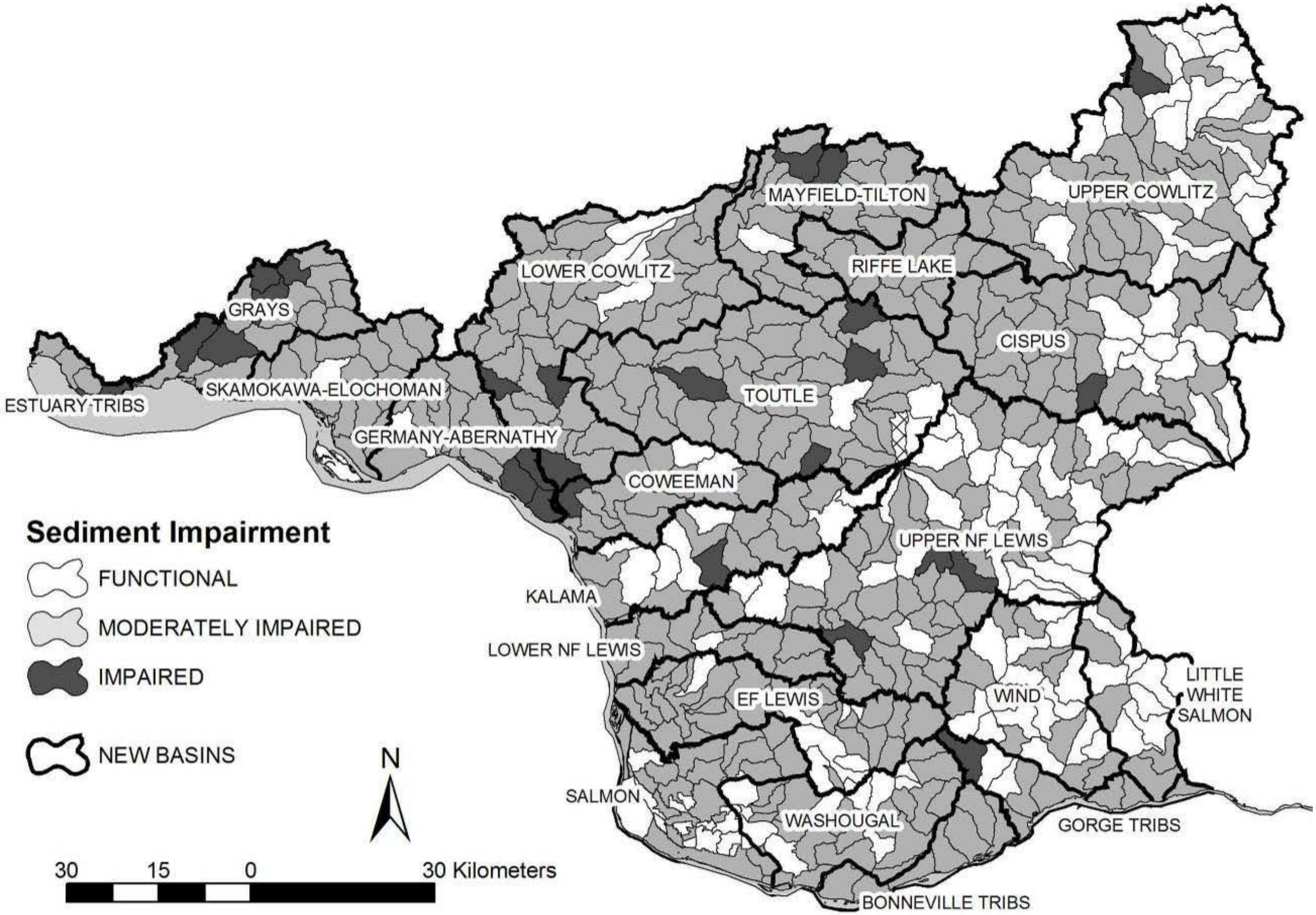

Figure 3-6. **Map of sediment supply problems across the lower Columbia region. Impairment categories were calculated as part of the Integrated Watershed Assessment (see Vol. II for presentation of subbasin-level results). These impairment ratings represent local sediment supply conditions, not including upstream effects.**

Large Woody Debris

Processes and Effects—Large woody debris is an important component of stream ecosystems. Removal of riparian vegetation can decrease wood recruitment as well as reduce bank stability (Beechie et al. 2000). Reduced bank stability increases sedimentation of pools and increases width to depth ratios, thus reducing the quality and quantity of pool habitat. Juvenile and adult salmonids rely directly on LWD for shade, protection from disturbance, and protection from predation (Bisson et al. 1988, Solazzi et al. 2000). Studies have shown that fish production is positively correlated with presence of large organic debris (Bjornn and Reiser 1991). Woody debris also retains organic matter, provides sites for macro invertebrate colonization, and can trap salmon carcasses (Murphy and Meehan 1991, Cederholm et al. 1989). An indirect benefit of LWD to salmonids is its influence on stream channel morphology and habitat complexity. LWD tends to be stationary in small streams, where it affects local bank stability and creates patches of scour and deposition. In large streams, LWD moves more readily and often forms jams. Accumulations of LWD affect bank stability, scour, bar formation, and may also induce rapid channel adjustments (Keller and Swanson 1979). In some streams, LWD may also be important for the establishment of floodplain and riparian habitats (Abbe and Montgomery 1996).

Another significant attribute of LWD is the role it plays in pool formation. Stable woody debris traps sediments and can form steps in otherwise uniform channels. In some cases, LWD can create depositional areas in channels that would otherwise be composed of bedrock (Montgomery et al. 1996). Abundance of LWD has been positively correlated with pool area, pool volume, and pool frequency (Carlson et al. 1990, Beechie et al. 2000). LWD is recruited to stream channels through bank erosion, mass wasting, blowdown, and debris torrents.

Box 3-6. Woody Debris Limiting Factors

- Reduced bank stability,
- Reduced cover habitat and refuge from predation,
- Loss of retention of organic matter, such as salmon carcasses,
- Lost substrate for macro invertebrate growth,
- Reduced habitat-forming vectors, and
- Habitat simplification.

Removal of riparian timber decreases the potential for future LWD recruitment. Although timber harvest may increase short-term wood loading in some instances, long-term recruitment and persistence of wood in streams is highest in older forest types (Bilby and Ward 1991, Beechie et al. 2000). LWD is removed from stream channels through fluvial transport or by direct removal. Direct removal of LWD was a common practice in the 1970s and 1980s when log jams were believed to impede fish passage. Wood removal has occurred in other locations in order to reduce flood potential (Shields and Nunnally 1984). As expected, the removal of LWD has been shown to alter channel morphology and decrease habitat complexity (Smith et al. 1993).

Current Conditions—The various agencies conducting stream surveys in the lower Columbia region define LWD differently. In general, minimum diameter to be considered for LWD ranges from about 4-14 inches (10-36 cm), while minimum lengths range from 6.5-49 ft (2.13-15 m). The definition of what constitutes poor conditions also varies, but is generally fewer than 80 pieces/mi or fewer than 0.2 pieces per channel width (NMFS 1996, Schuett-Hames et al. 2000, Wade 2000).

- LWD conditions are considered poor across much of the lower Columbia region. Only a handful of surveyed streams have good conditions.
- The amount of LWD affects the EDT habitat attribute 'habitat diversity'. For many lower Columbia stream systems, EDT modeling indicates that habitat diversity is the habitat factor that is serving to depress population performance to the greatest extent.
- In many areas where LWD is adequate, it is concentrated in large jams, although many of the large jams that existed historically on low-gradient, large systems such as the Cowlitz, are no longer present (Mobrand Biometrics 1999).
- Low LWD abundance in many upper basins is attributed to past timber harvest and scour from splash dam logging. In other areas, poor conditions are attributed to past fires that have reduced recruitment. USFS and other crews removed instream wood in some streams during the 1980s because it was believed to impede fish passage while in other streams local residents have removed LWD due to flooding and erosion concerns.
- In general, it is believed that LWD recruitment potential is increasing in most basins due to re-growth of riparian forests. Current riparian buffer regulations prevent significant harvest along most streams, which will eventually serve to restore instream LWD levels (WFPB 2000). Restoration projects that involve the re-introduction of wood into stream systems have and will continue to increase instream LWD.

Channel Stability

Processes and Effects—Channel stability conditions affect the quality and quantity of instream habitats. Channel erosion can directly impact fish through redd scour or redd smothering. Channel erosion affects fish indirectly through impacts to the distribution and condition of key habitat types as well as through impacts to floodplain connections and riparian conditions. Excessive sediment delivered from unstable stream banks can suffocate salmonid eggs, inhibit emergence of fry from gravels, decrease feeding success, and increase physiological stress. Unstable banks also increase mass wasting and have subsequent effects on channel morphology. Bank stability processes vary depending on location in a catchment. In steep headwater systems, channels are typified by stable substrates (i.e. bedrock, boulders) and thus have greater resistance to erosion. With the exception of debris flows, sediment entering these channels is predominantly from upslope sources. Channels lower in the catchment, on the other hand, tend to have higher rates of bank erosion, with, in many instances, channel sources contributing far more sediment than upslope sources. It is in these channels that the impact of unstable stream banks is greatest on salmonids.

Patterns of erosion and deposition within stream channels have a strong influence on channel form, including meander formation and floodplain development. The distribution and dimensions of aquatic habitats, such as pools and riffles, are therefore governed in part by bank stability. A study on Salmon Creek, a lower Columbia tributary, found that landslides increased the amount of sediment stored in channel bars at the expense of pools (Perkins 1989 as cited in Montgomery and Buffington 1998). Factors that control bank stability include bank material composition, flow properties, channel geometry, and vegetation (Knighton 1998). While vegetation may not have the greatest controlling influence on stability, it is readily altered by land use, and therefore of particular concern. Root systems increase resistance to the erosive forces of flowing water and denser vegetation generally results in narrower and deeper channels. The woody roots of trees are particularly useful in providing long-term channel stability (Beschta 1991).

Box 3-7. Channel Stability Limiting Factors

- Bed scour,
- Channel down-cutting (incision),
- Debris flows,
- Landslides,
- Bank failures,
- Displacement of instream structural components, and
- Redd displacement / smothering.

Land use activities that modify vegetation conditions and channel geometry can reduce bank stability. Timber harvesting and conversion of riparian forests to agriculture, residential, and other developed uses reduce vegetative cover on stream banks. These practices have been widespread in the lower Columbia region over the past century. Livestock grazing increases bank erosion through direct trampling and removal of vegetation (Trimble and Mendel 1995). Stream channelization may also increase channel erosion by increasing water depth, which increases shear stress (product of depth and slope) and therefore scour potential on the channel bed. Channel straightening increases stream gradient, which also increases scour potential and transport capacity (Knighton 1998). Increased runoff volumes due to upland land uses can increase stream power which can increase erosive forces. Increased stream flows due to urbanization can alter channels dramatically through widening and incision (Booth 1990). Alternatively, stream bank reinforcement for erosion control, such as riprap, reduces habitat complexity and can result in diminished salmonid abundance (Knudsen and Dilley 1987).

Current Conditions—Bank stability problems have been identified in most basins throughout the lower Columbia region. Loss of bank stability is attributed to a number of factors. These include most land use activities mentioned above, namely timber harvest, land use conversion, straightening and channelization, livestock grazing, and flow alterations. In some cases, the natural geology exacerbates instability. This is the case in areas underlain by sedimentary rock in coastal basins, mudflow deposits around Mt. St. Helens (Toutle and Lewis basins), and Bretz Flood deposits in lower portions of Columbia Gorge basins. Bank stability has been reduced in many lower catchment channels by riparian and floodplain development that has resulted in straightened and channelized streams. In some areas, natural channel movement is perceived as a bank stability problem when developed or agricultural property within the channel migration zone is threatened. There are bank stability concerns across the region.

- The stream channel has rapidly adjusted due to avulsions into gravel mining pits on Salmon Creek and the lower EF Lewis River. The impact of these avulsions on aquatic habitat may be minor in some cases.
- Livestock grazing has impacted stream banks. Efforts to exclude cattle with fences have reduced this impact.
- Timber harvests and road building have increased runoff and sediment supply to channels. Sediment inputs can increase in-channel sediment aggradation, resulting in high width-to-depth ratios and an elevated rate of channel movement. New forest practices rules that regulate road building, timber harvests on steep slopes, and riparian timber harvest should alleviate channel instability problems.
- Despite these problem areas, the limiting factors analyses noted generally good bank stability conditions in the Jim Crow, Skamokawa, Elochoman, lower Cowlitz, Kalama, and Washougal basins. Other areas of good bank stability are a result of erosion control projects which may present their own impacts on fish, as noted above.

Riparian Function

Riparian areas are the critical interface between upland and aquatic systems. Riparian vegetation directly and indirectly affects fish habitat suitability through influences on water temperature, habitat diversity, sedimentation, wood recruitment, and bank stability. Riparian degradation is often the causative factor of in-channel habitat impairments.

Processes and Effects—Riparian areas are an important interface between upland and aquatic systems (Gregory et al. 1991). Riparian vegetation directly and indirectly affects fish habitat suitability through influences on water temperature, habitat diversity, sedimentation, wood recruitment, and bank stability (Beschta 1991). Reaches with less canopy cover tend to exhibit higher maximum temperatures and larger diurnal temperature fluctuations than reaches with more canopy cover (Beschta et al. 1987, Sullivan et al. 1990). Shading from riparian canopy cover tends to be most important in summer due to high sun angles, reduced cloud cover, and longer days. In winter, canopy cover can inhibit the re-radiation of heat away from the stream, reducing the occurrence of extreme low temperatures (Beschta et al. 1987). Riparian cover also may be important for reducing wind velocities that contribute to convective heat loss (Sinokrot and Stefan 1993) and may have an important influence on the stream microclimate (Adams and Sullivan 1989, Rutherford et al. 1997), though these effects are not well understood. Canopy cover has a greater affect on small streams than large streams since wider streams are less likely to be shaded.

Riparian canopy cover provides other benefits in addition to moderating stream temperatures. Riparian canopies are an important source of allochthonous inputs (e.g. litter fall) of carbon and nitrogen to the stream system (Gregory et al. 1991, Beschta 1997a). Attenuation of light by tree canopies also may be an important factor affecting macro invertebrate distribution and abundance. Meehan (1996) found a significant difference in macro invertebrate abundance in shaded versus non-shaded reaches. Shade has also been shown to affect drift of benthic invertebrates. Algal growth and benthic productivity are affected by shade (Hynes 1970).

Box 3-8. Riparian Limiting Factors

- Reduced stream canopy cover (temperature impacts),
- Reduced bank/soil stability,
- Reduced floodplain roughness,
- Reduced channel margin cover,
- Altered nutrient exchange processes,
- Disrupted hyporheic processes,
- Reduced wood recruitment,
- Altered species composition,
- Exotic and/or noxious species, and
- Loss of contaminant buffering capability.

In addition to the benefits realized by adequate canopy cover, intact riparian forests also provide a source of LWD recruitment to stream channels. In small streams, fallen trees often remain where they fall and have a dramatic influence on habitat complexity. Wood has greater mobility in larger streams, where it more readily accumulates in jams. In-stream wood, as well as floodplain forests, provides roughness elements that increase flow resistance and reduces downstream flood effects. Trees also provide bank stability through erosion resistance created by roots. (See the Woody Debris section above for additional information on the importance of LWD to salmonids.)

Current Conditions — Riparian conditions are generally considered poor across the lower Columbia region. The IWA riparian assessment (Figure 3-7), which modeled riparian impairment across the region using vegetative cover characteristics, indicates that most of the region suffers from moderately impaired riparian conditions. The most intact riparian areas are located in the upper elevations of the upper Cowlitz and upper Lewis basins, while the greatest impairments are located in the lowest elevations, especially around the urbanized Vancouver, WA metropolitan area.

- Many lower elevation riparian zones that historically had forest cover have been converted to land uses such as agriculture, residential development, or transportation corridors.
- Cattle access to stream banks is an ongoing problem in many areas.
- Middle and upper basin riparian areas suffer from young forest stands and/or a predominance of deciduous vegetation due to past timber harvests. These conditions are expected to improve on forest lands with the relatively recent regulations (WAC 2000) that govern forest practices in riparian areas.

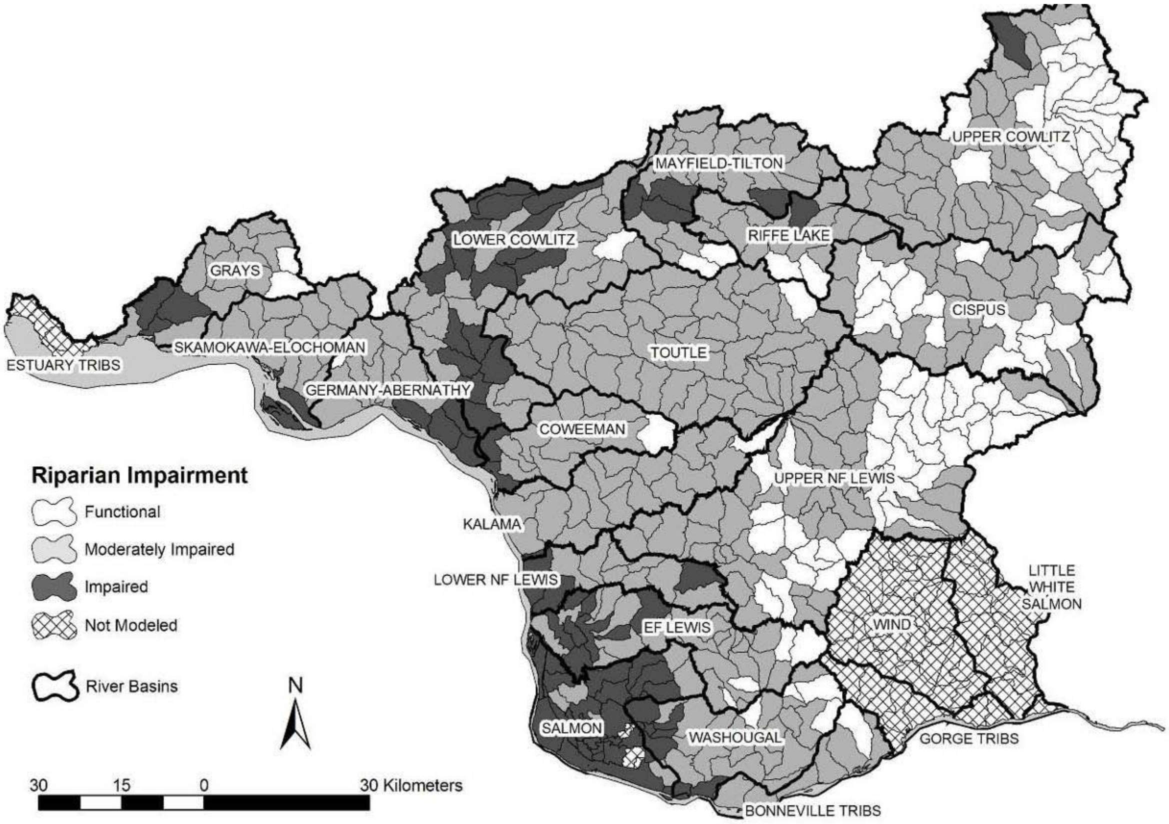

Figure 3-7. Map of riparian impairments across the lower Columbia region. Impairment categories were calculated as part of the Integrated Watershed Assessment (see Vol. II for presentation of subbasin-level results).

Floodplain Function

Processes and Effects—The interaction of rivers with their floodplains is important for flood flow dampening, nutrient exchange, and maintenance of stream and off-channel habitats. For example, several researchers have demonstrated the importance of off-channel floodplain habitats for juvenile coho salmon rearing (Cederholm et al. 1988, Nickelson et al. 1992). As a stream accesses its floodplain, the increase in cross-sectional area decreases the flow velocity, reducing downstream flow volumes and limiting erosion. If a stream is isolated from its floodplain, either through channel incision, diking, or floodplain filling, then the potential for downstream flooding and channel instability may be increased (Wyzga 1993, as cited in Knighton 1998). Floodplains also are important for nutrient exchanges between the stream and terrestrial vegetation. The stream hyporheic zones are especially important for maintenance of water quality, nutrient processing, and biological diversity (Edwards 1998). Hyporheic zones underlie most floodplain forests and are easily disrupted by activities that isolate floodplains or disrupt subsurface flow patterns.

Floodplains are isolated from rivers by human activities in a number of ways. Diking and channelization serve to fix the stream in a specific location, preventing overbank flows and meander migrations. This practice often occurs in combination with filling of floodplain sloughs, oxbow lakes, and side channels in order to facilitate development or create crop or pasture land. Floodplains can also be isolated from rivers through channel dredging intended to increase flow conveyance. As a result, flow magnitudes that historically would have inundated the floodplain are confined within the channel. Diking, dredging, and floodplain filling projects are often combined with channel straightening, which can increase stream gradients and in turn increase channel erosion potential. Road crossings of streams can limit floodplain function by forcing the stream into a particular location (e.g. at a bridge), preventing natural flooding and meander patterns.

Current Conditions—Floodplain function in the lower Columbia region has been altered by diking, channelization, channel incision, filling of side channels, and mining.

- Diking has occurred extensively within tidally influenced areas near the mouths of many streams. The effects on aquatic biota have been especially severe on coast range basins such as the Chinook and Grays rivers where a large percentage of off-channel estuary habitat has been isolated from the river. Dikes were constructed and floodplain channels were filled to create cropland. Recent strides have been taken to restore estuary habitat by breaching dikes and removing tide-gates.
- The lower reaches of many stream systems have been diked extensively for residential, commercial, and agricultural purposes. The most affected stream segments are the lower Cowlitz and lower North Fork Lewis rivers, where channelization projects have isolated large amounts of historically available habitats. Transportation corridors are a ubiquitous cause of floodplain constriction on many streams, as roads tend to follow stream valley bottoms. Many streams have been artificially straightened to accommodate roadways.

Box 3-9. Floodplain Limiting Factors

- Reduced availability of floodplain habitats,
- Altered nutrient exchange processes,
- Increased channel bed incision and bank erosion,
- Alterations to channel migration (restricted sediment-flow equilibrium processes),
- Downstream effects (flooding),
- Disrupted hyporheic processes, and
- Disrupted groundwater / surface water interactions.

3.2.3. Threats

Habitat threats are the human-derived activities that have created and/or are perpetuating the habitat limiting factors described above. Stream habitat threats are primarily related to past or current land-use or water use practices with direct effects on stream channels, riparian areas, and floodplains, as well as watershed process conditions that are believed to be impacting fish habitat. Threat factors (forestry, agriculture, urbanization, etc.) typically impact multiple limiting factors. (Impacts from large, hydropower dams are treated in a separate hydrosystem section below.)

Water Withdrawals

Water withdrawals for irrigation, livestock watering, or municipal use result in lower stream flows in some subbasins. The greatest period of risk is late summer and fall, when stream flows are naturally at their lowest and when fish are spawning. Flow withdrawals also impact fish by obstructing passage (dams, levees), stranding fish in diversion channels, and through impingement on intake screens. Significant water withdrawals only occur on a few lower Columbia streams. Threats to salmon include:

- Reduced instream flows and channel dewatering,
- Inadequate screening of intakes, and
- Passage obstructions (dams, weirs).

Dams, Culverts, and Other Barriers

Fish passage barriers that limit access to spawning and rearing habitats are a significant factor affecting salmon populations throughout the lower Columbia region. Numerically, the majority of barriers are culverts and dams with occasional other barriers, such as irrigation diversion structures, fish weirs, beaver dams, road crossings, tide gates, channel alterations, and localized temperature increases. Passage barriers effectively remove habitat from the subbasin, thereby reducing habitat capacity. In situations where a substantial amount of historical spawning or rearing habitat has been blocked, such as in the Cowlitz or Lewis River subbasins, production potential of salmonid populations have been severely reduced. (Large hydropower dams are addressed in a separate section below.) Ongoing threats to salmon from migration barriers include:

- Culverts on forest, agricultural, and urban roads,
- Toutle River Sediment Retention Structure,
- Irrigation diversions,
- Fish weirs,
- Tide gates,
- Temperature or dissolved oxygen barriers, and
- Channel alterations.

Forest Practices

Forest harvest is the most widespread land use in the region and occurs most heavily on private timberlands. Forest roads can present one of the greatest threats to watershed processes. Improperly located, constructed, or maintained forest roads can degrade stream flow and sediment supply processes. At the same time, wildfires increase sediment delivery to streams, alter runoff patterns, eliminate shade and increase temperature, and reduce recruitment of LWD with catastrophic effects on habitat conditions for fish. Forest practice impacts on federal lands have decreased significantly over the past decade, since the implementation of the President's Forest Plan in 1994. With the implementation of the revised WA State Forest Practices Rules (FPRs) beginning in 2001, practices on state and private timberlands have also improved substantially. Despite the new protections, improvements to watershed hydrologic and sediment supply processes will only be fully recognized in the long-term. Moreover, ongoing monitoring will be necessary to determine the adequacy of these recent protections. Examples of forest practices that can be detrimental to salmonids include:

- Timber harvests on unstable slopes (increased landslide risk),
- Clear cutting in rain-on-snow zone (increase of water available for runoff),
- Unsurfaced forest road building and use (surface erosion),
- Increase to drainage network from road ditches (decreased time of concentration of runoff),
- Forest roads on steep, unstable slopes (increased landslide risk),
- Inadequate road maintenance (increased landslide and surface erosion risk),
- Application of forest fertilizers, herbicides, and pesticides,
- Increased wildfire risks (fuel buildup), and
- Timber harvests in riparian areas (loss of bank stability, large woody debris, and stream shade).

Agriculture / Grazing

Agricultural land uses occur in many of the lowland valley bottoms in the lower Columbia region. Crops and pasture land are often located adjacent to streams, with direct impacts on riparian areas and floodplains. Many floodplain areas were filled and levees constructed to expand or improve agricultural land. Runoff from agricultural lands can carry harmful contaminants originating from the application of pesticides, herbicides, and fertilizers. Livestock grazing can directly impact soil stability (trampling) and streamside vegetation (foraging), as well as deliver potentially harmful bacteria and nutrients (animal wastes). Threats to salmon from agriculture include:

- Clearing of riparian and/or upland vegetation,
- Livestock grazing on or near stream banks,
- Application of pesticides, herbicides, and fertilizers, as well as run-off of animal wastes,
- Floodplain diking and filling (to create or improve crop and pasture land), and
- Tide gate blockages.

Urban and Rural Development

The Vancouver metropolitan area is the largest urban area in the region. Other sizeable urban areas include Washougal/Camas, and Kelso/Longview. Rural residential development is extensive throughout the region, much of it occurring within river valleys and alongside streams. Rooftops, pavement, and landscaping increase impervious surfaces, decrease rainwater absorption, increase runoff volumes during storms, and decrease groundwater recharge. Storm drains and road ditches concentrating runoff further alter flow patterns. Studies have shown that measurable impacts to stream flow can occur once approximately 10% of a drainage basin is converted to impervious surfaces. Conversion of agriculture and forest land to residential or urban uses is a problem in many areas, and is especially prevalent in the expanding metropolitan areas in Clark County. Threats to salmon include:

- Incremental land use conversion (resulting in loss of watershed functions),
- Increased impervious surfaces (resulting in more frequent and stronger flash floods),

- Increased drainage network (resulting in more frequent and stronger flash floods),
- Contaminant runoff (automobiles, household hazardous wastes, yard chemicals),
- Clearing of riparian and/or upland vegetation,
- Combined sewage overflows and leaking septic systems,
- Industrial point-source discharges,
- Harassment and poaching of spawners,
- Floodplain filling (for development),
- Artificial channel confinement, and
- Fish passage obstructions (culverts).

Mining

Sand, gravel, and gold mining occurs along several lower Columbia streams. Some by-products of mining are potentially harmful to water quality and aquatic biota if they are allowed to enter stream systems. Sand and gravel mining can impact stream channels by altering in-stream substrate and sediment volumes. In a few stream systems, including the EF Lewis and Salmon Creek, the stream channel has avulsed into stream-adjacent ponds created from the mining of floodplain sand and gravel. These avulsions have altered channel morphology and have generally destabilized channels. Ongoing threats to salmon from mining can include:

- Channel and/or floodplain substrate extraction,
- Floodplain filling,
- Mining contaminants in runoff,
- Increased water surface area (on and off-channel), and
- Stream channel avulsions.

Channel Manipulations

Changes to structural components within stream channels can have potentially detrimental impacts to habitat quality and quantity. Although strong regulatory mechanisms currently exist to prevent channel manipulations, there are cases where channel alterations have occurred. Considerable channel dredging, floodplain filling, and sediment retention damming occurred on the Toutle and lower Cowlitz Rivers following the 1980 Mt. St. Helens eruption, primarily to ensure the efficient conveyance of flood waters. Dredging has also occurred in other places to provide for flood conveyance. Structural components, including large woody debris and boulders, have been removed from some channels for flood conveyance and/or to facilitate river transportation or recreational uses. Many channels have been dredged, straightened, and floodplains filled to create agricultural land and to establish transportation corridors. Stream bank hardening has occurred along many channels to prevent erosion and/or to protect property. Threats to salmon from channel manipulations can include:

- Dredge and fill along streams and in off-channel habitats,
- Bank hardening,
- Clearing and snagging (fish passage, flood conveyance),
- Channel straightening and simplification, and
- Artificial confinement (for flood protection and to protect utility and transportation corridors).

Recreation

Boating, fishing, swimming, river floating, and dispersed camping in riparian areas all impact stream biota to some degree. Despite regulations, enforcement measures are often insufficient to prevent poaching of protected fish species. Even when protected fish are caught and released, hooking mortality can occur. In some streams, such as the Washougal River, summertime swimming in mainstem pools may affect spawning success. Boating can also harass fish in some instances and boaters often advocate for removal of large woody debris, which can potentially degrade in-stream habitats. Dispersed recreation within riparian areas can denude riparian vegetation, contribute to erosion, and create human waste inputs to streams. Continuing threats to salmon include:

- Fishing – direct mortality, including poaching,
- Fishing – indirect mortality (catch and release and snagging),
- River recreation (harassment),
- Dispersed recreation impacts (human wastes, stream bank erosion), and
- Boating (harassment, snagging).

3.2.4. Impact Assessment

Habitat impacts describe the relative reduction in fish numbers due to changes in stream habitat conditions from an historical template. The Ecosystem Diagnosis and Treatment Model (EDT) was used to infer fish numbers from descriptions of habitat characteristics that affect the fish life cycle. Habitat conditions are described for each stream segment or reach based on a compilation of the best available data which included field measurements of habitat parameters, visual descriptions during ground surveys, inferences and interpolations using spatial analysis, or expert opinion. Historical template conditions were based on expert judgment including inferences from habitat parameters in representative streams unaffected by human activities. In most cases the historical template exceeds properly functioning habitat conditions that reflect favorable habitat characteristics for salmonids. Relationships between habitat parameters and life stage-specific fish numbers in EDT for each species are based on a comprehensive review of the functional relationships described in the scientific literature. EDT estimates of fish numbers for lower Columbia streams were compared with known values in selected streams to verify that the model projections were accurate for existing conditions. The same EDT model was used to identify protection and restoration values of each stream reach for fish production and to identify critical limiting factors for each reach, life stage, and species. This information was described in detail in subbasin appendices to this Plan and used to identify and prioritize stream reaches and habitat measures for recovery.

Numbers of fish in virtually every population have been substantially reduced by stream habitat changes (Figure 3-8, Table 3-1).

Spring Chinook habitats have been reduced by 75% or more for the majority of the populations by changes in stream flow, temperature, sedimentation, and channel characteristics. These changes primarily occur due to development occurring in mid to high elevation valley bottom habitats, which the fish prefer, and in upstream watersheds that affect those stream areas.

Fall Chinook habitats have typically been reduced by 30-70%, by changes in stream flow, temperature, sedimentation and channel characteristics in the lower elevation river mainstems they prefer. These changes result from local effects of stream and floodplain development as well as the effects of upstream watershed development on habitat forming processes Fall Chinook in the North Fork Lewis River are a rare exception where habitat conditions remain very favorable in the mainstem downstream from Merwin Dam.

Chum habitats have been reduced by 75% or more for the majority of the populations by changes or loss of low elevation reaches and off-channel areas due to channel stabilization, loss of floodplain connectivity and function, and sedimentation due to land use activities throughout the entire watershed.

Coho habitats have been reduced by 40-95%. The healthiest remaining habitats are found in forested headwaters such as the upper Cowlitz and Lewis rivers. The most heavily impacted habitats occur in the developed lower elevation subbasins where streamflow, temperature, and riparian conditions have been severely affected.

Steelhead habitats have been widely reduced by 40-90% except in a few intact watersheds such as the upper North Fork Lewis River. Steelhead habitat impacts result from a combination of local stream and watershed development effects.

Similar estimates of declines in habitat conditions do not exist for bull trout. Bull trout prefer cold water and are often most abundant within headwater areas of subbasins where they are affected by many of the same habitat changes impacting other salmon and steelhead species.

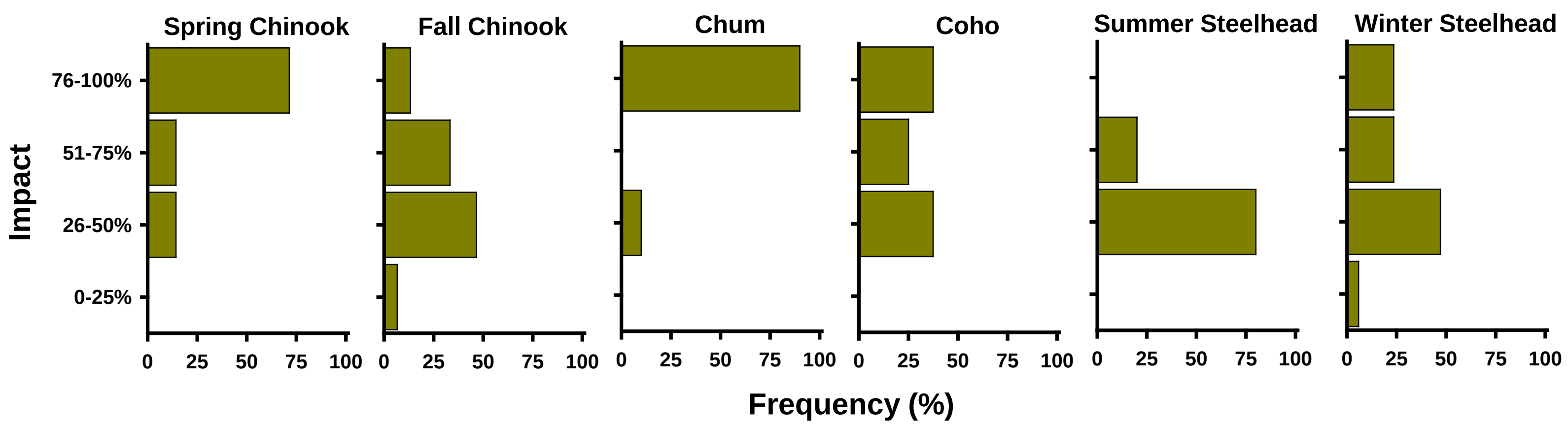

Figure 3-8. **Frequency distribution by population of habitat impacts by species and life history type for Washington lower Columbia River salmon and steelhead populations.**

Table 3-1. **Estimates of equilibrium adult fish abundance (thousands) for historical (T = template) and current (P=patient) stream habitat conditions estimated using the Ecosystem Diagnosis and Treatment (EDT) model. Impacts (I) represent the proportional reduction in fish numbers from historical to current conditions due to changes in stream habitat.**

Subbasin	Chinook						Chum			Coho			Steelhead					
	Spring			Fall									Summer			Winter		
	T	P	I	T	P	I	T	P	I	T	P	I	T	P	I	T	P	I
Grays-Chin	--	--	--	0.8	0.5	0.40	10.2	1.6	0.80	3.8	1.1	0.70	--	--	--	1.7	0.9	0.50
Eloch-Skam	--	--	--	3.0	2.0	0.30	16.3	1.6	0.90	6.5	2.4	0.60	--	--	--	1.1	0.7	0.40
Mill-Ab-Ger	--	--	--	2.5	1.4	0.40	6.6	0.6	0.90	2.8	1.4	0.50	--	--	--	0.9	0.6	0.40
Cowlitz L	--	--	--	24.0	8.2	0.70	195.0	7.9	0.96	18.2	4.6	0.70	--	--	--	1.4	0.4	0.70
Cowlitz U	21.8	3.0	0.90	28.0	5.1	0.80				17.7	11.0	0.40	--	--	--	1.4	0.9	0.40
Cispus	7.8	0.7	0.90	--	--	--				8.0	3.8	0.50	--	--	--	1.5	0.6	0.60
Tilton	5.4	0.9	0.80	--	--	--				5.6	0.3	0.95	--	--	--	1.7	0.2	0.90
Toutle (NF)	3.1	0.2	0.90	10.9	4.6	0.60				27.5	3.2	0.90	--	--	--	3.6	0.6	0.80
Toutle SF													--	--	--	--	--	--
Coweeman	--	--	--	3.5	1.9	0.50				5.0	0.9	0.80	--	--	--	0.9	0.4	0.50
Kalama	4.9	0.4	0.90	2.7	1.6	0.40	20.6	1.6	0.90	0.8	0.2	0.70	1.0	0.6	0.43	0.8	0.4	0.50
Lewis (NF)	15.7	9.9	0.40	23.0	21.4	0.10	124.6	9.1	0.90	39.8	23.8	0.40	n/a	n/a	0.40[1]	8.3	7.3	0.10
Lewis EF	--	--	--	2.6	1.5	0.40				3.1	0.6	0.80	0.6	0.2	0.70	0.9	0.5	0.50
Salmon	--	--	--			0.90			0.98			0.90	--	--	--			0.80
Washougal	--	--	--	2.6	1.7	0.30	18.1	0.7	0.96	2.9	0.5	0.80	0.8	0.4	0.40	0.9	0.4	0.50
Gorge L	--	--	--	n/a	n/a	0.70[1]	n/a	n/a	0.40[1]	0.4	0.3	0.50	--	--	--	n/a	n/a	0.60[1]
Gorge U	--	--	--	n/a	n/a	0.70[1]	10.9	0.4	0.97	0.2	0.1	0.50	2.2	1.2	0.50	n/a	n/a	0.60[1]
Wh.Salmon	n/a	n/a	0.70[1]	n/a	n/a	0.70[1]												

[1] EDT not available, impacts assumed from representative populations.

3.3. Habitat—Estuary & Columbia Mainstem

3.3.1. Background

This Plan provides an overview of estuary habitat factors, threats, working hypotheses, strategies, and measures that are treated in greater detail in the Columbia River Estuary Recovery Plan Module (NOAA Fisheries 2007). The Estuary Module provides a comprehensive and consistent treatment of habitat factors and threats in the lower Columbia River mainstem, estuary, and plume for recovery plans developed for each of the 13 listed ESUs in the basin. The Estuary Module was not available during the completion of the interim Washington Plan, adopted in 2004. The interim Plan independently developed an estuary component, which was subsequently replaced by a regional estuary planning effort. This portion of the Washington lower Columbia Plan was therefore revised for consistency with the current Estuary Module.

For the purposes of this Plan, the estuary is defined to include the tidally-influenced Columbia River mainstem from its mouth upstream to Bonneville Dam at river mile 146 (Figure 3-9). The estuary also includes the Columbia River plume and tidally-influenced areas of the Columbia River tributaries. Many of the habitat changes in the estuary are related to effects of upstream dam construction and operation on river discharge patterns and related habitat-forming processes. This Recovery Plan treats these habitat effects in this estuary section. Other dam-related effects including passage and local habitat effects of Bonneville Dam construction and operation are treated in a later section focused specifically on dams. Ecological factors including predation are discussed extensively in NMFS's estuary module – in this Recovery Plan they are treated in a separate section.

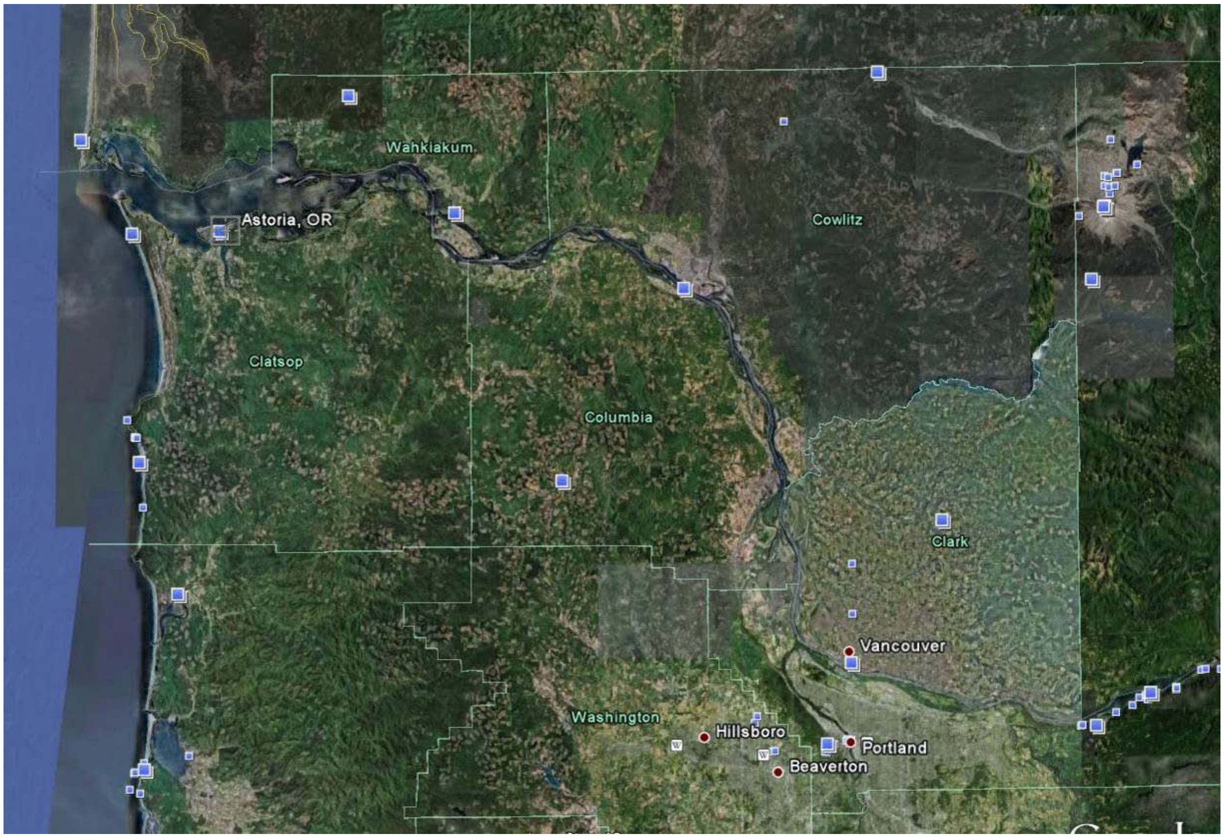

Figure 3-9. The lower Columbia River estuary.

Juvenile and adult salmon may be found in the Columbia River estuary at all times of the year, with different species, life history strategies, and size classes continually moving into tidal waters. Estuaries have important impacts on juvenile salmonid survival by providing juveniles with the opportunity to achieve the critical growth necessary to survive in the ocean (Neilson and Geen 1985, Wissmar and Simenstad 1988 as cited in Nez Perce et al. 1995, Aitkin 1998 as cited in USACE 2001, Miller and Sadro 2003). In fact, juvenile Chinook salmon growth in estuaries often is superior to river-based growth (Rich 1920a, Reimers 1971, Schluchter and Lichatowich 1977). Estuarine habitats also provide young salmonids with a productive feeding area, free of marine pelagic predators, where smolts can undergo the physiological changes necessary to acclimate to the saltwater environment. Studies conducted by Emmett and Schiewe (1997) in the early 1980s have shown that favorable estuarine conditions translate into higher salmonid survival. These findings are consistent with the results of Kareiva et al. (2000, as cited in Fresh et al. 2005), which demonstrated that improvement of juvenile salmon survival during the estuarine and early ocean stage significantly improves salmon population growth rates.

Favorable habitats for salmonid growth and survival in the estuary include high-energy feeding areas in proximity to lower-energy refuge areas. In particular, tidal marsh habitats, tidal creeks, and associated complex dendritic channel networks may be especially important to subyearlings. The sinuous channels, overhanging vegetation, and undercut banks in these habitats offer high densities of insect prey and potential refuge from predators (McIvor and Odum 1988). Furthermore, areas of adjacent habitat types distributed across the estuarine salinity gradient may be necessary to support annual migrations of juvenile salmonids (Bottom et al. 2005). For example, as subyearlings grow, they move across a spectrum of salinities, depths, and water velocities. For species like chum and ocean-type Chinook salmon that rear in the estuary for extended periods, a broad range of habitat types in the proper proximities to one another may be necessary to satisfy feeding and refuge requirements within each salinity zone. Additionally, the connectedness of these habitats likely determines whether juvenile salmonids are able to access the full spectrum of habitats they require (Bottom et al. 1998).

Juvenile salmonids must continually adjust their habitat distribution in relation to twice-daily tidal fluctuations as well as seasonal and anthropogenic variations in river flow. Juveniles have been observed to move from low-tide refuge areas in deeper channels to salt marsh habitats at high tide and back again (Healey 1982). These patterns of movement reinforce the belief that access to suitable low-tide refuge near marsh habitat is an important factor in production and survival of salmonid juveniles in the Columbia River estuary.

Feeding and refuge areas may be important even for species that move more quickly through the estuary. Stream-type salmon smolts feed during their estuary migration period (Bottom et al. 2005). Additionally, radio-tagged coho in the Grays Harbor estuary move alternatively from low-velocity holding habitats to strong-current passive downstream movement areas (Moser et al. 1991). Fresh et al. (2005) reported that both small and large Chinook salmon (i.e., ocean- and stream-type Chinook from upper and lower basin populations) used peripheral marsh and forested wetland habitat in the Columbia River estuary. Dittman et al. (1996) suggest that habitat sequences at the landscape level may be important even for species and life history types that move quickly through the estuary during the important smoltification process, as salmon gather the olfactory cues needed for successful homing. Dittman et al. theorize that these cues may depend on the environmental gradients juveniles experience during migrations.

The Estuary Module synthesizes information from current literature and area experts—including staff from NMFS' Northwest Fisheries Science Center and Northwest Regional Office, the Lower Columbia River Estuary Partnership, and the Lower Columbia Fish Recovery Board—to identify limiting factors for salmon and steelhead in the lower Columbia mainstem, estuary, and plume and relate those limiting factors to their underlying causes or sources, referred to as threats. Threats are prioritized based on their contribution to one or more limiting factors and the significance of those limiting factors. Often there is not a one-to-one correlation between a single limiting factor and a threat because limiting factors and threats are so interrelated. The module then identifies management actions to address threats, and explores implementation considerations related to potential actions' cost and effectiveness.

The Estuary Module draws on the following key documents to identify limiting factors in the estuary and plume:

- Salmon at River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon (Bottom et al. 2005)—NMFS technical memorandum
- Role of the Estuary in the Recovery of Columbia River Basin Salmon and Steelhead: An Evaluation of the Effects of Selected Factors on Salmonid Population Viability (Fresh et al. 2005)—NMFS technical memorandum
- Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan and its supplement—Northwest Power and Conservation Council (2004)

These documents notwithstanding, the state of the science surrounding salmonid species, habitat conditions, and habitat-forming processes in the lower mainstem, estuary, and plume is such that quantitative answers to questions about estuarine ecology are not necessarily available at this time. This is true in part because of the complexity of the ecological processes in the estuary, but also because the lower mainstem, estuary, and plume are only now being studied at a level of detail that allows knowledge about these ecosystems to be integrated into the understanding of life history patterns of salmon and steelhead—patterns that have been comparatively well documented in the upstream portions of the basin.

What is clear, however, is that the Columbia River estuary and plume play a unique and essential role in the life cycles of ocean- and stream-type salmonids. The estuary is where juvenile and adult salmonids undergo the vast physiological changes needed to transition to and from saltwater, and a properly functioning estuary provides juveniles with refugia from predators and opportunities for significant growth. Also, unlike a tributary, whose habitat supports salmonids from only a limited number of populations, the estuary and plume are used by all of the more than 150 extant salmon and steelhead populations of the Columbia River basin during key stages of their life cycles. In fact, over evolutionary time, salmonid populations developed life history strategies in which juveniles from different populations staggered their use of the estuary and plume throughout the year, exploiting estuarine habitats in different ways for different lengths of time to take maximum advantage of the food and refuge the estuary and plume offer. Because all Columbia River basin salmon and steelhead make use of the estuary and plume, improvements in estuary conditions can be expected to benefit not just local lower Columbia River ESUs but salmonid populations throughout the basin.

3.3.2. Limiting Factors

Over the last 200 years the ability of the lower Columbia mainstem, estuary, and plume to meet the needs of salmon and steelhead has been seriously compromised. The timing, magnitude, and duration of flows do not resemble those of historical flows, access to the estuary floodplain has been virtually eliminated, sediment transport processes that depend on flows and upstream sediment sources are radically different than they were historically, water quality has degraded as a result of contamination, water temperatures are approaching and sometimes exceeding lethal limits, and there have been fundamental changes at the base of the estuarine food web, with associated alterations in inter- and intra-species relationships. Limiting factors in the estuary are intricately interrelated. Factors act together to limit the biological performance of salmonids in the estuary and plume. Likewise, there is not necessarily a one-to-one relationship between limiting factors and their underlying causes or sources, as several threats may bring about one or more limiting factors.

Flow-Related Changes in In-Channel Estuary Habitat

Over the last 4,000 years, Columbia River salmon have adapted to habitats created by characteristics of the land and of water flow (Fresh et al. 2005). Key attributes of flow include quantity and timing, both of which have changed significantly in the lower Columbia mainstem and estuary over the last century (see Figure 3-10). Jay and Naik (2002) reported a 16 percent reduction of annual mean flow in the last 100 years and a 44 percent reduction in spring freshet flows. Jay and Naik also reported a shift in the hydrograph to 14 to 30 days earlier in the year, meaning that spring freshets are occurring earlier in the season than they did historically. In addition, the interception and use of spring freshets (for irrigation, reservoir storage, etc.) have caused flows during other seasons to increase (Fresh et al. 2005). Winter flows, for example, have increased by about 30 percent. In some locations, even daily instream flow can vary significantly as hydrosystem operations change to accommodate fluctuations in power demand.

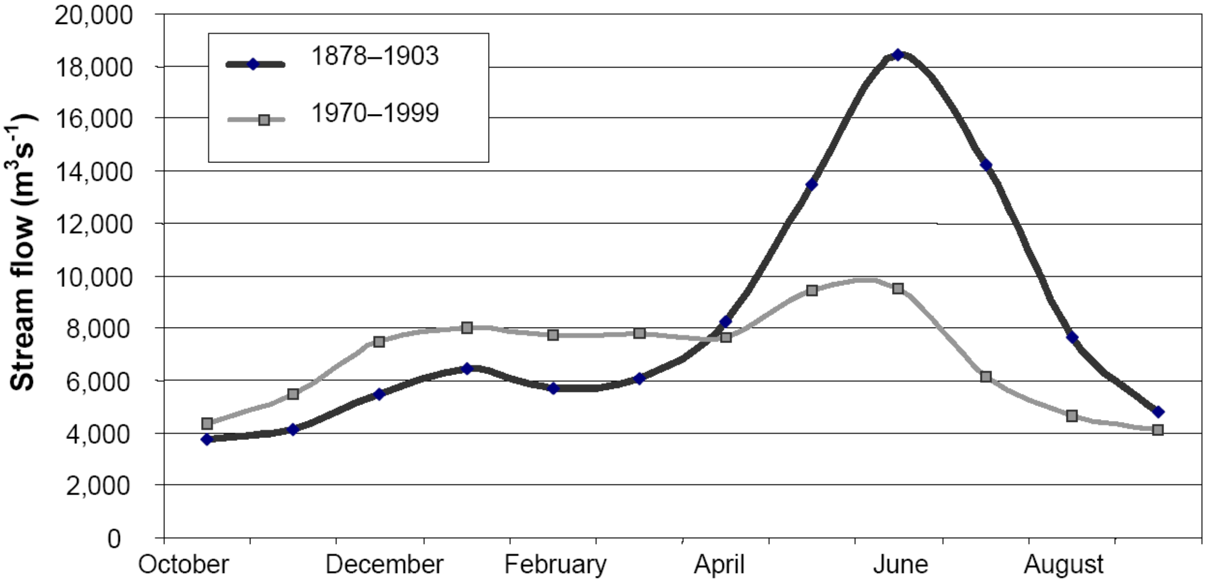

Figure 3-10. Changes in the annual Columbia River flow measured at Beaver Army Terminal near Quincy, Oregon. (Flows for 1878 to 1903 are reconstructed averaged flows.) (Reprinted from Bottom et al. 2005.)

Instream flow greatly affects juvenile salmonids' ability to access and benefit from habitat (Fresh et al. 2005). Changes in the quantity and seasonality of flows in the estuary have a direct bearing on whether key habitats are available to salmonids, when those habitats are available, and whether and how they connect with other key habitats. In some cases, changes in flow patterns can dewater redds or strand juveniles (NMFS 2000c). Alterations in flow have removed habitat from the estuarine ecosystem and converted some habitat types to others that may not be meeting the needs of salmonids as well as historical habitats did. For example, the estuary has seen significant losses of tidal swamps and other forested or vegetated wetlands that ocean-type salmonids use for refuge and foraging.

In addition, juvenile salmonids have physiological or behavioral traits that set the timing for their migration to saltwater, and changes in flows can interrupt this timing. Smolt travel times through the Columbia and Snake mainstems have increased significantly as a result of flow regulation and reservoir construction, and the potential delay of emigrants reaching the estuary during a critical physiological window for smoltification or ocean dispersion is a significant concern. This is especially true for upriver salmon and steelhead stocks that migrate long distances.

Alterations in river flow also affect salinity distribution in the estuary. Together with tidal energy, river discharge determines the location, size, shape, and salinity gradients of the estuary turbidity maximum zone; these characteristics in turn affect the seasonal species distributions and structure of entire fish, epibenthic, and benthic invertebrate prey species assemblages throughout the Columbia River estuary. Even small changes in the distribution of salinity gradients can change the type of habitats available when juvenile salmon make the critical physiological transition from fresh to brackish water.

Changes in the Columbia River hydrograph are limiting factors for salmon and steelhead and have affected habitat opportunity and capacity in the estuary.

Flow-Related Changes in Access to Off-Channel Habitat

Columbia River access to its historical floodplain is an important factor for rearing ocean-type juvenile salmonids. Historically, flows that topped the river's bank were a vital source of new habitats, providing juvenile salmonids with access to low-velocity areas they used as refugia and for rearing. Overbank flows also contributed key food web inputs to the ecosystem and influenced wood recruitment, predation, and competition in the estuary (Fresh et al. 2005). Typically, overbank flows were driven by spring freshets, which occurred at the time of year when there was the greatest variety of juvenile salmon and steelhead using the estuary (Fresh et al. 2005).

Today, overbank flows occur much less frequently than they did historically (Jay and Kukulka 2003). Mainstem habitat in the Columbia River has been reduced to a single channel (Northwest Power and Conservation Council 2004), and the surface area of the estuary itself is approximately 20 percent smaller than it was 200 years ago (Fresh et al. 2005). It is estimated that channelization of the estuary has eliminated access to 77 percent of historical tidal swamps (Fresh et al. 2005) and 43 percent of tidal marsh habitat (Thomas 1983)—habitat types that juvenile salmonids use in adjusting to twice-daily tidal fluctuations and other variations in river flows. Juveniles move from low-tide refuge areas in deeper channels to salt marsh habitats at high tide and back again (Healy 1982), and access to suitable marsh habitat near low-tide refugia is an important factor in production and survival of salmonid juveniles in the Columbia River estuary.

Reduced access to off-channel habitats is a limiting factor for salmon and steelhead because of impacts on food webs and the reduced availability of habitats preferred by fry and fingerlings.

Flow-Related Plume Changes

Evidence suggests that the Columbia River plume supports ocean productivity by increasing primary plant production during the spring freshet period, distributing juvenile salmonids in the coastal environment, concentrating salmonid food sources such as zooplankton, and providing refugia from predators in the relatively turbid, low-salinity plume waters (Fresh et al. 2005).

Changes in the Columbia River hydrograph have altered both the size and structure of the plume during the spring and summer months (Northwest Power and Conservation Council 2000). Conditions caused by reductions in spring freshets and associated sediment transport processes may now be suboptimal for juvenile salmonids (Casillas 1999), who rely on the plume for food, refuge, and transitional saltwater habitat between brackish estuarine waters and the ocean. Stream-type ESUs in particular are affected by the size, shape, behavior, and composition of the plume (Fresh et al. 2005). Plume attributes affected by changes in flow include surface area and volume, extent and intensity of frontal features, and extent and distance offshore of plume waters (Fresh et al. 2005).

Bankfull Elevation Changes

The construction of dikes and levees has contributed to reductions in the frequency of overbank flows. Because diked floodplain is higher than the historical floodplain, more water is needed to cause overbank flow and inundate floodplain habitats. Diking in the Columbia River floodplain has been extensive (see Figure 3-11), and today the bankfull level is 24,000 m^3/s —fully one-third more than the historical bankfull level of 18,000 m^3/s. Only five overbank events have occurred since 1948 (Jay and Kukulka 2003). Increases in bankfull elevation are a limiting factor because the resulting reduction in overbank flows reduces the availability of food and refugia for ocean-type juveniles rearing in off-channel areas of the estuary.

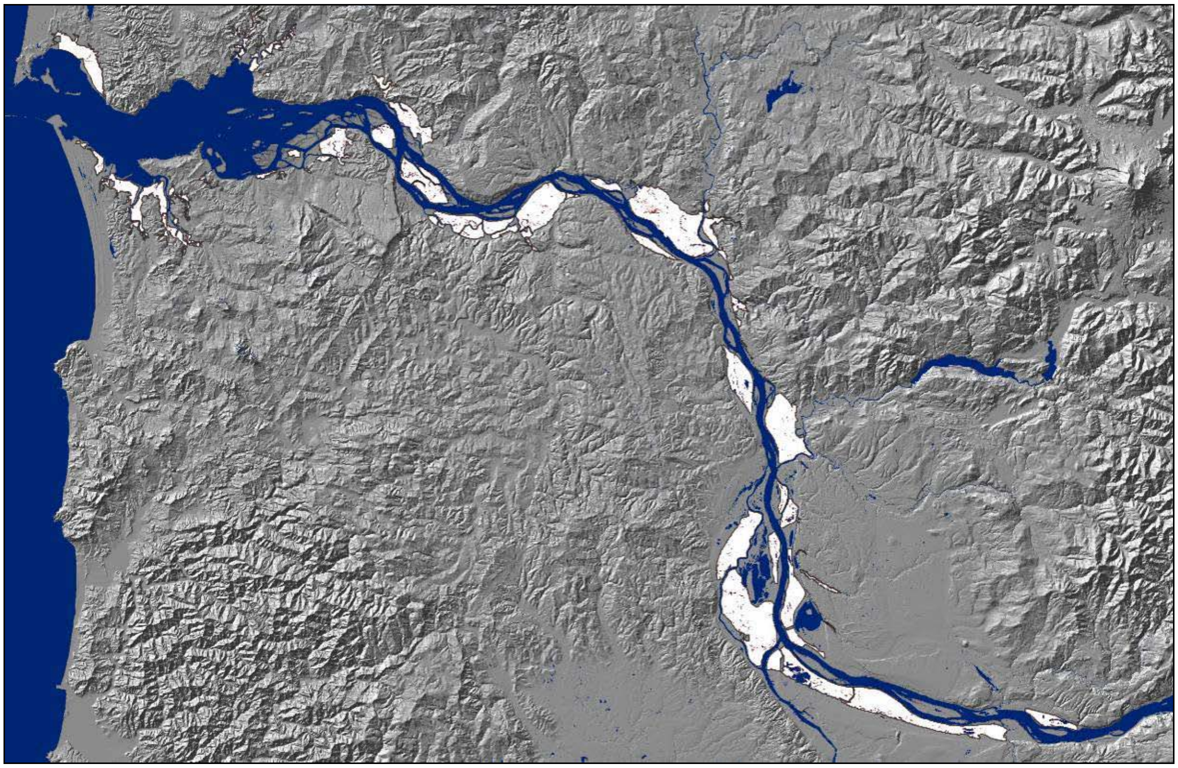

Figure 3-11. Diked areas in the Columbia River Estuary. (Reprinted from NOAA Fisheries 2006).

Sediment/Nutrient-Related Estuary Habitat Changes

The transport of sediment suspended in the water column is fundamental to habitat-forming processes in the estuary through sediment deposition and erosion (Fresh et al. 2005). Sediment from the estuary and upstream sources also affects the formation of nearshore ocean habitats north and south of the Columbia River entrance.

Since the late nineteenth century, sediment transport from the interior basin to the Columbia River estuary has decreased about 60 percent and total sediment transport has decreased about 70 percent (Jay and Kukulka 2003). The largest single factor in decreased sediment transport appears to be the reduction of spring freshet flow as a result of water regulation and irrigation withdrawal. Although the consequences of the reduced transport of sediment through the estuary and plume are not fully understood, the magnitude of change is very large compared to historical benchmarks (Fresh et al. 2005) and is presumed to be a limiting factor for salmon and steelhead.

In addition to forming shallow-water habitats, sediment provides important nutrients that support food production in the estuary and plume. Micro detrital food particles adhere to sediment suspended in the water column, making different food sources available to different species than was the case with the historical macro detritus-dominated food web. Currently, organic matter associated with fine sediments supplies the majority of estuarine secondary productivity in the food web (Simenstad et al. 1984 as cited in Northwest Power and Conservation Council 2004).

Sediment/Nutrient-Related Plume Changes

It is believed that fine sediments and associated nutrients transported from the estuary to the plume fuel ocean productivity and shelter juvenile salmonids from predation (Casillas 1999). This is particularly true for stream-type ESUs, who use the plume more extensively than ocean types do and thus are more affected when characteristics of the plume have been altered, as they have over the last 200 years.

Water Temperature

Flow regulation, reservoir construction, and riparian practices have increased the average water temperature in the Columbia River mainstem to the point that summer water temperatures regularly exceed optimum levels for salmon and steelhead (NMFS 2000a). Water temperatures of between 20° and 24° C are considered the upper range for cold-water species such as salmonids (National Research Council 2004). Since 1938, summer water temperatures at Bonneville Dam have increased 4 degrees on average, and annual variability in temperature has been reduced by 63 percent since 1970. As shown in Figure 3-12, temperatures of water entering the estuary (as measured at Bonneville Dam) have increased steadily since 1938. Temperatures also exceed 20° C earlier during the year and more frequently than they did historically (National Research Council 2004).

Alterations in water temperature affect the metabolism, growth rate, and disease resistance of salmonids, as well as the timing of adult migrations, fry emergence, and smoltification (NMFS 2000). High water temperatures can cause migrating adult salmon to stop their migrations or seek cooler water that may not be in the direct migration route to their spawning grounds (NMFS 2000a). The effects of such migration delays are unknown.

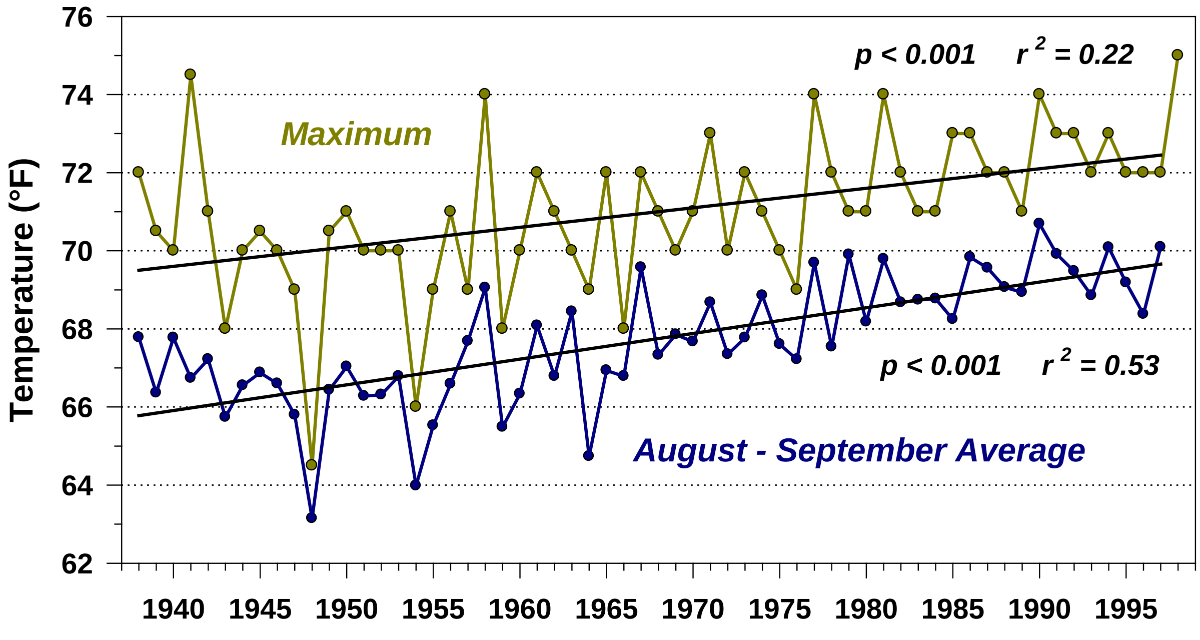

Figure 3-12. Historical changes in summer water temperatures at Bonneville Dam.

Ecosystem Effects

The estuarine food web formerly was supported by micrometrical inputs of plant materials that originated from emergent, forested, and other wetland rearing areas in the estuary (Northwest Power and Conservation Council 2004). Today, detrital sources from emergent wetlands in the estuary are approximately 84 percent less than they were historically (Bottom et al. 2005). This decline is the result of the construction of revetments along the estuary shorelines, the disposal of dredged material in what formerly were shallow or wetland areas where plant materials or insects could drop into the water, and reductions in flow. (Flow reductions affect detrital sources by limiting the amount of wetlands—areas that normally would be contributing macro detritus to the food web—and cutting the number of overbank flows, which historically provided access to additional shallow-water habitat for juvenile salmonids and allowed significant detrital inputs to the estuary.) Instead of being supported by local plant production, the current food web is based on vastly increased amounts of decaying phytoplankton delivered from upstream reservoirs.

The switch in primary production in the estuary has lowered the productivity of the estuary (Bottom et al. 2005), contributed to changes in the spatial distribution of the food web (Bottom et al. 2005), and permanently altered complex intra- and inter-species relationships (Northwest Power and Conservation Council 2004). Historically the macro detritus-based food web was distributed evenly throughout the estuary, including in the many shallow-water habitats favored by ocean-type salmonids. The contemporary micrometrical food web is concentrated within the estuarine turbidity maximum in the middle of the estuary (Bottom et al. 2005). This location is less accessible to ocean-type ESUs that use peripheral habitats and more accessible to species such as American shad that feed in deep-water areas. Pelagic fish such as shad may also benefit from the fact that the estuarine turbidity maximum traps particles and delays their transport to the ocean up to 4 weeks, compared to normal transport of around 2 days (Northwest Power and Conservation Council 2004). The estuarine turbidity maximum is thought to contain bacteria that attach to detritus. Phytoplankton detritus and the associated bacteria represent the primary food source in the estuary today (Northwest Power and Conservation Council 2004).

Salmonid production in estuaries is supported by detrital food chains (Healey 1979, 1982). Therefore, habitats that produce and/or retain detritus, such as emergent vegetation, eelgrass beds, macro algae beds, and epibenthic algae beds, are particularly important (Sherwood et al. 1990). Diking and filling activities in the estuary have likely reduced the rearing capacity for juvenile salmonids by decreasing the tidal prism and eliminating emergent and forested wetlands and floodplain habitats adjacent to shore (Bottom et al. 2005, NMFS 2000c). Dikes throughout the lower Columbia River and estuary have disconnected the main channel from a significant portion of the wetland and floodplain habitats. Further, filling activities (i.e. for agriculture, development, or dredge material disposal) have eliminated many wetland and floodplain habitats. Thus, diking and filling activities have eliminated the emergent and forested wetlands and floodplain habitats that many juvenile salmonids rely on for food and refugia, as well as eliminating the primary recruitment source of large woody debris that served as the base of the historic food chain. The current estuary food web is micro detritus based, primarily in the form of imported phytoplankton production from upriver reservoirs that dies upon exposure to salinity in the estuary (Bottom and Jones 1990 as cited in Nez Perce et al. 1995, Bottom et al. 2005, USACE 2001). The historic macro detritus-based food web was distributed throughout the lower river and estuary, but the modern micro detritus-based food web is focused on the spatially confined ETM region of the estuary (Bottom et al. 2005). This current food web is primarily available to pelagic feeders and is a disadvantage to epibenthic feeders, such as salmonids (Bottom and Jones 1990 as cited in Nez Perce et al. 1995, Bottom et al. 2005, USACE 2001).

Columbia River mainstem reservoirs trap sediments and nutrients, as well as reduce sediment bed load movement, thereby reducing sediment and nutrient supply to the lower Columbia River. The volume and type of sediment transported by the mainstem Columbia River has profound impacts on estuarine habitat formation, food webs, and species interactions. For example, organic matter associated with the fine sediment supply maintains the majority of estuarine secondary productivity (Simenstad et al. 1990, 1995 as cited in Bottom et al. 2005). Also, turbidity (as determined by suspended sediments) regulates light penetration needed for primary production and decreases predator efficiency on juvenile salmonids. Further, the type of sediment transported has profound effects on habitat formation. Sand and gravel substrates are important components of preferred salmonid habitat in the estuary, but sand

and gravel transport has been reduced more (>70% reduction compared to predevelopment flow) than silt and clay transport (Bottom et al. 2005).

Decreased habitat diversity and a modified food web has decreased the ability of the lower Columbia River mainstem and estuary to support the historic diversity of salmonid life history types that used streams, rivers, the estuary, and perhaps the Columbia River plume as potential rearing areas. Bottom et al. (2001) identified several forms of ocean-type Chinook life histories, based on the scale pattern, length, and historical run timing data collected by Rich (1920). Wissmar and Simenstad (1998) and Bottom et al. (2001) suggest there may be as many as 35 potential ocean-type Chinook salmon life history strategies. Bottom et al. (2001) suggested that human effects on the environment have caused Chinook life history patterns to be more constrained and homogenized than historic data show. Most modern ocean-type Chinook fit into one of three groups: subyearling migrants that rear in natal streams, subyearling migrants that rear in larger rivers and/or the estuary, or yearling migrants. Abundance patterns of juvenile Chinook in the estuary may have shifted somewhat toward more yearling juveniles because of hatchery management practices.

Stranding

In the estuary and lower mainstem, large ships passing through the navigational channel produce bow waves that crash against shorelines in Oregon and Washington. Small ocean-type fry and fingerlings rear within inches of shore and may become stranded as waves intersect the bank and recede (Ackerman 2002), although the extent of this problem is unclear. A 1977 study by the Washington Department of Fisheries estimated that more than 150,000 juvenile salmonids—mostly Chinook—were stranded at five test sites (Bauersfeld 1977). A new study being conducted as part of the U.S. Army Corps of Engineers' channel deepening project is expected to better characterize conditions that contribute to stranding events and the prevalence of these conditions throughout the estuary and lower mainstem.

Contaminants

The quality of habitats in the Columbia River estuary is degraded as a result of past and current releases of toxic contaminants (Fresh et al. 2005), from both estuary and upstream sources. Current environmental conditions in the Columbia River estuary indicate the presence of contaminants in the food chain of juvenile salmonids including DDT, polychlorinated biphenyls (PCBs), and polyaromatic hydrocarbons (PAH) (NMFS 2001). Potentially toxic water-soluble contaminants, trace metals, and chlorinated compounds have been observed in the estuary (Fresh et al. 2005), and DDT and PCBs have been detected at elevated levels in juvenile salmonids using the estuary. These substances concentrate in animals near the top of the food chain. Sublethal concentrations of contaminants affect the survival of aquatic species by increasing stress, predisposing organisms to disease, delaying development, and disrupting physiological processes, including reproduction. NMFS (2008c) found that juvenile salmonids in the Columbia River estuary have contaminant body burdens in the range where sublethal effects can occur. In juvenile salmonids, contaminant exposure can result in decreased immune function and generally reduced fitness (Northwest Power and Conservation Council 2004). In a 2005 study by Loge et al., cumulative delayed disease-induced mortalities were estimated at 3 percent and 18 percent for juvenile Chinook residing in the Columbia River estuary for 30 to 120 days, respectively (Loge et al. 2005).

A variety of organochlorines (including aldrin, dieldrin, trichlorobenzene, and PAHs) in the estuary are above state and federal guidance levels (Northwest Power and Conservation Council 2004). As mentioned above, sublethal concentrations of contaminants can affect the survival of aquatic species by increasing stress, predisposing organisms to disease, delaying development, and disrupting physiological processes (Northwest Power and Conservation Council 2004).

3.3.3. Threats

Threats are human actions or natural events, such as floodplain development or volcanic eruptions, which cause or contribute to limiting factors. In the lower Columbia mainstem and estuary, many threats to salmon and steelhead are anthropogenic and are related to man-made structures or to changes in river flow, sediment transport and delivery processes, food web dynamics, or water quality, as follows:

- Flow-related threats: Climate cycles and global warming, water withdrawal, and flow regulation
- Sediment-related threats: Entrapment of sediment in reservoirs, impaired sediment transport, and dredging
- Structural threats: Pile dikes and navigational structures, dikes and filling, reservoir heating, and over-water structures
- Food web-related threats: Reservoir phytoplankton production, altered predator/prey relationships, and ship ballast practices (See Section 3.7 Ecological Interactions)
- Water quality-related threats: Agricultural, rural, urban, and industrial practices
- Other threats: Riparian practices and ship wakes

In many cases, threats in the estuary and plume reflect activities conducted throughout the Columbia River basin whose impacts are readily conveyed downstream via river flow. Contaminants in the estuary, for example, come in part from agricultural activities in the Yakima and Willamette valleys, while water temperatures are affected by surface water heating in reservoirs and riparian practices in estuary and mainstem tributaries. Likewise, just as the estuary acts as a “sink” for the effects of upstream actions, it may also be the linchpin for recovery of certain upstream salmonid populations. There are more than 150 distinct salmonid populations in the Columbia River basin, and all of them migrate downstream to the estuary, where they rely on estuarine and plume habitats during critical stages of their life histories. The extent of their reliance is evidenced by recent estimates of juvenile mortality rates in the estuary and plume of 25 to 35 percent (Ferguson 2006a), or possibly even 50 percent for some ESUs (NOAA Fisheries 2006). This suggests that recovery of some upriver salmonid stocks may hinge on improved conditions in the estuary and plume.

Although threats to salmon and steelhead are presented discretely in this Plan, in reality they often are interconnected, particularly those threats related to flow, sediment delivery, and the food web. For example, diking, deposition of dredged materials, and reductions in flow act together to eliminate vegetated wetlands and reduce overbank flow events. This limits juvenile salmonids’ access to critical off-channel habitat and alters the food web by decreasing micrometrical inputs and the amount of insect prey for salmonids. These effects may be compounded by alterations in sediment transport, which itself is a fundamental habitat-forming process in the estuary. Suspended sediments also provide important nutrients that support food production in the estuary and plume, and they increase turbidity, which shelters stream-type salmonids from predators. Changes in the estuarine food web as a result of flow or sediment processes can ripple through the ecosystem, altering feeding patterns, predator/prey relationships, and competition within and among species, including fish such as northern pikeminnow and walleye that prey on salmonids.

Water Withdrawal

Historically, flow conditions in the estuary were determined by seasonal climate effects and hydrology. Today, the magnitude and timing of flows entering the estuary and plume also are influenced by upstream withdrawals of surface water and groundwater for commercial, industrial, municipal, domestic, and other purposes (National Research Council 2004). This includes surface water withdrawals for irrigation, which accounts for approximately 96 percent of total water used (National Research Council 2004).

Reduction in the amount of instream flow in a river system is an important measure of alterations to the system (Fresh et al. 2005). Since the latter part of the nineteenth century, water withdrawals for human use have reduced flows of the Columbia River by 7 percent (Jay and Kukulka 2002). Water withdrawals affect salmonids by:

- Reducing flow, thus altering habitat-forming processes,
- Reducing access to off-channel habitat, and
- Reducing micrometrical inputs to the food web.

Flow Regulation

Flow regulation is a function of the hydrosystem in the United States and Canada. More than 450 dams have been built in the Columbia River basin, and they supply British Columbia with half of its electricity and the American Northwest with about two-thirds of its electricity (Columbia Basin Trust). Columbia River dams also provide flood control, enhance irrigation, and improve navigation. The total active storage of water in the Columbia River Basin is 42 million acre-feet, with dams in Canada accounting for about half of the total storage (Northwest Power and Conservation Council 2001).

Flow regulation in the Columbia River basin has been a major contributor to changes in the ecology of the lower mainstem and estuary. Both the timing and magnitude of spring freshets have been drastically altered by management of the Columbia River hydrosystem (Fresh et al. 2005), which accounts for 26 percent of the reduction in freshet flows since the late nineteenth century (Jay and Kukulka 2002). Together with irrigation, flow regulation has increased fall and winter flows, and much of the seasonal timing of flows in the estuary is determined by flood control and hydroelectric operations. Flow regulation—combined with other factors—can decrease salmonids’ ability to access habitats and the capacity of habitats to sustain salmonids (Bottom et al. 2005). Flow alterations also affect sediment transport, which is a habitat-forming process. In the lower Columbia mainstem and estuary, alterations in the timing, magnitude, and duration of flows are responsible for dramatic changes in habitat opportunity and capacity.

Both ocean- and stream-type juveniles are influenced by alterations in flow. Ocean types rely on shallow vegetated swamp and marsh habitats in the estuary (Northwest Power and Conservation Council 2004) that become less accessible as flow levels fall and seasonal overbank flows become less frequent. Chum salmon, an ocean type that spawns in the mainstem, are affected by low flows during the spawning and egg incubation life stages; in extreme cases, redds may be dewatered.

Stream-type juveniles are affected by flow-related changes to the Columbia River plume, which recent research suggests they use as they adjust to saltwater conditions (Fresh et al. 2005). Columbia River flows have a direct effect on the plume’s surface area, volume, frontal features, and extent offshore (Fresh et al. 2005).

Recently, changes in hydrosystem operations have included increasing flows to benefit spring juvenile salmonid migration in the mainstem Snake and Columbia Rivers; this action helps flows in real time instead of filling reservoirs. Also, summer flows have been augmented to assist Snake River fall Chinook migration. Finally, a minimum flow has been administratively set from November through April to reduce the potential for dewatering of chum redds, primarily in the upper reaches of the lower mainstem.

Flow regulation can affect salmonids by:

- Disrupting natural flow patterns, estuarine circulation, and salinity patterns,

- Reducing overbank flows and access to off-channel habitat,
- Altering habitat-forming processes,
- Reducing sediment delivery to the estuary and plume,
- Reducing turbidity such that predation of salmonids is enhanced (particularly avian predation of stream-type salmonids),
- Reducing micrometrical inputs to the food web, and
- Stranding juveniles during downstream migration.

Entrapment of Sediment in Reservoirs

Silt, clay, and other fine sediments that enter the estuary originate in the upper watersheds of the Snake River (Northwest Power and Conservation Council 2004). Reduced water velocities behind upstream reservoirs act as a sink to these sediments and likely reduce amounts delivered to the estuary (Northwest Power and Conservation Council 2004). Currently, organic matter associated with fine sediments supplies the majority of estuarine secondary productivity in the food web (Simenstad et al. 1984 as cited in Northwest Power and Conservation Council 2004). Entrapment of sediment in reservoirs affects salmonids by:

- Altering habitat-forming processes,
- Reducing turbidity such that predation of salmonids is enhanced (particularly avian predation of stream-type salmonids), and
- Altering food web dynamics related to the organic matter that adheres to fine sediments.

Impaired Sediment Transport

Historically, the force of spring freshets moved sand down the river and into the estuary, where it formed shallow-water habitats that are vital for salmonids, particularly ocean types. Today, alterations to spring freshet flows have reduced sand discharge in the Columbia River estuary to 70 percent of nineteenth-century levels (Jay and Kukulka 2002). Impaired sediment transport into the estuary affects salmonids by:

- Altering habitat-forming processes,
- Decreasing the amount of shallow-water habitats,
- Reducing turbidity such that predation of salmonids is enhanced (particularly avian predation of stream-type salmonids), and
- Altering food web dynamics related to the organic matter that adheres to fine sediments.

Dredging

Over the last century, dredging—with the associated deposition of dredged material in water, along shorelines, and on upland sites—has been a major cause of estuarine habitat loss, particularly of vegetated wetlands. Currently, three times more sand is dredged from the estuary than is replenished by upstream sources (Northwest Power and Conservation Council 2004), and deposition of dredged material accounts for most of the filling activities in the estuary. In addition to causing habitat loss, dredging may also impair sediment circulation systems in nearshore ocean areas. Dredge and fill activities affect salmonids by:

- Reducing the availability of wetlands and other habitat types in the estuary and plume, and

- Creating favorable habitat for Caspian terns, who prey on juvenile stream-type salmonids.

Pile Dikes and Navigational Structures

Construction of the North and South jetties has altered sediment accretion and erosion processes near the mouth of the Columbia River, decreasing the inflow of marine sediments into the estuary (Northwest Power and Conservation Council 2004) and altering saltwater intrusion patterns. In addition, the extensive use of dike fields and other structures to maintain the shipping channel has affected natural flow patterns, such as by reducing flow to side channels and peripheral bays (Northwest Power and Conservation Council 2004). These changes affect salmonids by:

- Altering habitat-forming processes in the estuary and plume,
- Changing circulation patterns, and
- Creating roosting habitats for double-crested cormorants and microhabitats for exotic fish that prey on juvenile salmonids.

Dikes and Filling

Dikes are thought to have caused more habitat conversion in the estuary than any other human or natural factor (Thomas 1983, as reported in Northwest Power and Conservation Council 2004). The greatest impacts have been to the highest elevation estuarine habitats: forested wetlands, followed by shrub wetlands and marshes. Diking effectively removes these vegetated habitats from the estuary, reducing their availability to juvenile salmon and steelhead, cutting off sources of large woody debris, decreasing micrometrical inputs to the food web that originate from wetland vegetation, and lessening the amount of insect prey for salmonids. As a result of diking and filling practices and flow alterations, emergent plant production in the estuary has decreased by 82 percent and microalgae production has decreased by 15 percent (Northwest Power and Conservation Council 2004). Diking also helps to concentrate flow in a single main channel, rather than to the side channels and peripheral bays that provide critical refuge and forage opportunities for ocean-type juveniles. Dikes and filling affect salmonids by:

- Altering habitat-forming processes in the estuary and plume,
- Reducing the amount and availability of off-channel habitats,
- Reducing overbank flows,
- Reducing macro detrital inputs to the food web, and
- Allowing exotic plants to become established.

Reservoir Heating

More than 450 dams have been built in the Columbia River basin (Columbia Basin Trust). The relatively large surface area of the reservoirs behind dams allows increased solar heating of the impounded water. Together with reduced flows from upstream impoundments, this heating contributes to high water temperatures downstream in the lower Columbia mainstem and estuary. Periods of increased temperatures in the Columbia River are lasting longer than they did historically (National Research Council 2004), with average and maximum water temperatures being well above 20° C; this approaches the upper limits of thermal tolerance for cold-water fishes such as salmon (National Research Council 2004). Reservoir heating affects salmonids by:

- Increasing water temperature, and
- Interrupting migration and rearing opportunities.

Over-Water Structures

Docks, transient moorage, log rafts, and other over-water structures in the Columbia River estuary number in the thousands. These structures block sunlight, decrease flow outside the main channel, trap sediments downstream of pilings, and reduce the amount of edge habitat available to ocean-type salmonids. Over-water structures also create microhabitats favorable to predators such as northern pikeminnow and walleye, and research suggests that salmon fry tend to concentrate in higher densities around over-water structures, thus increasing the risk of predation (Williams and Thom 2001). Stream-type salmonids that leave the deeper channels to forage in shallow-water habitats may also fall victim to predators congregating near structures. Over-water structures affect salmonids by:

- Altering estuarine habitats and habitat-forming processes,
- Changing circulation patterns and sediment accretion and erosion , and
- Increasing predation by exotic fish.

Toxic Contaminants Resulting from Agricultural Practices

The health of the aquatic ecosystem is substantially affected by wastewater discharge and runoff from agricultural areas both within the estuary itself and throughout the Columbia River basin. Types of contaminants linked to agricultural practices include water-soluble toxins, nutrients such as nitrogen and phosphorus, and organic and trace metals (National Research Council 2004). Commonly used pesticides detected in the lower Columbia mainstem include simazine, atrazine, chlorpyrifos, metolachlor, diazinon, and carbaryl. Water-soluble contaminants, trace metals, and chlorinated compounds have been detected in the estuary (Fresh et al. 2005), and samples of fish tissue from the estuary reveal elevated levels of DDT, PCBs, dioxins, and metals (Northwest Power and Conservation Council 2004). Agricultural practices affect salmonids by:

- Exposing salmonids to short-term and bioaccumulative toxins.

Toxic Contaminants Resulting from Urban and Industrial Practices

The lower Columbia mainstem and estuary receive urban and industrial contaminants both in runoff from upstream sources and from the urbanized stretch of river downstream of Bonneville Dam. Along with surface and storm water runoff, more than 100 point sources contribute contaminants to the estuary (Fuhrer et al. 1996 as referenced in Fresh et al. 2005).

In general, PCB and polycyclic aromatic hydrocarbon (PAH) concentrations in salmon and their prey in the estuary are comparable to those in organisms in other moderately to highly urbanized areas (Fresh et al. 2005). PCBs, PAHs, other industrial contaminants, and pesticides have been found in sediments in the lower Willamette River in Portland (PAHs at levels exceeding state or federal guidelines), while PCB and DDT hot spots have been identified in the lower Columbia mainstem near Vancouver, Longview, and the Astoria Bridge (Fresh et al. 2005). In addition, the Portland and Vancouver sewage treatment plants are the largest sources of effluent in the area (Fresh et al. 2005). Urban and industrial practices affect salmonids by:

- Exposing salmonids to short-term and bioaccumulative toxins.

Riparian Practices

Riparian practices along the estuary mainstem and in tributaries throughout the Columbia River basin have contributed to increases in water temperature in the estuary by changing hydrology and removing riparian habitats (National Research Council 2004), which—among other ecological functions—provide insects and macro detrital inputs to the food web. Practices of concern include shoreline modifications, timber harvest, agricultural activities within buffer zones, and residential, commercial, and industrial land uses. Riparian practices affect salmonids by:

- Altering hydrology,
- Modifying shoreline habitats used by ocean-type salmonids,
- Increasing water temperatures,
- Reducing macro detrital inputs, and
- Contributing to the establishment of exotic plants.

Ship Wakes

Ships traveling through the Columbia River estuary produce waves and an up rush which, under certain circumstances, causes juvenile salmonids and other fish to become stranded on shore (Bauersfeld 1977). The extent of this problem is unclear. A new study that is part of the U.S. Army Corps of Engineers' channel deepening project may help characterize the magnitude of ship wake stranding in the estuary. Ship wakes affect salmonids by:

- Causing juveniles to become stranded on shore.

3.3.4. Impact Assessment

Quantifying the impact of habitat changes in the estuary on juvenile salmon mortality is extremely difficult. Other assessments have measured changes in habitat conditions that are know to affect salmonid life history. For example, approximately 77% of the historical tidal swamp has been lost while other shallow water habitats have increased significantly (NOAA 2007). Similarly, mean river flow through the estuary has declined by about 16% and peak spring flows have declined about 44% in the last 100 years (NOAA 2007). However, translating these habitat changes into fish values is difficult because the relationships are complex and have not been extensively investigated.

Recent research based on PIT tag mark-recapture studies has provided approximate estimates of total mortality of migrants. Approximately 50% of ocean-type salmon and 40% of stream-type salmon are estimated to die during the critical rearing, migration and saltwater acclimation periods that occurs in the lower Columbia mainstem, estuary, and plume (NOAA 2007). This includes natural mortality that would have occurred even under pristine habitat conditions, additional mortality directly related to changes in habitat condition due to human activities, and assumed increments for additional mortality in the plume.

The human-caused portion of this total is unknown but is likely significant due to large-scale changes in river discharge patterns and estuary habitats related to water use, channel maintenance, and activities. The Estuary Module does not distinguish between human and other unmanageable and potentially-manageable sources of mortality. However, the Module does identify a 20% improvement in estuary survival as an interim planning target to guide the development of a habitat restoration program. Based on module assumptions of a 50% ocean-type life history survival and a 60% stream-type life history survival, this translates into a net survival increase or mortality decrease of 10% for ocean types and 12% for stream types (including predation).

In order to place estuary habitat impacts in perspective relative to other potentially-manageable factors affecting salmonids, estuary habitat impacts were assumed account for half of the non-predation related total mortality of juveniles in the estuary from Caspian terns, cormorants, and northern pikeminnow (Figure 3-13). Predation mortality is distinguished from habitat impacts by this plan in order to evaluate the relative significance of each factor category. Removal of juvenile predation mortality rates from total estuary mortality leaves an average balance of 30% for spring Chinook, winter steelhead, and for summer steelhead, 32% for coho, 46% for fall Chinook, and 50% for chum. Rates vary among species and among populations depending on time and area of vulnerability. These rates are considered hypotheses subject to additional research and refinement in the future.

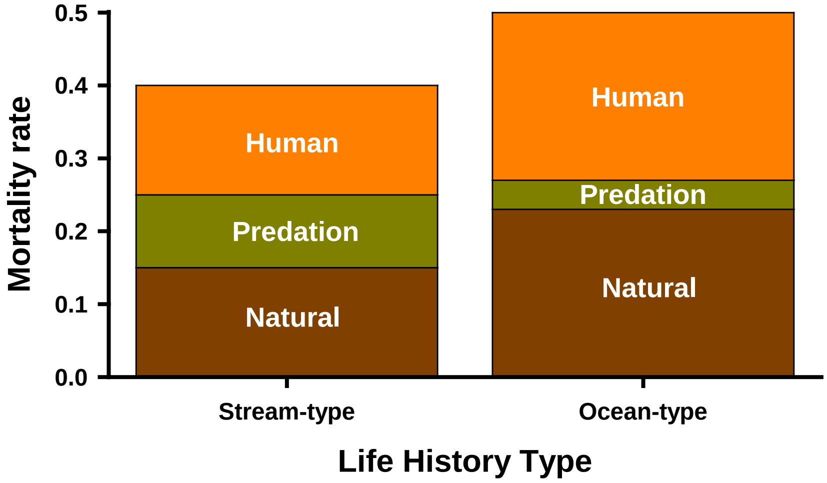

Figure 3-13. Estimated estuary mortality of juvenile salmonids during migration including predation, and assumed "natural" and "human" portions (species and population averages by life history type).

3.4. Dams

3.4.1. Background

A complex of dams and reservoirs has been developed throughout the region for power generation, flood control, sediment retention, and municipal, industrial, and agricultural uses (Figure 3-14, Table 3-2). The widespread economic and standard-of-living benefits of this system are undeniable. However, these benefits have come at a significant cost to the salmon and steelhead that depend on unfettered access between freshwater and ocean habitats as well as functional stream and river habitat conditions. In major streams and rivers throughout the region, dam construction and operation has blocked access of anadromous fish to some of the most productive historical spawning and rearing areas, reduced numbers and productivity of salmon and steelhead through juvenile and adult passage mortality, and fundamentally altered habit processes and conditions for fish.

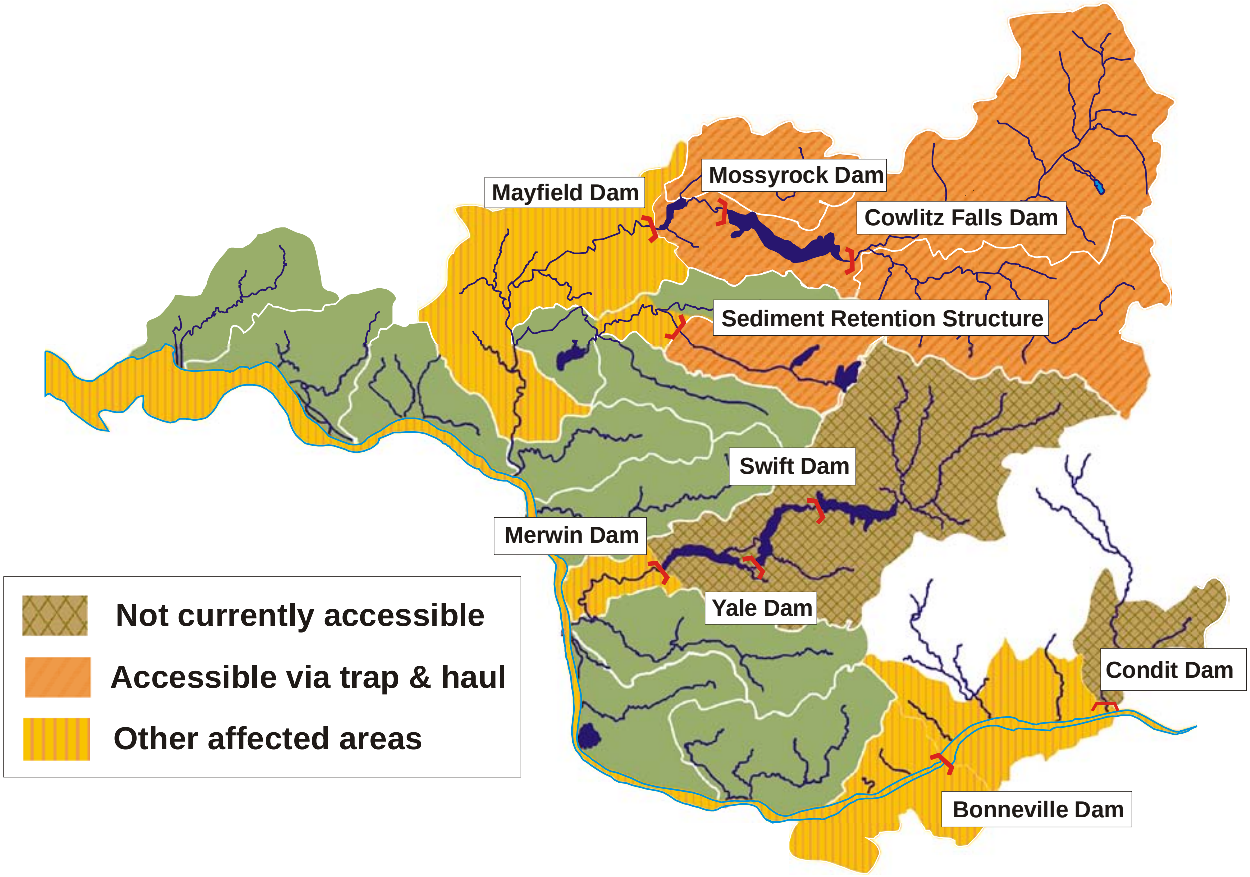

Figure 3-14. Map of significant dams and affected areas on the lower Columbia River and tributaries.

Table 3-2. Major dams in the Washington lower Columbia River region.

Basin	Dam	Operator	Date	Height (ft)	Reservoir Area (acres)	Fish Passage	(Re-) licensed
Columbia	Bonneville	U.S. Army Corps of Engineers	1938	197	20,000	Yes	n/a
Cowlitz	Mayfield	Tacoma Power	1963	200	2,250	Limited[2]	2003
	Mossyrock	Tacoma Power	1968	365	11,830	No	2003
	Cowlitz Falls	Lewis Co. PUD	1994	140	700	Limited[1]	1986
Toutle NF	Sediment Retention Structure	U.S. Army Corps of Engineers	1989	184	3,200	Limited[2]	n/a
Lewis NF	Merwin	PacifiCorp	1931	313	4.040	Limited[3]	2008
	Yale	PacifiCorp	1953	323	3,780	No	2008
	Swift #1	PacifiCorp	1958	512	4,600	No	2008
	Swift #2	Cowlitz Co. PUD		--	0	No	2008
White Salmon	Condit	PacifiCorp	1913	125	92	No	n/a

[1] Juvenile collection facility is operated at Cowlitz Falls Dam.
[2] Adult collection facility downstream from the structure provides fish for upstream release.
[3] Adult collection facility is operated downstream from Merwin Dam (trap and transport design).
n/a = not applicable

Bonneville Dam: Bonneville Dam was built from 1933-1938 on the mainstem Columbia River 146 miles from the ocean. The project was expanded with completion of a second powerhouse in 1981. This dam is operated for power generation and navigation as part of the large and complex Federal Columbia River Power System (FCRPS). The FCRPS consists of 14 projects, each composed of dams, powerhouses, and reservoirs, that are operated as a coordinated system for power production and flood control (while also effectuating other project purposes) on behalf of the Federal government under various Congressional authorities. Extensive adult and juvenile passage facilities have been developed but Bonneville Dam continues to delay upstream and downstream passage, and cause mortality of a portion of the migrants. Construction and operation has also affected habitat and environmental conditions upstream as far as The Dalles Dam and downstream in the Bonneville tailrace. Fish effects, mitigation, and management actions related to the FCRPS are directed by the Northwest Power and Conservation Council and are subject to extensive ESA consultations in a series of Biological Opinions issued by the NMFS and implemented by federal action agencies including the U. S. Army Corps of Engineers, U. S. Bureau of Reclamation, and the Bonneville Power Administration. In most cases, hydropower programs and operations are intended to avoid jeopardy and contribute to recovery (NMFS 2008c). Columbia River hydropower projects are also addressed in greater detail by a recovery plan module prepared by NMFS (2008c) for reference by all recovery plans throughout the region.

Cowlitz River: A series of dams have been built on the upper Cowlitz mainstem, primarily for hydropower generation. These include Mayfield and Mossyrock dams which were completed in the 1960s. Initial attempts to collect out migrating smolts with Lake Merwin type traps were unsuccessful and discontinued after 1973 which effectively eliminated anadromous fish production in the upper watershed. Anadromous impacts were mitigated with the development of a large hatchery program downstream from Mayfield Dam.

In 1994, the Cowlitz Falls Project was completed immediately upstream from Riffe Reservoir (impounded by Mossyrock Dam). Construction of a downstream anadromous fish collection facility at Cowlitz Falls Dam provided the opportunity to attempt to reintroduce spring Chinook, coho, and winter steelhead into 240 miles of productive habitat in the upper Cowlitz and Cispus rivers. The reintroduction program has been underway since 1994. Success will hinge on the efficiency of collection and passage of juveniles which to date has not been adequate to restore self-sustaining anadromous fish populations to harvestable levels in the upper watershed.

According to the Federal Power Act of 1920, hydropower producers are periodically required to apply for license renewal from the Federal Energy Regulatory Commission. A hydroelectric license includes terms and conditions for project operations, as well as environmental protection, mitigation and enhancement measures to mitigate project impacts on the surrounding environment and natural resources. Current fish reintroduction and mitigation activities were addressed in a 2003 settlement agreement developed in the re-licensing process. Fish-related plans were prepared and are being facilitated by a Fisheries Technical Committee including biologists from Tacoma power, State and Federal Agencies, the Yakama Nation, and conservation groups.

Toutle River: A dam was completed in 1989 in the Toutle River North Fork to retain sediment created since the 1980 eruption of Mount St. Helens. The objective was to reduce sediment-related navigation problems downstream in the Cowlitz and Columbia rivers. The structure was built without fish passage facilities and presents a barrier to upstream migration. To facilitate upstream fish passage, an adult collection facility was constructed one mile downstream from the structure to capture coho salmon and winter steelhead for transport and release upstream.

Lewis River: Hydro facilities were built on the North Fork Lewis between 1931 and 1958, and are operated primarily for power generation. The Merwin, Yale and Swift #1 projects include high-head dams and associated reservoirs. Water discharged through the Swift #1 powerhouse flows through a canal before entering a second powerhouse (Swift #2) before being returned to the upper end of Yale Reservoir. These projects do not currently provide anadromous fish passage and, except for occasional releases of excess hatchery fish, no anadromous fish populations currently exist upstream from Merwin Dam. Approximately 174 miles of anadromous fish habitat is blocked including an estimated 117 miles upstream from Swift #1 Dam. To mitigate for fish losses, a large hatchery mitigation program was developed in the basin.

New licenses were issued by FERC in 2008. An anadromous fish reintroduction program above Merwin Dam is a centerpiece of a final relicensing settlement agreement completed in 2004. The program includes a comprehensive suite of salmon protection and restoration measures and actions that will be implemented in a phased approach over the terms of the licenses to primarily benefit spring Chinook, winter steelhead, coho, and bull trout. Plans call for improvements in the Merwin adult collection facility to trap, transport fish to Swift, Yale, and Merwin reservoirs and develop downstream passage facilities at all three dams consisting of modular surface collectors. Success of the reintroduction effort will hinge on the efficiency of collection and passage of juveniles. (Fish passing downstream through the turbines rather than the collection facilities will suffer high mortality.) The agreement also provides for continued collection of upstream migrating bull trout at the Yale and Swift #2 tailraces and transport to Yale Lake and Swift Reservoir from which suitable spawning habitats are accessible. In addition, the agreement includes a variety of flow and habitat measures for the benefit of anadromous and resident fish.

White Salmon: Condit Dam is located on the White Salmon River approximately 3.3 miles upstream from the confluence with the Columbia. The dam was completed in 1913 to provide electrical power for the Crown Willamette Paper Company in Camas, WA. Fish ladders were included in the original design but were twice destroyed by floods soon after the dam’s completion. All upstream access of anadromous fish was subsequently blocked and local populations of steelhead, spring Chinook, and coho were extirpated. Condit's license expired in 1993 and the facility has since been operated under annual license extensions while approval was sought from FERC for decommissioning. A license settlement agreement currently calls for project removal, which is now expected to commence in 2011 pending completion of environmental permitting.

3.4.2. Limiting Factors

Migration Barriers

Blocked and Inundated Habitat—The major hydropower systems on the Cowlitz and Lewis rivers are responsible for the greatest share of blocked habitat in the lower Columbia region. (Culverts and other barriers are also a concern throughout the region, but are treated in the stream habitat section above.) In the Lewis River basin alone, the 240-foot high Merwin Dam has blocked 80% of steelhead habitat, all spring Chinook habitat, and the majority of fall Chinook habitat since 1931. In the Cowlitz basin, the three mainstem dams inundated a total of 48 miles and blocked a total of 240 miles of historical steelhead, Chinook, and coho habitat. Efforts are underway to reestablish spawners upstream of the Cowlitz dams but survival of downstream migrants has been poor thus far. In the Columbia River, Bonneville Dam has inundated significant spawning habitats in the mainstem and lower reaches of tributaries in the Columbia River gorge.

Adult Dam Passage—On the mainstem Columbia, Bonneville Dam affects upstream migration of adults as well as downstream migration of juveniles. Fish ladders provide for upstream dam passage of adult salmon but are not 100% effective. Salmon may have difficulty locating ladder entrances and fish also may fall back over the dam after exiting from the fish ladder (NMFS 2000c). Average per dam survival rates in the lower Columbia River mainstem have been estimated at approximately 98% for spring Chinook, 96% for fall Chinook, and 98% for steelhead (NMFS 2008b).

Box 3-10. Migration Barrier Limiting Factors

- Complete blockages of spawning and rearing habitat,
- Habitat inundation,
- Adult upstream delays and mortalities,
- Juvenile downstream delays and mortalities, and
- Increased susceptibility to predation.

Fallback of adult salmon and steelhead after dam passage can be substantial (up to 20%); especially during periods of high flow and spill (Bjornn and Peary 1992). Keefer and Bjornn (1999) estimated recent fallback rates at Bonneville Dam of 12-15% for Chinook (1996–98), 4-13% for sockeye (1997), and 5-10% for steelhead (1996–97). Fallback was substantially greater at the Bradford Island ladder exit at Bonneville Dam than the Washington shore ladder (Bjornn et al. 1998); 14-21% of sockeye and Chinook salmon fell back over the dam (Reichel and Bjornn 2003). Some adults that fall back or migrate downstream pass through project turbines and juvenile bypass systems where mortality can be significant. However, most adult salmonids that fall back over dams re-enter the fish ladder, successfully pass the dam, and continue their upstream migration.

Passage delays in dam tailraces result from dynamic and complex flow patterns and the relatively small volume of water comprising ladder attraction flows. Fish may require a few hours or a few days to locate ladders once they reach the tailrace. The delay is generally longer when flows are high and when large amounts of water are being spilled (NMFS 2000). Ladder systems at Columbia River dams are operated to produce hydraulic conditions that maximize fish attraction and minimize delay. Operations are based on criteria developed by NMFS, USACE, and state and tribal fishery managers. The criteria relate to such factors as water depth and head on the gate entrances, collection channels, ladder flows and ladder exits (NMFS 2000).

Adult passage delays at dams are at least partially offset by more rapid movement of fish through slack water reservoirs, so the net effect of dam and reservoir construction on upstream travel time for adults may be neutral or even positive. There is no indication that reservoirs substantially delay adult upstream migration (Ferguson et al. 2005). While the upstream migration of adults can be slowed as fish search for fishway entrances and navigate through the fishways themselves, they migrate more quickly through the relatively slow reservoirs (NMFS 2008c). The OFC (1960) found that, prior to impoundments in the Snake River, Chinook migration rates averaged 11-15 mi/day (17.7-24.1 km/day). Chinook salmon migration rates through the Snake River reservoirs in 1991-93 ranged from 19.3 to 40.4 mi/day (31-65 km/day), while migration rates through free-flowing river sections above Lower Granite Dam ranged generally less than 6.8 mi/day (11 km/day) (Bjornn 1998). Bjornn et al. (1999) estimated that median travel time for salmon to pass the four dams and reservoirs in the lower Snake River in 1993 was the same or less with the dams as without the dams. Quinn et al. (1997) found that travel time between Bonneville and McNary dams over the last 40 years has decreased.

Unlike other Pacific salmonids, a large fraction of the adult steelhead does not die after spawning and instead attempts to migrate back to the Pacific Ocean. Termed kelts, very few post-spawn adult steelhead survive downstream passage through the hydrosystem and so do not return and spawn again (NMFS 2008c). Estimates of FCRPS passage survival ranged from 4.1 to 6.0% in the low flow year 2001 to 15.6% in 2002 and 34% in 2003 (Boggs and Peery 2004; Wertheimer and Evans 2005). At present, juvenile collection and bypass systems are not designed to safely pass adult fish including kelts (NMFS 2008c). In addition to injury and mortality, kelt downstream migrations are delayed by the mainstem projects (Wertheimer and Evans 2005; NMFS 2008c).

Juvenile Dam Passage—Downstream travel has been shown to be active rather than passive; in addition to water velocity, the rate of travel is affected by date, temperature, the location where the fish begin their migration, fish size, and the extent of the parr-smolt transformation (NMFS 2008c). Survival through the migration corridor declines with distance traveled, whether due to natural hazards (including predation), mortality due to passage at hydroelectric projects, or other factors associated with development (exotic predators, habitat conditions that make native predators more efficient, water quality, etc.) (NMFS 2008c).

Delay and mortality of juvenile salmon at mainstem dams has proved to be one of the most difficult and contentious problems associated with hydropower development. Smolts typically migrate near mid-channel in the upper water column where water velocities are greatest. Juveniles are delayed in dam forebays, when they are reluctant to enter submerged turbine or spillway intakes. Migration travel times are also increased by flow and impoundment-related decreases in water velocity. Increased travel time (migration delay) presents an array of potential survival hazards to migrating juvenile salmon and steelhead: increasing their exposure to potential mortality vectors in the reservoirs (e.g. predation, disease, thermals stress), disrupting arrival timing to the estuary (which likely affects predator/prey relationships) depleting energy reserves, potentially causing metabolic problems associated with smoltification (smoltification is the process of metabolic changes required to allow juvenile fish to convert from freshwater to saltwater environments), and for some steelhead and all Chinook salmon, contributing to residualism (a loss of migratory behavior) (NMFS 2008c). Effects are greatest for fish originating in the upper Columbia and Snake River portions of the system.

A substantial proportion of juvenile salmon and steelhead can be killed while migrating through dams, both directly through collisions with structures and abrupt pressure changes during passage through turbines and spillways, and indirectly, through non-fatal injury and disorientation, which leave fish more susceptible to predation and disease and result in delayed mortality (NMFS 2008c). Juveniles may experience substantially different mortality rates depending on whether passage occurs via turbines, spill, or a fish bypass system. The turbines are typically the most hazardous passage route. Mortality results from abrupt pressure changes in the turbines and from mechanical injury. Iwamoto and Williams (1993) reviewed fish survival data through the Columbia River system and concluded that turbine survival, taken as a whole, averaged about 90% per dam.

Spillways typically are a much safer passage route than turbines (Whitney et al. 1997). Holmes (1952) reported that spillway survival at Bonneville Dam was 97% using pooled data and 96% using weighted averages. Numerous improvements to spillway and tailrace configurations have been implemented and additional research at many other Columbia and Snake River projects has estimated that spill survival is around 98-100% (NMFS 2000). Historical operations attempted to minimize spill in order to maximize power generation. Current practices provide dedicated spill (up to 50% at mainstem FCRPS projects) to facilitate dam passage by juveniles.

Juvenile bypass systems to divert fish from turbine intakes are now in place at most mainstem dams in the Columbia River system, including Bonneville Dam. Most systems involve submersible traveling screens that project downward into the intakes of turbines and deflect fish upward from the turbine intake into the gate well. Fish guidance efficiency (FGE) measures the proportion of fish entering turbine intakes that is guided into the bypass system (Brege et al. 1988). FGE varies by species, stock, fish condition, time of day, dam, turbine unit, season, environmental conditions, and project operation (NMFS 2000).

Flow Alterations

Flow regulation, water withdrawal, and climate change have reduced the Columbia River's average flow, altered its seasonality, and reduced sediment discharge and turbidity (NRC 1996; Sherwood et al. 1990; Simenstad et al. 1982 and 1990; Weitkamp 1994). Annual spring freshet flows through the Columbia River estuary are about one-half of the pre-development levels that flushed the estuary and carried smolts to sea (NMFS 2008c).

Changes in flow patterns can affect salmon migration and survival through both direct and indirect effects. Juvenile and adult migration behavior and travel rates are closely related to river flow. Flow fluctuations may stimulate or delay juvenile emigration or adult migration, thereby affecting synchrony of juvenile arrival in the estuary or adult arrival at the spawning grounds. Greater flows increase velocity, which increases travel rates of juveniles (related to reservoir survival) and decreases adult travel rates. Higher flows generally increase the survival of juveniles as they pass Columbia River mainstem dams, because more fish can pass over the spillways, where mortality is generally lower, than through the powerhouses, where turbine passage mortality can be significant. In contrast, increased flow and spill can increase mortality and delay upstream passage of adults at dams as fish have a more difficult time locating the entrances to fishways and also are more likely to fall back after exiting the fish ladder. Flow also affects habitat availability for mainstem spawning and rearing stocks. Rapid diurnal changes in flow can disrupt spawners, leave redds dewatered, or strand juveniles.

Box 3-11 Hydropower Flow Limiting Factors

- Delayed migrations,
- Reducing survival through reservoir (juveniles) or dams (adults),
- Disrupting spawning activities, and
- Stranding juveniles.

Altered Ecosystems

Dam construction and operation has drastically altered conditions within much of the mainstem Columbia River. NMFS (2008c) notes that alterations include "inundation of many mainstem spawning and shallow-water rearing areas (loss of spawning gravels and access to spawning and rearing areas); altered water quality (reduced spring turbidity levels), water quantity (seasonal changes in flows and consumptive losses resulting from use of stored water for agricultural, industrial, or municipal purposes), water temperature (including generally warmer minimum winter temperatures and cooler maximum summer temperatures), water velocity (reduced spring flows and increased cross-sectional areas of the river channel), food (alteration of food webs, including the type and availability of prey species), and safe passage (increased mortality rates of migrating juveniles)" (Ferguson et. al 2005).

Critical features of mainstem migratory corridors for fish generally include: substrate, water quality, water quantity, water temperature, water velocity, cover/shelter, food (prey), riparian vegetation, space, and safe passage (NMFS 2008c). Mainstem habitat also serves as important spawning and rearing habitat for fall Chinook and chum salmon which require specific conditions of spawning gravel, water quality, water quantity, water temperature, food, riparian vegetation, and access to spawning and rearing areas (NMFS 2008c).

Modifications of riverine habitat to impoundments result in changes in habitat availability, migration patterns, feeding ecology, predation, and competition. Downstream migration is significantly slower through impoundments. Food webs are different in the impoundments than in natural rivers. Predation is a major source of mortality in mainstem impoundments and just downstream of Bonneville Dam. Other fishes—including northern pikeminnow, walleye, smallmouth bass, and salmonids—prey on juvenile salmonids. Pikeminnow have been estimated to consume millions of juveniles per year in the lower Columbia. Predation losses have also been documented at Cowlitz and Lewis river hydropower dams. Additionally, at Bonneville Dam, marine mammals (both the more common California sea lion and ESA-listed Stellar sea lion) are increasingly using the Bonneville Dam tailrace as a foraging area, presumably because the adult Chinook, steelhead, and lamprey upon which they feed are concentrated and delayed in this area as they seek entrance to the dam's adult fishways (NMFS 2008c).

Box 3-12 Ecosystem Alteration Limiting Factors

- Loss of spawning and rearing habitats,
- Migration and emigration delays,
- Increased predation on juveniles, and
- Altered food webs and availability of preferred prey..

Water Quality

Flow regulation and reservoir construction have altered seasonal water temperature patterns in the Columbia River mainstem. Warm temperatures can increase the fishes' susceptibility to disease. Due to the thermal inertia of the reservoirs (both in mainstem and upstream storage projects), atmospheric cooling of water temperatures is delayed in the fall and warming is delayed in the early spring which can affect pre-spawning mortality, gamete viability, and subsequent development and survival of fish through the egg to fry life stages (NMFS 2008c). Flow regulation and reservoir construction also have increased water clarity during the spring freshet. Increased water clarity can affect salmon through via changes in food availability and susceptibility to predation.

Water supersaturated with atmospheric gases, primarily nitrogen, can occur when water is spilled over high dams and has resulted in significant salmon mortality. Mortality is most significant where the depth of the river is inadequate for behavioral avoidance or normal migration patterns are disrupted by dam passage. (Each meter of depth reduces the concentration of total dissolved gas by about 10% compared to the surface.) These high concentrations of gases are absorbed into the fishes' bloodstream during respiration. When the gas comes out of solution, bubbles may form and subject the fish to gas bubble disease as in the bends suffered by human divers. The severity of gas bubble disease varies depending on species, life stage, body size, duration of exposure, water temperature, swimming depth, and total dissolved gas (Ebel et al. 1975, Fidler and Miller 1993). Gas supersaturation poses the greatest risk for Washington lower Columbia basin salmon stocks that must pass Bonneville Dam or areas immediately downstream in the mainstem.

High dissolved gas levels associated with dam operations have resulted in significant salmon mortality—especially before the problem was identified and measures taken to reduce its incidence (Ebel 1969). Measures implemented over the last 40 years include increasing headwater storage during spring, installing additional turbines, and installing flip-lip flow deflectors to reduce plunging and air entrainment of spilled water (Smith 1974).

Box 3-13 Hydropower Water Quality Limiting Factors

- Elevated temperatures,
- Increased susceptibility to disease, and
- Gas bubble disease (supersaturated water).

Because gas levels equilibrate slowly, sub-lethal levels of super-saturation may still have chronic effects, such as increased susceptibility to disease or predation. The issue of gas supersaturation has been discussed in detail in the Total Maximum Daily Load report developed jointly by the Oregon Department of Environmental Quality and the Washington Department of Ecology for dissolved gas levels in the lower Columbia River (Pickett and Harding 2002). Currently, total dissolved gas levels due to fish spill operations are limited to 120% as measured in the tailrace of Bonneville Dam. This level has consistently shown minimal impacts to juvenile or adult salmon (only minor injuries such as bubbles in the fin rays are observed). Supersaturation levels caused by high run-off conditions or over-generational spill have been correlated with increased severity of the symptoms, becoming more pronounced when TDG levels exceed 125%.

3.4.3. Threats

Hydropower projects directly affect fish passage, stream flow patterns, sediment transport dynamics, stream water quality, and stream habitat, as described in the preceding section on Limiting Factors. The Columbia River mainstem dam at Bonneville, and the hydropower systems on the mainstem Lewis and Cowlitz Rivers have significant impacts on fish populations. Only a few other hydropower operations exist in the lower Columbia region, and they have relatively minor impacts on fish populations.

Water Management

Water and flow management at interior storage reservoirs and all upstream flood control and irrigation operations have significantly altered Columbia River flows from their natural patterns. For this reason, many fish and hydrosystem managers support implementation of a water budget of prescribed flows to facilitate fish migration rates and dam passage. However, in times of low flows, fish water needs may be superseded by hydroelectric or other needs. Seasonal and daily flow fluctuations also can result in gas supersaturation, stranding of juveniles, disruption of mainstem spawning, and dewatering of chum redds in the Bonneville tailrace. Threats to salmon from hydropower water management include:

- Alteration of the natural diurnal and seasonal flow pattern,
- Gas supersaturation during high flows,
- Stranding of juveniles,
- Disrupted chum spawners, and
- Dewatered chum redds.

Obstructed and/or Delayed Passage

Continued blockages to significant upstream habitats by hydroelectric dams on the Cowlitz and Lewis Rivers is one of the most substantial salmon recovery problems in the lower Columbia region. Attempts to rebuild salmon runs upstream of the Cowlitz dams have been limited by downstream migrant survival. At Bonneville Dam on the mainstem, fish ladders provide for upstream dam passage of adult salmon but are not 100% effective. Likewise, approximately significant numbers of downstream-migrating juveniles die as they pass Bonneville Dam. Certain species, such as chum salmon, do not negotiate fish ladders very well; their historical habitats at the lower ends of gorge tributaries have been inundated by the reservoir behind Bonneville Dam. Ongoing threats include:

- Passage obstructions – blocked spawning and rearing habitat,
- Poor passage facilities,
- Poor passage conditions (inappropriate flows), and
- Passage delays and mortality of juveniles and adults.

Ecological Changes from Impoundments

Hydroelectric dams have altered the natural habitats of salmon by creating slow-moving impoundments upstream and preventing natural sediment flow to downstream areas. Because of physical habitat changes, ecological communities have shifted and predators have flourished. These alterations will continue to present potential threats to the survival and productivity of salmon, including:

- Habitat alterations in impoundments,
- Predation in impoundments and tailraces,
- Competition for food in impoundments,
- Lack of sediments downstream of dams, and
- Changes to stream temperature regime.

3.4.4. Impact Assessment

Dam-related impacts include loss of access to historical production areas, habitat inundation, direct adult and juvenile passage mortality, delayed mortality due to changes in migration timing or passage-related injuries, and indirect effects of habitat and environmental impacts. Some of the more direct impacts have been quantified but many of the more indirect impacts have not. This assessment generally focuses on habitat losses due to lack of passage, habitat losses due to inundation, and direct passage mortality of juveniles and adults. Indirect effects of migration, habitat, and environmental changes caused by dam construction and operation may be significant but are difficult to estimate and are addressed in this Plan by qualitative rather than quantitative considerations.

Access impacts were defined as the proportional reduction in habitat availability for a population where dams block passage or flood key spawning or rearing areas. Impact estimates were based on the quantity and quality of the lost and remaining habitat inferred using the Ecosystem Diagnosis and Treatment model. Values were based on historical (template) fish production estimates expressed in terms of equilibrium abundance of spawners. Loss of habitat availability because of dams was considered separate from other habitat impacts in tributaries. Fish populations with significant access impacts included those of the upper Cowlitz, Lewis, and White Salmon basins where dams block access and have also inundated significant habitat. Upper gorge populations have been affected through inundation of historical spawning habitat in the Columbia River mainstem and lower reaches of gorge tributaries flooded by impoundment of Bonneville Dam.

Passage impacts included mortality of adults and juveniles originating from upper gorge populations and passing Bonneville Dam. Estimates were based on values reported in the Biological Opinion for the Federal Columbia River Power System (NMFS 2008) and summarized in NMFS (2008c). Juvenile passage mortality rates at Bonneville Dam were estimated at 4.9% for fall Chinook, 9.4% for spring Chinook and steelhead, and 4.9% for coho. Juvenile passage mortality of chum salmon is unknown but was assumed to be greater than for other species (20%) due to their early stage of emigration, early migration timing (during low spill periods), and assumed benefit limitations for this species of the existing juvenile collection system. Juvenile passage at Bonneville Dam is complex, with turbine and bypass routes of passage at each of the two powerhouses and the spillway. Assumed passage mortality rates reflect current attraction and collection efficiencies as well as direct mortality in all routes of passage. Per project adult mortality rates were estimated to be 1.4% for spring Chinook, 3.1% for LCR fall Chinook, and 1.6% for coho and steelhead (NOAA 2008).

Bonneville Dam impacts for lower gorge mainstem populations of chum and fall Chinook also included an assumed 30% reduction to recognize the effects of variable dam discharge patterns on spawning and incubation success. Other habitat and environmental effects of the FCRPS are addressed in the estuary habitat assessment.

3.5. Fisheries

3.5.1. Background

Fisheries are unique among the listing factors considered in this Plan in that they are both a goal of recovery and a factor that can jeopardize continued existence. Healthy stocks of salmon in favorable habitats free from significant human impacts will support large, renewable “harvestable surpluses” that can be sustainably exploited without affecting species viability. However, the compounding effects of high fishery mortality coupled with substantial habitat and ecosystem alteration has reduced the numbers, distribution, resilience, and diversity of salmon and steelhead throughout the lower Columbia region. The long-term goal of this Plan is to reduce the complex of human impacts to a point where wild lower Columbia River salmon can again sustain some level of harvest and the fishery benefits associated with harvest.

By nature of their wide-ranging migrations, anadromous salmonids can be exposed to a variety of freshwater and ocean fisheries from their basin of origin all the way to Canada and Alaska. Lower Columbia River salmonids are caught in commercial, sport, and tribal fisheries throughout the West Coast of the United States and Canada. This broad distribution can substantially complicate consultation, analysis and protection efforts for specific stocks. Harvest limitations for Columbia River species can have wide-spread implications effects on fisheries.

Fisheries have changed drastically over the last century in response to shifts in demand, declining wild runs, and increasing regulation. Very large and productive commercial fisheries were operated on the lower Columbia River during the early part of the 20th century. Ocean fisheries became more important in the late 1950s, and peaked in the 1970s and 1980s. More recently, ocean and lower Columbia freshwater commercial and recreational fisheries have been substantially reduced as a result of international treaties, fisheries conservation acts, regional conservation goals, the Endangered Species Act, and state and tribal management agreements.

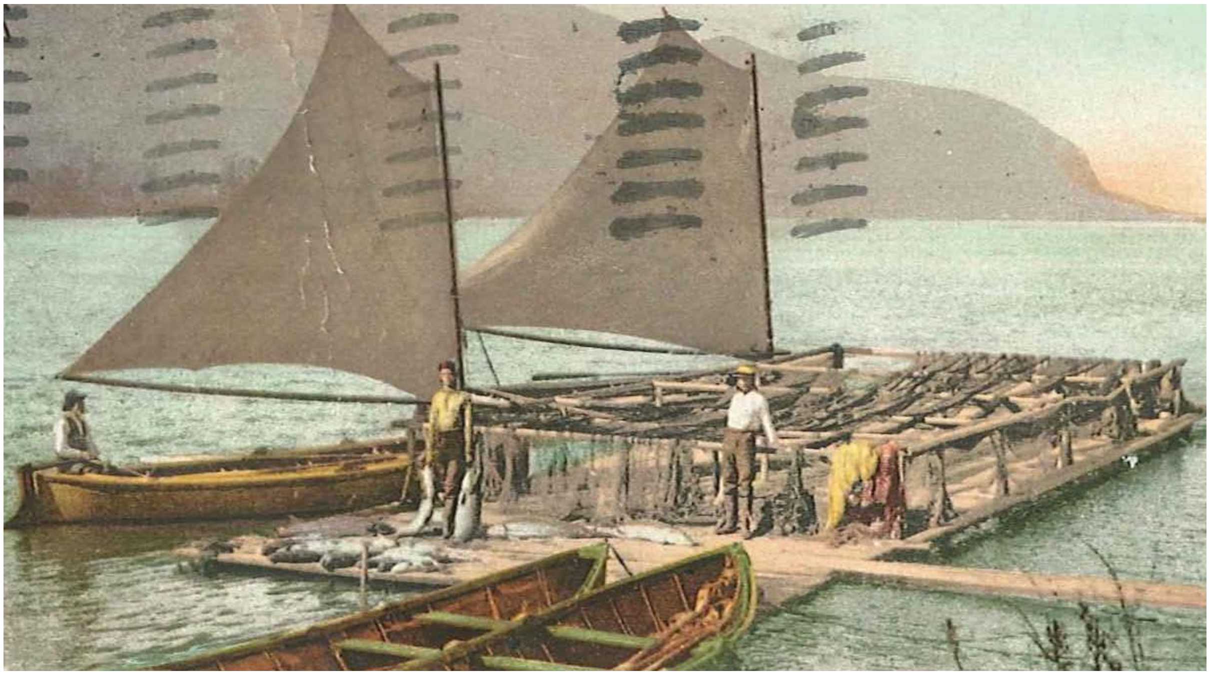

Figure 3-15. Historical postcard of sail-powered Columbia River commercial butterfly boats (circa 1899).

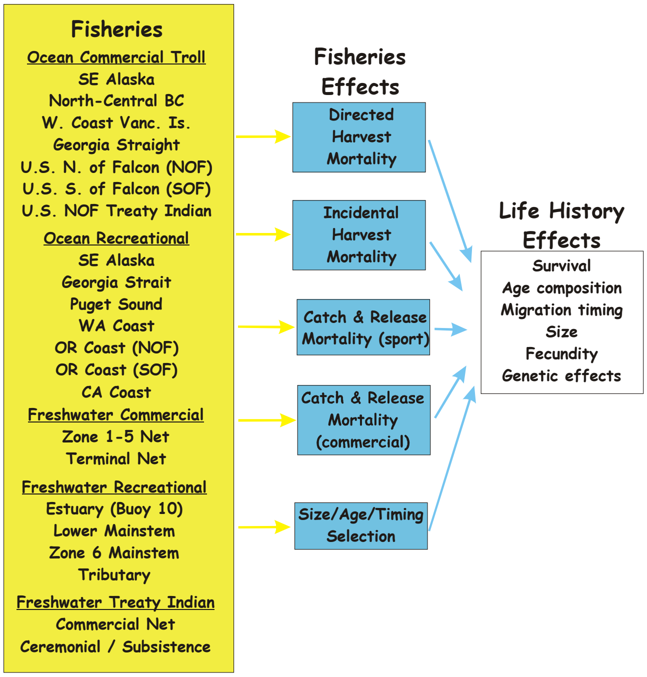

Figure 3-16. Fisheries, fisheries effects, and life history effects.

Fisheries can have both direct and indirect effects (Figure 3-16). Direct effects include mortality in fisheries that are managed to specifically harvest target stocks. Indirect effects include incidental mortality of fish that are caught and released, encounter fishing gear but are not landed, or are harvested incidentally to the target species or stock. Indirect effects also might include genetic, growth, or reproductive changes when fishing rates are high and selective by size, age, or run timing.

Over the last 30 years, many fisheries have been reduced in order to protect weak wild stocks, including those listed under the ESA.[3] Remaining fisheries have generally attempted to focus on hatchery-origin or healthy wild stocks using a combination of time, area, and mark-selective regulations. However, significant numbers of some listed stocks continue to be harvested in some fisheries. All Columbia River fisheries are now regulated based on incidental fishery impacts. These limits, intended to protect weak stocks and populations in mixed stock fisheries, can substantially reduce access to healthy wild or hatchery runs.

This Plan identifies a recovery strategy that continues to restrict and further reduce fishery impacts on listed wild fish in the interim until habitat and other actions are adequate to restore harvestable wild populations. Freshwater and U.S. ocean fisheries will be managed with a primary objective of avoiding directed harvest and limiting incidental impacts to levels that do not jeopardize the continued existence of these species or preclude recovery. In the near-term, fishing opportunities in the Columbia River and nearby ocean will continue to be focused on hatchery-produced fish and healthy wild populations. This Plan includes a series of measures and actions for implementing these strategies for specific species and fisheries.

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[3] "Weak stocks" in a traditional salmon fishery management context have typically been defined to include multiple populations of a common origin, life history pattern and run timing (e.g. lower Columbia River tule fall Chinook, Columbia River early run coho). Fishery impacts were typically indexed based on an aggregate of multiple populations or specific populations deemed to be representative of the aggregate. More recently, fishery management has increasingly also considered protection for the weaker populations within each stock (e.g. Grays River tule fall Chinook).

Fisheries Types and Areas

Canada/Alaska Ocean — Numerous fisheries in Canada and Southeast Alaska harvest far-north migrating Chinook stocks from the lower Columbia River basin. Some Columbia River coho salmon are also harvested in many Canadian fisheries. Canadian marine fisheries include commercial troll and net fisheries as well as recreational sport fisheries in northern BC, Central BC, West Coast of Vancouver Island, Strait of Georgia, and Strait of Juan de Fuca. In Southeast Alaska, treaty (i.e. U.S./Canada agreement described below) Chinook marine fisheries include commercial troll and net fisheries as well as recreational sport fisheries. In recent years, Chinook harvest in terminal fisheries and harvest of Alaska hatchery production has increased, although these harvests are not subject to Pacific Salmon Treaty limitations.

In June 1999, under the PST, Canada and the U.S. agreed on a framework for Chinook fishing regimes for 1999–2008 wherein Southeast Alaska (all gear), northern BC (troll and recreational), and West Coast Vancouver Island (troll and outside recreational) fisheries are to be regulated under aggregate abundance-based management (AABM) regimes. These fishery regimes establish catch ceilings derived from estimates of total aggregate abundance of all stocks contributing to specific components of the fisheries and target fisheries harvest rates. Eventually, the U.S. and Canada plan to incorporate management regimes for AABM fisheries based on total mortality rather than catch. For fisheries not driven by AABM regimes, the 1999 agreement established conservation obligations to reduce harvest rates on depressed Chinook stocks by 36.5% for Canadian fisheries and 40% for U.S. fisheries, relative to levels observed during 1979-1982.

The June 1999 agreement included commitments to develop abundance-based regimes for fisheries along the Washington-British Columbia border. The purpose is to conserve natural coho production units from Washington, Oregon, and southern BC by establishing exploitation rate constraints based on projected resource status. These regimes are still under development.

In May, 2008 the Pacific Salmon Commission recommended to the Governments of Canada and the United States a new bilateral agreement for the conservation and harvest sharing of Pacific salmon. The new fishing regimes are in force from the beginning of 2009 through the end of 2018 and are contained in Chapters 1, 2, 3, 5, and 6 of Annex IV of the Treaty.

United States West Coast Ocean — Ocean fisheries along the U.S. West Coast are separated into four major management areas (Figure 3-17):

- U.S./Canada border to Cape Falcon, Oregon
- Cape Falcon, Oregon to Humbug Mountain, Oregon
- Humbug Mountain, Oregon, to Horse Mountain, California
- Horse Mountain, California to the U.S./Mexico border.

These management areas are further divided into subareas depending on the type of fishery. Numerous treaty Indian commercial troll, non-Indian commercial troll, and recreational marine fisheries exist along the West Coast (Figure 3-18 and Figure 3-19).

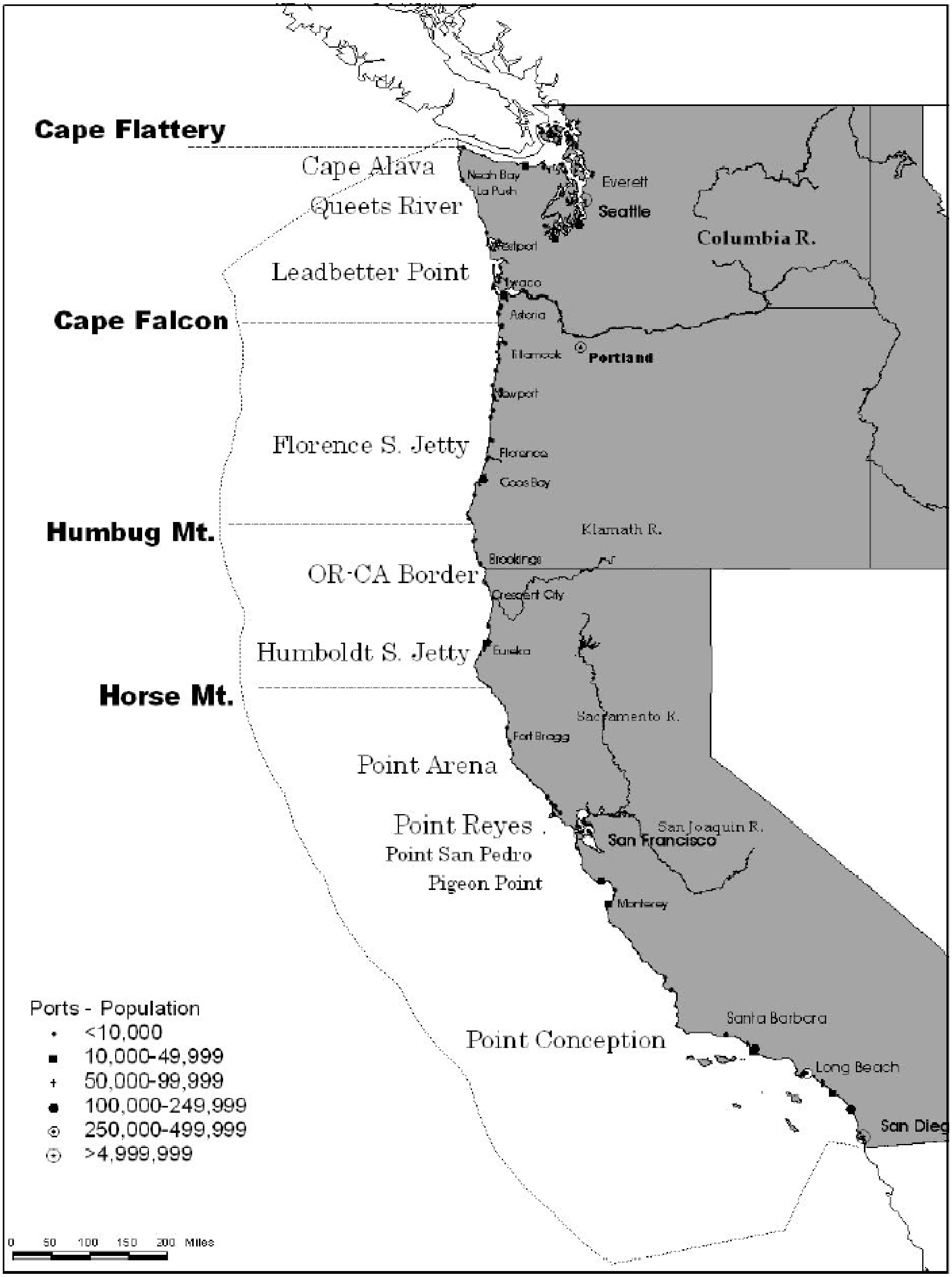

Figure 3-17. Major management areas in U.S. West Coast ocean fisheries.

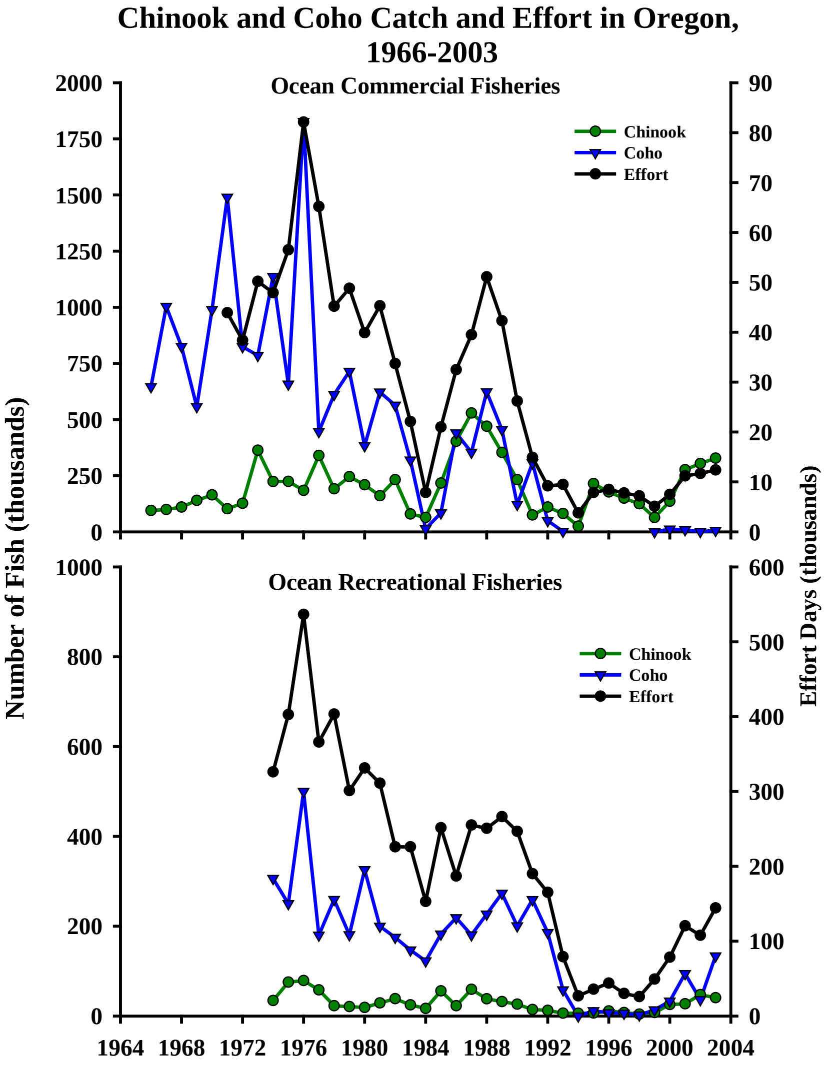

Figure 3-18. Commercial and recreational ocean catch and effort for Chinook and coho in Oregon, 1966–2003.

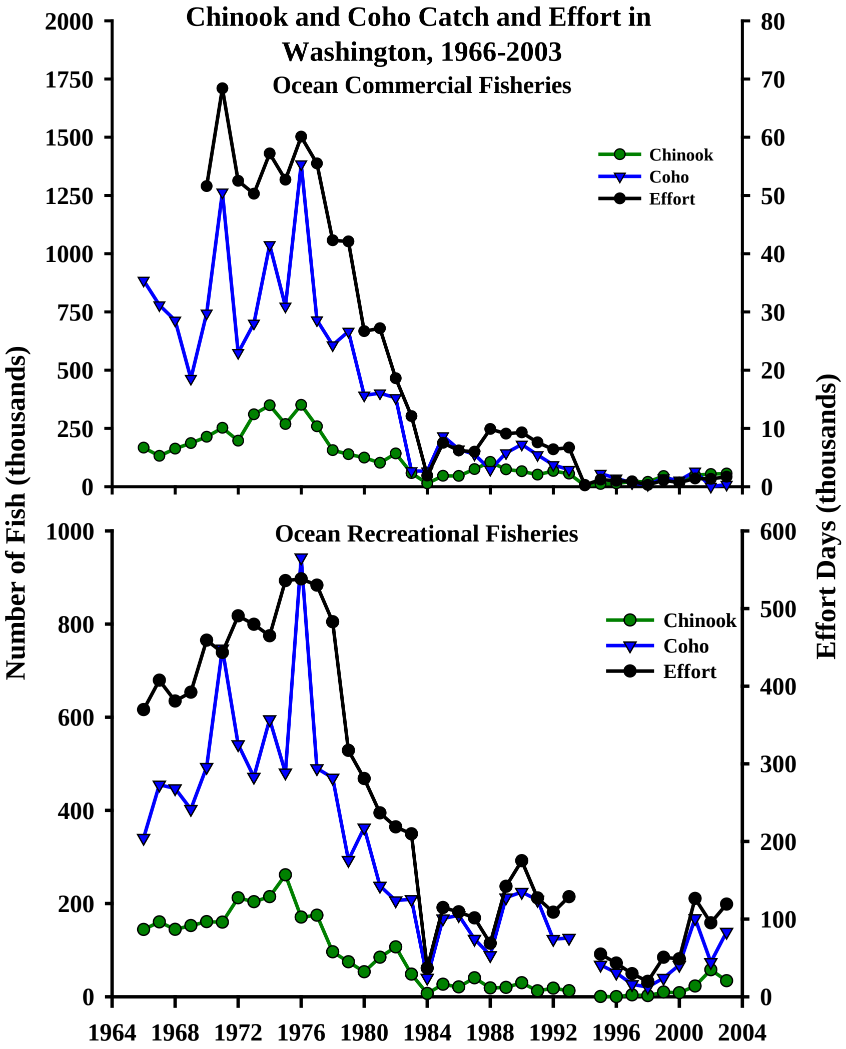

Figure 3-19. Commercial and recreational ocean catch and effort of Chinook and coho in Washington, 1966–2003.

Lower Columbia River Commercial — Europeans began using Pacific salmon around 1830 and, by 1861, commercial fisheries became important. In 1866, salmon canning began in the Northwest and the non-Indian commercial fishery grew rapidly. Salmon and steelhead landings exceeded 40 million pounds annually several times between 1883 and 1925 (Figure 3-20). Since 1938, landings have ranged from a high of 31.6 million pounds (2,122,500 fish) to a low of 0.9 million pounds in 1995 and 1999 (around 68,000 fish).

Since the early 1940s, Columbia River commercial landings of salmon and steelhead have steadily declined, reflecting changes in fisheries in response to declines in salmonid abundance. Recent annual commercial harvests have fluctuated for each species, primarily depending on variable abundance of hatchery production (Figure 3-24). In the late 1950s, non-Indian commercial harvest comprised almost 100% of the Columbia River commercial fisheries landings; the percentage steadily declined to about 25% in 1995. The non-Indian percentage of commercial landings has increased to about 50% in recent years (Figure 3-25). Treaty Indian commercial landings became a larger portion of the total Columbia River commercial landings following a 1968 federal court ruling regarding equitable Indian and non-Indian harvest sharing (Figure 3-25).

Lower Columbia River non-Indian commercial fisheries occur below Bonneville Dam in the mainstem (statistical Zones 1-5) (Figure 3-21) or in select off-channel fishing areas (statistical Zones 7, 71, 74, and 80). Commercial fishing seasons in the mainstem Columbia River are established by the Columbia River Compact, while Select Area seasons are established by the state in which the fishery occurs. Zone 6 (from above Bonneville Dam to McNary Dam) was open to non-Indian commercial fishing until 1956; gill nets, set lines, and seines were used, although seines were finally prohibited in 1950. In 1957, Zone 6 was closed to non-Indian commercial fishing (see further discussion under Treaty Indian Fishery below).

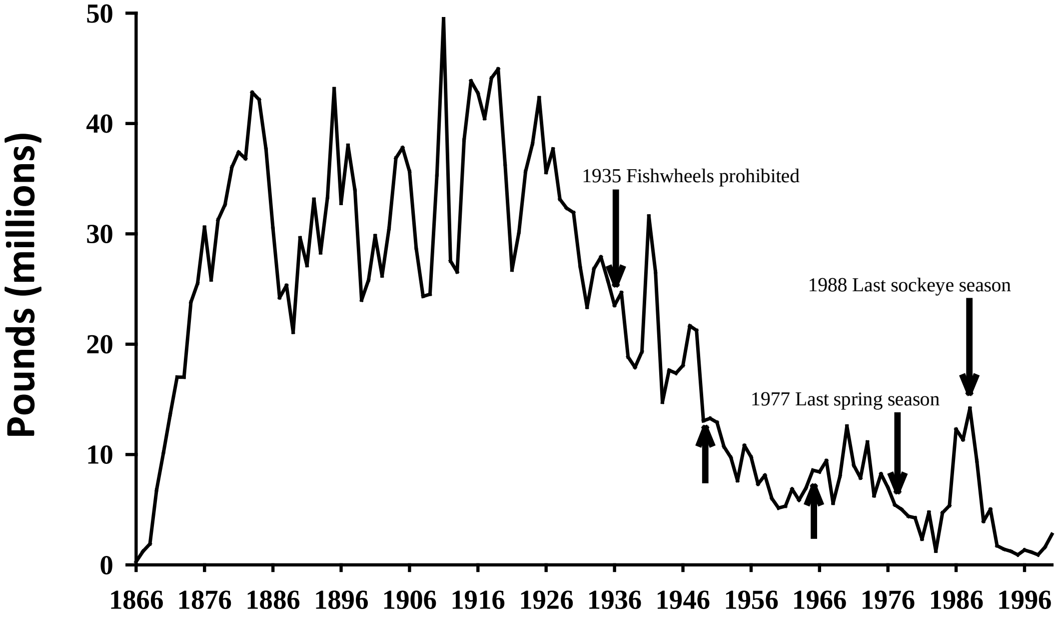

Figure 3-20. Commercial landings of salmon and steelhead from the Columbia River in pounds, 1866–1999 (ODFW and WDFW 2000).

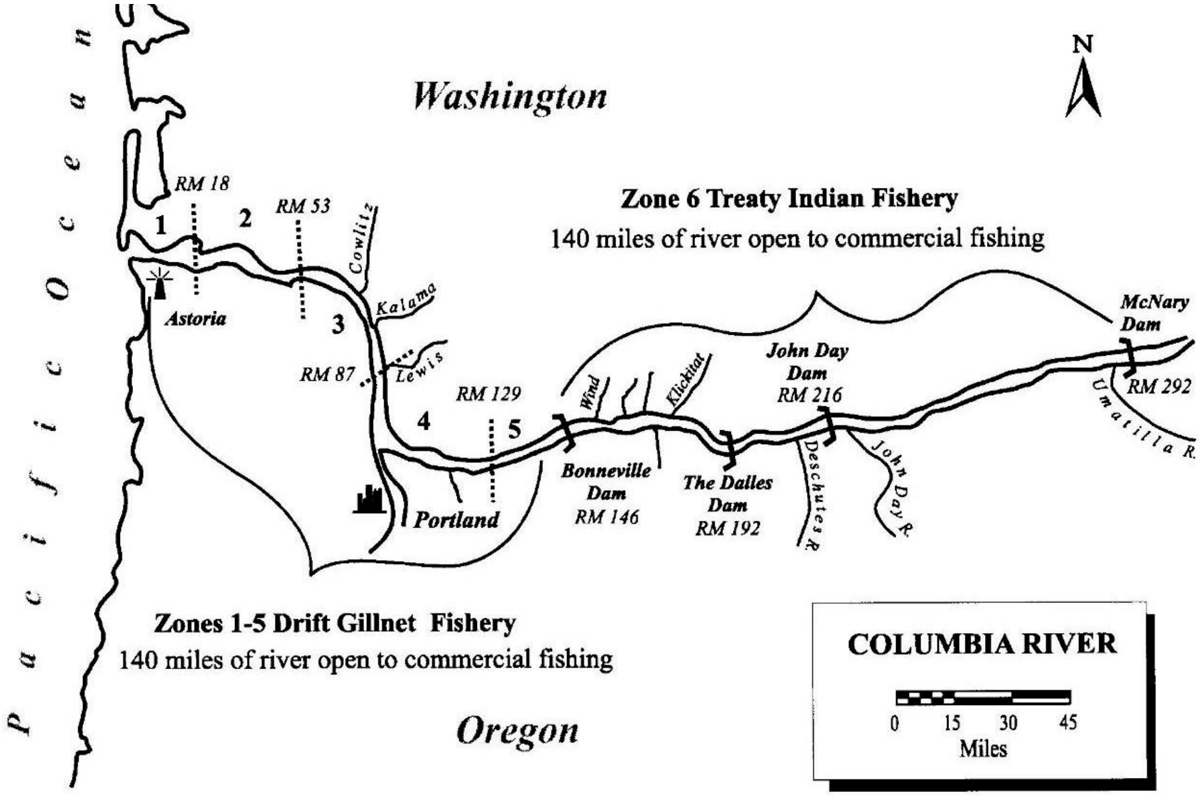

Figure 3-21. Columbia River commercial fishing zones.

The number of drift gill net licenses in the commercial fishery declined after 1938, with a low of 597 in 1969, but increased to a high of 1,524 in 1979. In 1980, a limited entry vessel permit moratorium went into effect. In the mid-1980s, 288 licenses were purchased and permanently retired; 135 licenses were bought back by Washington in 1995–96. In 1999, Columbia River commercial licenses totaled 591.

The number of seasons and fishing days allowed for the commercial mainstem fishery has declined dramatically since 1938. Initially, fishing seasons were closed only in March and April and from August 25–September 10. There has been no summer fishing season since 1964 and spring seasons have been closed or substantially reduced since 1977. Throughout the 1980s and 1990s, August and September seasons have been limited by time, area, and harvest quotas. Before 1943, over 270 fishing days were allowed annually. From 1977 through the 1980s, an average of 38 fishing days were allowed annually and, in the 1990s, 29 average annual fishing days were allowed.

Commercial fishing in Columbia River off-channel areas was initiated in 1962 with the adoption of salmon seasons for Youngs Bay, Oregon. Initially, openings were concurrent with the late fall mainstem gill net seasons; however, seasons have been separate since 1977. Recent declines in mainstem fishing opportunities prompted Bonneville Power Administration (BPA) to fund a research project to expand net-pen programs to select off-channel fishing areas. The result of this effort was the Select Area Fishery Enhancement (SAFE) project, which has expanded to Tongue Point/South Channel and Blind/Knappa Slough in Oregon and Deep River and Steamboat Slough in Washington. These fisheries primarily target hatchery coho returning to the release sites; Select Area bright fall Chinook also are targeted in the Youngs Bay fishery.

Lower Columbia River Recreational — Large and population sport fisheries occur for salmon and steelhead on the lower Columbia River. The lower Columbia River mainstem below Bonneville Dam is separated into two main areas for recreational harvest; Buoy 10 (ocean/in-river boundary) to the Rocky

Point/Tongue Point line, and the Rocky Point/Tongue Point line to Bonneville Dam. Recreational harvest does occur in Zone 6 above Bonneville Dam, but catch is very low compared to the fisheries below Bonneville. The Buoy 10 fishery is extremely popular, especially with small boat anglers. Chinook and coho are the targeted species, although other salmonids are harvested. The main harvest and effort time is mid-August to Labor Day and effort can be substantial, especially in years of high salmon abundance. During 1986-2000, effort in the Buoy 10 fishery ranged from 9,300 angler trips in 1994 to 186,000 angler trips in 1988.

Before 1975, recreational fisheries in the lower Columbia mainstem primarily focused on salmon and steelhead (Figure 3-22). During 1975-1983 fishery closures for spring Chinook and summer steelhead severely reduced salmonid angling opportunities. During 1984–1993, improved upriver summer steelhead, upriver fall Chinook, and lower river spring Chinook runs provided greater salmonid angling opportunities. Poor returns in the mid- to late 1990s again limited recreational salmon fishing opportunities. Since 2001, improved spring Chinook runs and selective fishery implementation has increased angler effort by approximately 100,000 trips, increasing the lower Columbia salmon and steelhead sport fishing effort to about 250,000 trips per year (Figure 3-23). Since 1986, lower Columbia sturgeon angler effort has ranged from approximately 140,000 to 200,000 trips per year.

Lower Columbia Tributary Recreational — Salmon and steelhead sport fishing occurs in most Washington lower Columbia River tributaries. Tributary harvest is principally managed to meet wild salmon and steelhead escapement objectives and to meet the objectives of the artificial propagation programs. Fishing seasons are established based on forecasts of salmon and steelhead returning to the tributaries. In years when returns are forecasted below escapement requirements, harvest is reduced or eliminated. Harvest reductions are made by time and area closures, gear restrictions, or changes in bag limits.

Most of the tributary harvest is focused on hatchery-produced returns of steelhead, Chinook, and coho. An exception is in the North Lewis River where tributary harvest of the healthy, wild fall Chinook return is allowed in most years. Hatchery-produced winter and summer steelhead, spring Chinook, and coho are marked as juveniles with an adipose fin-clip, which enables tributary sport anglers to identify hatchery fish for retention and release unmarked wild fish. All hatchery-produced fall Chinook originating in lower Columbia River tributaries are currently marked. However, fishing for fall Chinook is prohibited in the Coweeman and East Fork Lewis Rivers, where no hatchery fish are released. Trout fisheries in the streams are regulated to minimize impacts to anadromous salmonids. The general season commences June 1, after salmon smolts have migrated, and minimum size limits and gear restrictions also offer protection for juvenile salmonids.

Tributary spring Chinook fisheries generally occur from February to August with a peak in April-May. Fall Chinook fisheries occur from August to January, with a tule peak in late August-mid September and a lower river bright peak in mid September-mid October. Coho fisheries occur during August-January with two peaks; September for early coho and October for late coho. Fisheries targeting winter steelhead are concentrated from December through February and close by March 15, except the Cowlitz, Kalama, Lewis, and Washougal extend to May 31. Summer steelhead enter tributary fisheries from March through October with most of the catch occurring from late May through August.

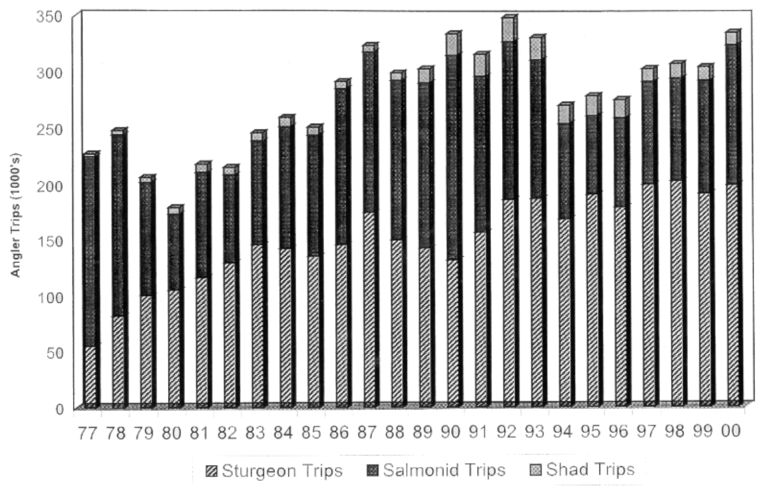

Figure 3-22. **Angler effort by species on the lower Columbia River, 1977–2000.**

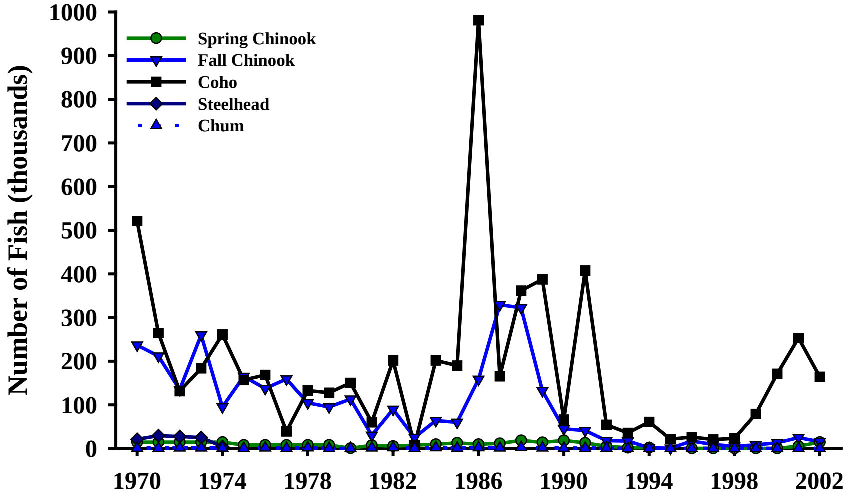

Figure 3-24. **Non-Indian commercial fishery catch in the Columbia River, 1970–2002.**

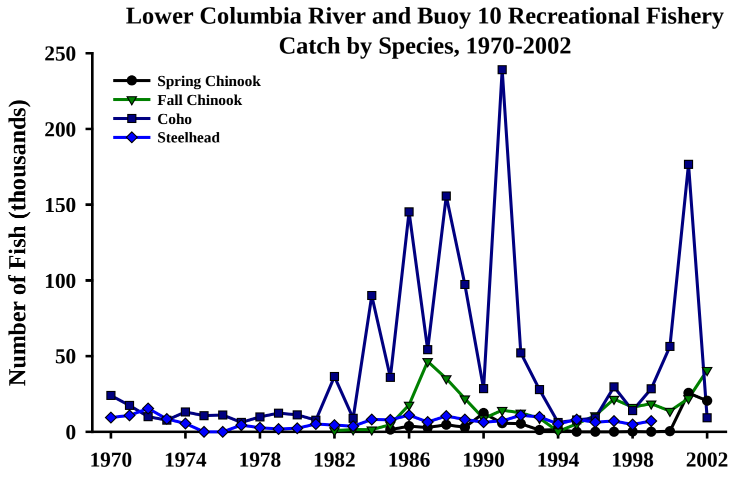

Figure 3-23. **Recreational fishery catch in the lower Columbia River, 1970–2002.**

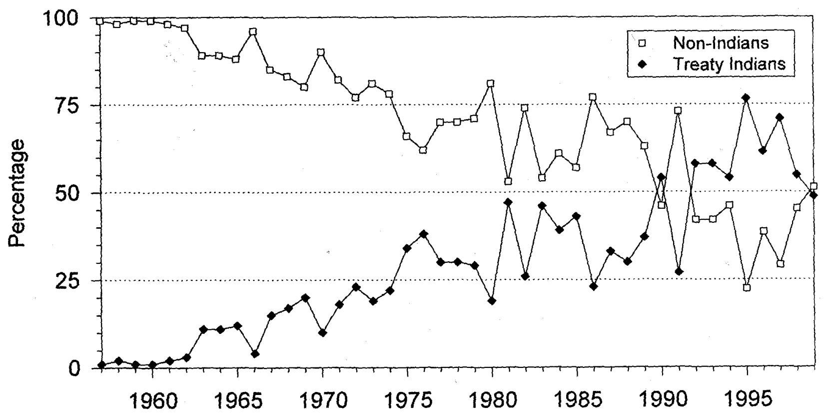

Figure 3-25. **Percentage of Columbia River commercial landings of salmon and steelhead in pounds made by non-Indians and treaty Indians, 1957–02 (ODFW and WDFW 2004).**

Tributary sport harvest of hatchery salmon and steelhead can be significant (see species sections below). Steelhead tributary fisheries harvest 30-70% of the returning hatchery adults. Steelhead returning to hatcheries are often recycled downstream to provide an additional sport catch opportunity. Harvest of hatchery spring Chinook can also be substantial if forecasts indicate a strong return. Harvest rates are typically 20-40%, but can range as high as 70% in the Lewis River if there are no regulatory restrictions. Fall Chinook and coho tributary harvest rates typically range from 5 to 25%, but the total numbers of fish harvested can be substantial in many years, due to large numbers of adult hatchery coho and fall Chinook returning to the rivers.

Treaty Indian — Treaty Indian harvest includes commercial and ceremonial and subsistence (C&S) fisheries. The treaty Indian set net fishery above Bonneville Dam (statistical Zone 6) involves members of the four Columbia River treaty Indian tribes: Yakama Nation, Nez Perce Tribe, Confederated Tribes of the Umatilla Indian Reservation, Confederated Tribes of the Warm Springs Reservation. The tribal C&S fisheries are of highest priority and generally occur before tribal commercial fishing. The Columbia River treaty tribes regulate treaty Indian C&S fisheries in Zone 6.

Indian and non-Indian commercial harvest was permitted in Zone 6 until 1956. The boundaries of Zone 6 were from Bonneville Dam upstream to the mouth of the Deschutes River during this period. In 1957, Oregon and Washington jointly closed Zone 6 to commercial fishing, but treaty Indian fisheries were permitted during 1957-1968 through tribal ordinances. In 1968, the states reestablished commercial fishing in Zone 6 exclusively for treaty Indian harvest. In 1969, the upstream boundary of the zone was extended to the mouth of the Umatilla River, river mouth closure and dam sanctuary areas were established, and gear restrictions were set. The fishery is conducted primarily with set gill nets, although some dip netting still occurs primarily at Cascade Locks, the Lone Pine site, and below John Day Dam.

Similar to the non-Indian commercial fishery, the number of seasons and fishing days allowed for the treaty Indian commercial fishery has declined dramatically. Despite the decline in fishing opportunity, the percentage of Columbia River commercial fishery landings made by treaty Indians has steadily increased since the late 1950s (Figure 3-26). In 1999, 59 commercial fishing days were allowed in the treaty Indian fishery, although most of those days were in February and March during the targeted sturgeon fishery. Fishing effort targeting fall salmonids occurs in late August and September. Fall Chinook harvest increased substantially in 2001 and 2002 as a result of significant increases in fall Chinook returns. As with non-Indian harvest, treaty Indian harvest of salmon increased in 2001 and 2002 as a result of a significant increase in Columbia River salmon abundance (Figure 3-26).

C&S fisheries are usually open year-round; ceremonial fishing is conducted with gill nets via tribal permit while subsistence fishing is conducted by individuals primarily using dip nets, hook and line, or gill nets. Some tribal permits allow subsistence fishing with gill nets when commercial fisheries are closed. Spring Chinook salmon are the most important ceremonial fish for the Columbia River treaty tribes. Significant tribal commercial harvest of spring Chinook occurred in 2001 for the first time since 1977 as a result of a substantial increase in upper Columbia spring Chinook returns (Figure 3-26). C&S fisheries are currently regulated under a 2008-2017 Columbia River management agreement which establishes ESA fishery impact limits.

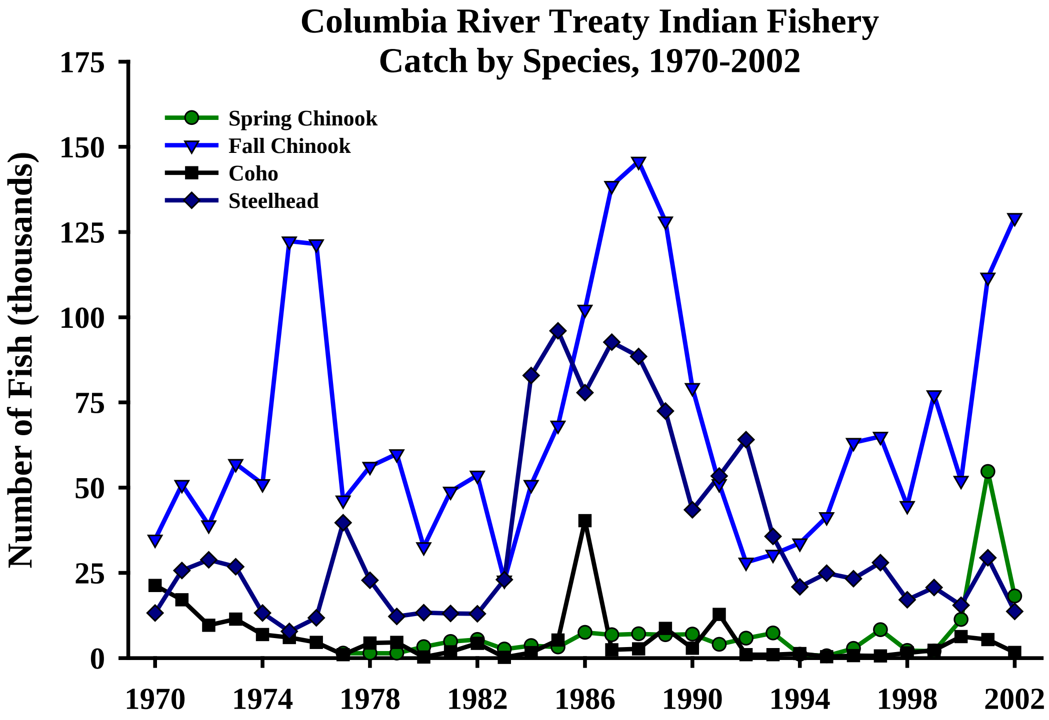

Figure 3-26. Treaty Indian fishery catch, 1970–2002.

Fisheries Management System

Because of Pacific salmon and steelhead's exposure to fisheries across large geographic regions of the West Coast, their management is governed by numerous regional organizations. Fisheries of the Columbia River are established within the guidelines and constraints of the Pacific Salmon Treaty (PST), the Columbia River Fish Management Plan (CRFMP), and the Endangered Species Act (ESA). Programs considered include the Pacific Fishery Management Council (PFMC), which manages Pacific Ocean fisheries in the U.S. south of Canada consistent with sustainable fishing requirements of the U.S. Magnuson-Stevens Act; the Pacific Salmon Commission (PSC) which oversees management by the domestic managers of fisheries subject to a treaty involving Alaskan, and Canadian fisheries; and Columbia River mainstem and tributary fisheries which are regulated by the Columbia River Compact (Oregon and Washington concurrent jurisdiction), The Columbia River treaty Indian tribes, and the Washington and Oregon Fish and Wildlife Commissions.

Pacific Salmon Commission — Management of Pacific salmon has long been a matter of common concern to the United States and Canada. After many years of negotiation, the PST was signed in 1985 to set long-term goals for the benefit of the salmon and the two countries. The principal goals of the treaty are to enable both countries, through better conservation and enhancement, to increase production of salmon and to ensure that the benefits resulting from each country's efforts accrue to that country.

The Pacific Salmon Commission (PSC) is the body formed by the governments of Canada and the United States to implement the treaty. The Commission itself does not regulate the salmon fisheries but provides regulatory advice and recommendations to the two countries. It has responsibility for all salmon originating in the waters of one country which are 1) subject to interception by the other, 2) affect management of the other country's salmon, or 3) biologically affect the stocks of the other country. In addition, the PSC is charged with taking into account the conservation of steelhead trout while fulfilling its other functions.

The Commission has a dual role; to conserve Pacific salmon in order to achieve optimum production, and to divide the harvests so that each country reaps the benefits of its investment in salmon management. The Commission has a variety of tools at hand to achieve its mandate. It may recommend that the countries implement harvest limitations, time and area closures, gear restrictions, or other measures to control harvests. In addition, the Commission may recommend use of enhancement techniques to strengthen weak runs, mitigate for damage done by logging, mining or dam building, or for other purposes. The PSC gives both countries a forum through which to resolve the difficult problems surrounding salmon harvest management.

PSC members represent the interests of commercial and recreational fisheries as well as federal, state, and tribal governments. Each country has one vote; the agreement of both is required for any recommendation or decision. Four regional panels (Southern, Northern, Tran boundary, and Fraser River) provide technical and regulatory advice; panel membership reflects a range of governmental and fishing interests.

Pacific Fishery Management Council — The Magnuson-Stevens Fishery Conservation and Management Act of 1976 is the principal law governing marine fisheries in the United States. The Act was adopted for the purposes of managing fisheries 3-200 miles offshore of the U.S. coastline, phasing out foreign fishing activity within this zone, recovering overfished stocks, and conserving and managing fishery resources. In 1996, Congress passed the Sustainable Fisheries Act, which revised the Magnuson Act and reauthorized it through 1999; later reauthorization bills have been presented but have not been enacted. The Pacific Fishery Management Council (PFMC) is one of eight regional fishery management councils established by the Magnuson Act. The PFMC is responsible for fisheries off the coasts of California, Oregon, and Washington. Thus, the Council is responsible for all ocean fisheries, including salmon, ground fish, pelagic fish, etc., and does not focus solely on salmonids.

Chinook and coho salmon are the main salmon species managed by the PFMC in waters extending from the Canadian border to Mexico, and 3-200 nautical miles offshore (Figure 3-17). In odd-numbered years, the Council may also manage special fisheries near the Canadian border for pink salmon. Sockeye, chum, and steelhead are rarely caught in the Council's ocean fisheries. The Council's Salmon Fishery Management Plan (SFMP) describes the goals and methods for salmon management. Central parts of the plan are annual spawner escapement goals for the major salmon stocks and an allocation of the harvest among different fisheries or locations (i.e. allocations are set for ocean or inland commercial, recreational, or tribal fisheries as well as for specific ports). The Council uses management tools such as season length, quotas, bag limits, and gear restrictions to achieve fishery management goals.

Annually, a preseason process of meetings and public hearings is used to develop recommendations for management of the ocean fisheries. Past harvest data and preseason salmon abundance forecasts are the primary basis for management decisions concerning season structure and harvest quotas. Final recommendations are adopted annually in April and implemented by NMFS beginning in May. The Salmon Technical Team (STT) provides technical information and data analysis to the Council; the team is comprised of eight representatives from state, federal, and tribal fisheries management agencies. The Salmon Advisory Subpanel (SAS) has 17 members who represent commercial, recreational, and tribal interests, as well as a public representative and a conservation representative.

Impacts to each species vary widely, depending on many complicated factors which include annual salmon abundance and ESA restrictions. The NMFS provides guidance to the PFMC for each upcoming ocean fishing season. The standards for 2003 are presented for those ESUs with potential connections to lower Columbia River salmonids (Table 3-3). Further ESA restrictions that apply to specific Columbia River fisheries are discussed in more detail in the species-specific sections to follow.

Table 3-3. List of species managed by the PFMC with potential impacts on lower Columbia River salmonids.

ESU	Stock Representation in Salmon FMP	2010 ESA Consultation Standard
Lower Columbia River Chinook	Sandy, Cowlitz, Kalama, Lewis spring	No specific requirements
	Fall Chinook (tule stock)	Brood year adult equivalent exploitation rate on Coweeman tule fall Chinook < 38% (2010 standard for combined ocean & freshwater fisheries)
	North Fork Lewis fall	5,700 MSY level adult spawning escapement
Upper Willamette River Chinook	Upper Willamette River spring	No specific requirements in Council fisheries (occurrence is rare), Willamette Fishery Management Evaluation Plan wild fish impact limitations (15%) and hatchery escapement targets
Upper Columbia River spring Chinook	Upper Columbia River spring	No specific requirements in Council fisheries (occurrence is rare), Sliding scale abundance standards for freshwater adopted in 2008-2017 U.S. v OR agreement,
Snake River fall Chinook	Snake River fall	30% reduction from 1988-1993 base period in ocean fisheries, Sliding scale abundance standards adopted for freshwater in 2008-2017 U.S. v OR agreement,
Snake River spring/summer Chinook	Snake River spring/ summer	No specific requirements in Council fisheries (occurrence is rare), Sliding scale abundance standards adopted for freshwater in 2008-2017 U.S. v OR agreement,
Oregon Coast coho	S. central OR coast N. central OR coast N. OR coast	Sliding scale abundance standards (15% in 2010)
Lower Columbia River coho	Sandy and Clackamas River	Sliding scale abundance standards (15% in 2010)

North of Falcon — Folded into the PFMC management process is a parallel public process referred to as North of Falcon (NOF). The NOF process integrates management of ocean fisheries between Cape Falcon (on the north Oregon coast) and the Canadian border with inland area fisheries. Columbia River fisheries are a significant part of the NOF process. Coordination and shaping of the ocean and freshwater fisheries occurs to assure that fish conservation objectives are met and there is reasonable sharing of the conservation burden between the fisheries and various user groups. In this process there are allocation agreements reached between Oregon and Washington ocean and freshwater commercial and sport fisheries as well as mandated allocation agreements between the states and treaty Indian tribes. Conditions for incidental take permits concerning ESA-listed Columbia River populations are often developed during the NOF process.

State Fishery Regulations — Regulations for lower Columbia tributary sport fisheries are developed through state public process and adopted into law by the respective Fish and Wildlife Commissions of Washington and Oregon for their jurisdictional waters. Mainstem Columbia joint waters are coordinated for consistency in the Compact forum (see below) but are adopted into law by the respective states. The state regulatory process includes adoption of permanent rules as well as emergency regulations to enable quicker adjustments of fisheries when needed to meet conservation objectives or provide additional harvest opportunity. The state regulations are made consistent with management strategies reached in the NOF process.

U.S. v. Oregon — In 1968, the U.S. District Court ruled that Columbia River treaty Indians were entitled to an equitable share of the upper Columbia River fish returns, in a court case known as U.S. v. Oregon. After 20 years of legal tests and negotiations, the Columbia River Fish Management Plan (CRFMP) was adopted by District Court order in 1988 and agreed to by the parties: the United States; the states of Oregon, Washington, and Idaho; and the four treaty Indian tribes. The purpose of the CRFMP as defined by the court was to:

“. . . provide a framework within which the Parties may exercise their sovereign powers in a coordinated and systematic manner in order to protect, rebuild, and enhance upper Columbia River fish runs while providing harvests for both treaty Indian and non-Indian fisheries. In order to achieve the goals of the CRFMP, the Parties intend to use habitat protection authorities, enhancement efforts, artificial production techniques, and harvest management to ensure that Columbia River fish runs continue to provide a broad range of benefits in perpetuity.”

In 1996, the parties to U.S. v. Oregon negotiated three-year (1996–98) management agreements: one each for upper Columbia fall Chinook and upper Columbia spring Chinook, summer Chinook, and sockeye. The agreements were a result of a 1995 court settlement where the parties agreed to discuss the possibility of amending the CRFMP and include fisheries in the lower Columbia River and management Zone 6 (Bonneville to McNary Dam). The 1996–1998 management agreements formed the basis for recent agreements, and included escapement goals, production measures and harvest allocations. Annual agreements have occurred for fall Chinook, coho, and summer steelhead during 1999-2003. A 5-year agreement for harvest was reached for spring Chinook, summer Chinook, and sockeye for the period 2001–2005. A new 10-year agreement was adopted for 2008-2017.

Columbia River Compact — In 1918, the U.S. Congress ratified a compact between Oregon and Washington covering concurrent jurisdiction of Columbia River fisheries. The Columbia River Compact comprises the Washington Fish and Wildlife Commission (WFWC) and the Oregon Fish and Wildlife Commission (OFWC). In recent years, the commissions have delegated decision-making authority to the state fish and wildlife agency’s director or designee. Periodic hearings to adopt or review seasonal commercial regulations are held just before major fishing seasons to consider current information and establish season dates and gear restrictions. Additional hearings are held in-season when updated information concerning run size, attainment of escapement goals, or catch guidelines indicates a need to adjust the season.

The Compact jurisdiction includes the Columbia River from the mouth to just upstream of McNary Dam. The Compact sets fishing seasons in the non-Indian commercial Zones 1-5 (Mouth to Bonneville Dam) and in the treaty Indian commercial area Zone 6 (Bonneville Dam to McNary Dam) (Figure 3-21).

Fishery Management

Each fishery is controlled by a series of regulating factors. Many of the regulating factors that affect harvest impacts on Columbia River stocks are associated with treaties, laws, policies, or guidelines established for the management of other stocks or combined stocks, but indirectly control impacts of Columbia River fish as well (Table 3-4). Harvest managers configure fisheries to optimize harvest of strong stocks within the series of constraints for weak stock protection. Listed fish generally comprise a small percentage of the total fish caught by any fishery. Every listed fish may correspond to tens, hundreds, or thousands of other stocks in the total catch. As a result of weak stock constraints, surpluses of hatchery and strong naturally-spawning runs often go unharvested. Small reductions in fishing rates on listed populations can translate to large reductions in catch of other stocks and recreational trips to communities which provide access to fishing, with significant economic consequences.

Weak stock management (the practice of limiting fisheries based on annual abundance of particular stocks of concern) of Columbia River fisheries became increasingly prevalent in the 1960s and 1970s in response to continuing declines of upriver runs affected by mainstem dam construction (Table 3-5). In the 1980s coordinated ocean and freshwater weak stock management commenced. More fishery restrictions followed ESA listings in the 1990s.

Table 3-4. Recent harvest regulating factors affecting lower Columbia naturally-spawning salmon and steelhead and the fisheries in which certain regulatory factors apply.

	Regulating Factor	Fisheries Applied To
Lower Columbia Spring Chinook	Hatchery escapement goal	All U.S. fisheries
	Abundance Based Management Agreement	PSC Ocean
	Tule fall Chinook abundance	West Coast Ocean
	Willamette ESA	Columbia River
	Upriver ESA	Columbia River
	U.S. v. OR management agreement	Columbia River
	Selective fisheries	Columbia River, Tributary
	Commercial gear restrictions	Columbia River
	FMEP	Tributary sport
Fall Chinook Tules	Abundance Based Management Agreement	PSC Ocean
	Hatchery escapement goals	All U.S. fisheries
	Coweeman ESA	W. Coast Ocean, Columbia R.
	Coweeman, EF Lewis closures	Tributary sport
	Snake Fall Chinook ESA	Columbia River
	U.S. v. OR management agreement	Columbia River
	FMEP	Tributary sport
Fall Chinook Lower Brights	Abundance Based Management Agreement	PSC Ocean
	NF Lewis wild escapement goal (5,700)	All U.S. fisheries
	Snake Fall Chinook ESA	Columbia River
	U.S. v. OR management agreement	Columbia River
	FMEP	Tributary sport
Chum	Sport retention closed	Columbia River, Tributary
	November commercial closed	Columbia River
	Late October commercial area closures	Columbia River
	FMEP	Tributary sport
	Columbia Chum ESA	Columbia River
Coho	Hatchery escapement goals	All U.S. fisheries
	OCN Coho ESA	West Coast Ocean
	Oregon state coho ESA	Columbia River
	Sport selective fisheries	Columbia River, Tributary
	Commercial select area fisheries	Columbia River
	Commercial time/area closures	Columbia River
Steelhead	Commercial harvest prohibition	Columbia River
	Selective sport fisheries	Columbia River, Tributary
	Wild/Hatchery escapement goals	Tributary fisheries
	Commercial mesh size restrictions	Columbia River
	U.S. v. Oregon ESA, FMEP	Columbia River, Tributary sport

Fishery impact limits to protect listed weak populations are generally based on risk assessments that identify points where fisheries do not pose jeopardy to the continued persistence of a listed group of fish. In many cases, these assessments identify the point where additional fishery reductions provide little reduction in extinction risks. A population may continue to be at significant risk of extinction but those risks are no longer substantially affected by the specified fishing levels. Often, no level of fishery reduction will be adequate to meet naturally-spawning population escapement goals related to population viability. In those cases, elimination of harvest will not in itself lead to the recovery of a population. However, prudent and careful management of harvest can help close the gap in a coordinated effort to achieve recovery.

Table 3-5. Summary of major events affecting harvest of Columbia River salmon and steelhead.

Year	Event
1918	Columbia River Compact for joint state salmon fishery management ratified by Congress
1935	Fish wheels, seines, and traps prohibited in Washington (Oregon follows)
1943	Columbia River commercial seasons reduced (from 270 to 200 days)
1949	Columbia River commercial seasons reduced to 170 days
1956-59	Ocean fishery begins to expand; Columbia River commercial seasons reduced to 100 days
1964	Last Columbia River summer Chinook season
1968	U.S. v. Oregon court settlement- Tribal fishing rights and states' management authority defined
1973	Congress passes Endangered Species Act
1976	Congress passes Magnuson-Stevens Fishery Conservation and Management Act
1977	Columbia River Fish Management Plan – 5 yrs (U.S. v. Oregon court order)
	Columbia River spring seasons closed
1980	Northwest Power and Conservation Act
1983-88	New Columbia River Fish Management Plan negotiated (conservation, allocation)
1984	Ocean and freshwater coordinated weak stock management (North of Falcon) began
	Selective fisheries for hatchery steelhead begin
1988	Renewed Columbia River Fish Management Plan-10 yrs duration. adopted by Federal Court
1991	ESA listing of Snake River sockeye
1992	ESA consultation and harvest limitations for Snake River sockeye
1992	ESA listing of Snake River spring, summer, and fall Chinook
1993	Ocean and freshwater ESA consultation & limitations for Snake R. fall and spring/summer Chinook
1994	Annual U.S. Oregon negotiations begin concerning ESA constraints and Indian and non-Indian allocation
1996	Congress passes Sustainable Fisheries Act (reauthorizes Magnuson-Stevens Act)
	Three year ESA agreement reached in U.S. v. Oregon for spring/summer Chinook
1997	ESA listing of upper Columbia and Snake River steelhead
1998	ESA listing of lower Columbia steelhead
	ESA consultation and harvest limitations for steelhead
	ESA management of Oregon coastal coho
	Selective fisheries for hatchery coho begin
	Renegotiation of Columbia River Fish Management Plan begins
1999	ESA listing of lower Columbia, Willamette, and upper Columbia spring Chinook, lower Columbia fall Chinook, Columbia River chum, middle Columbia and Willamette steelhead, and Oregon state listing of lower Columbia coho
	ESA consultation and harvest limitations for 1999 listings
	U.S. - Canada Treaty Agreement for Abundance Based Management Plan
2001	U.S. v. Oregon 5-year Agreement for management of listed spring Chinook, summer Chinook, and sockeye
	Selective fisheries for hatchery spring Chinook begin
2008	U.S. v. Oregon 10-year Management Agreement (2008-2017)
2008	U.S. - Canada Treaty Agreement (2009-2018)

3.5.2. Limiting Factors

Directed Harvest Mortality

Harvest mortality occurs in fisheries directed at a particular species or stock; this harvest can occur in single (terminal) or mixed (intercept) stock fisheries. The most effective method for targeting a specific stock is the prosecution of single stock fisheries. Single stock fisheries most commonly occur in terminal harvest areas where one stock is known to be present through the use of stock identification techniques, historical run timing data, or escapement survey methods.

In mixed stock fisheries, the management challenge is to harvest from mixed populations having various available surpluses, sometimes including populations with no surplus, as the populations move through the fishery area at various rates and abundances. Harvest of specific stocks has been adjusted by management decisions (e.g. fishery openings when the targeted stock is abundant relative to other stocks), fishery adaptations (e.g. gear designed to target specific stock/species), or fishery regulations (e.g. prohibitions of retaining certain species). Scale pattern analysis, CWT analysis, and genetic stock identification techniques have been applied in-season to determine the stocks present in a fishery, providing managers with timely stock composition data. Time and area fishery openings are also effective in targeting specific stocks and reducing impact to other stocks when information is available about the migration timing and migration route of a specific stock. In many cases where the targeted stock is a distinct size relative to other stocks in the fishery, gear modifications, such as specific mesh size requirements, can be effective in harvesting certain size fish while allowing other fish to escape the fishery. In the Columbia River, certain fisheries are focused on harvesting adipose fin-clipped hatchery-reared fish only by targeting marked hatchery fish while utilizing gear modifications to allow protected stocks to escape.

Incidental Harvest Mortality

Salmonid migration timing and routes are dynamic and considerable variation can occur from year to year. Thus, despite the various methods discussed above to target a specific stock and minimize effects on weak stocks, incidental harvest of non-targeted stocks still occurs. Most fisheries have specific reporting requirements and limits for incidental bycatch that are intended to lessen the harvest impacts to non-targeted stocks. In the case of the Columbia River, specific incidental harvest percentages are set for protected stocks; fisheries are managed so as not to exceed these harvest limits of protected stocks.

Access to strong stocks in Columbia River and ocean fisheries is regulated by impact limits on weak populations mixed with the strong. Each fishery is controlled by a series of regulating factors. Many regulating factors that affect harvest impacts on Columbia River stocks are associated with laws, policies, or guidelines established to manage other individual or combined stocks, but indirectly control impacts of Columbia River fish as well. Harvest managers configure fisheries to optimize harvest of strong stocks within the series of constraints for weak stock protection. ESA-listed fish generally comprise a small percentage of the total fish caught by any fishery. Every harvested ESA-listed fish may correspond to tens, hundreds, or even thousands of other fish in the total catch. As a result of weak stock fishery constraints, strong hatchery and wild runs may go unharvested. Small reductions in fishing rates on ESA-listed populations can translate to larger reductions in catch of other stocks, with substantial economic consequences.

Catch and Release Mortality

Catch and release regulations have been used for years to manage sport fisheries. Generally, catch and release restrictions allow resident fish to grow older and larger, thereby creating improved angling opportunities. More recently, catch and release has been employed in anadromous fish management practices to enable retention of hatchery salmon and steelhead and release of wild fish in mixed-stock fisheries. Because of the wide range of knowledge among sport anglers regarding proper fish handling techniques and the different degrees of how fish species react to handling stress, mortality occurs as a result of catch and release. Although sport fishing catch and release mortality varies widely among fisheries, it is believed to be low compared to other harvest-related mortality.

Catch and release has been employed in the Columbia River commercial fishery since 1950 for non-legal size sturgeon and since 1975 for steelhead. Catch and release is a relatively new concept for commercial salmon fishing, and has recently become a significant part of managing Columbia River spring Chinook stocks. Recent recovery efforts in the Columbia Basin have focused on maintaining and rebuilding native wild stocks. The hatchery practice of marking released fish with an adipose fin clip has allowed fishery managers to implement fisheries which harvest only hatchery fish while requiring the release of protected wild stocks. Significant gear modifications are continually being evaluated and utilized to reduce any handling mortality that can occur as a result of being caught and released by the commercial fishery. Delayed catch and release mortality of wild fish in these hatchery-selective fisheries is not completely understood and is presently being evaluated.

Gear or Fishery Selectivity

Commercial fishing gear can be size-selective, depending on the type of gear (i.e. gill net vs. seine) or the size of gear (i.e. mesh size). As mentioned in the mixed stock fishery discussion, size selectivity can be a desired result if the gear is designed to harvest a specific size stock or species. However, commercial fishing gear size selectivity can also be undesirable. For example, if a fishery disproportionately harvests the larger individuals in a population, the remaining smaller individuals comprise the effective population (i.e. those individuals that spawn in any given year). If this process is repeated annually, the effect on the adult population is a decreased average size at maturity or potentially a modified age composition.

Fisheries may also be selective for a particular timing or segment of the run, depending on management practices. For example, a fishery may disproportionately harvest the early portion of a run because of market- or industry-driven needs. Because run timing is heritable (Garrison and Rosentreter 1981), fisheries may alter run timing traits due to systematic temporal removals from populations over time. Although there is evidence that run timing alterations have occurred in certain stocks, it is not a forgone outcome for all stocks exposed to fisheries. In the Columbia River, hatchery coho-targeted fisheries, in conjunction with hatchery practices, may have altered run timing (Cramer and Cramer 1994). Hatchery coho brood stock was often obtained from the early part of the run, which generally resulted in early run timing for hatchery adults. Effort in fisheries targeting hatchery fish is concentrated during the time of hatchery fish abundance. Consequently, consistent harvest of wild fish with the early run trait can also occur, thereby reducing this early run trait in the spawning population and altering run timing of the wild stock. Effects of selective fisheries are most likely to occur if harvest rates are high; lower harvest rates will likely mitigate for selectivity.

Population Effects

Fishing has direct and indirect effects on salmon populations, especially if harvest rates are high and/or prolonged. Harvest can influence the number, biomass, age, size, and fecundity of spawners, as well as the genetic characteristics and population structure. In many lower Columbia salmon populations, as well as others, the biological characteristics of contemporary populations have been shaped by continued harvest patterns.

Abundance — Following other mortality causes in each returning cohort, harvest clearly determines the number of adult salmon remaining to perpetuate the population. Much of the future discussion about recovery and sustainability will be focused on a new paradigm for determining the number of salmon required to fill the habitat to capacity (Schoonmaker et al. 2003). In addition to the important function of salmon spawning escapement for supplying eggs for subsequent generations, recent scientific evidence has shown that adult salmon carcasses provide a significant source of nutrients delivered from marine to freshwater ecosystems (Kline et al. 1993, Bilby et al. 1996, Cederholm et al. 1999). Not only do the carcasses form the basis of a nutrient pathway via primary production, but flesh and eggs are directly consumed by aquatic insects (Wipfli et al. 1999) and by rearing fish (Bilby et al. 1996). This biological feedback loop benefits future salmon production. The chronic depression of salmon biomass to freshwater ecosystems may be contributing to reduced carrying capacity for salmon (Cederholm et al. 1999, Knudsen 2002). Probably the most important implication for Pacific salmon is that the production relationship (returning adults per spawner) is influenced not only by the number of eggs deposited in the gravel, but also by the amount of biomass delivered and retained in the watershed (Cederholm et al. 1999). The carrying capacity for freshwater production depends on both the physical space available and the amount of nutrients provided to the system. This varies, depending on the freshwater life history of the species and the nutrient interdependence among species but, in any case, there is a feedback mechanism relating the number of adults allowed to escape harvest directly to the productivity of the system. This biological control factor must be considered in contemporary productivity analyses.

Age, Size, Sex, Fecundity — Selective fishing (as described above) affects salmon population age, size, sex, and fecundity structure directly by influencing certain characteristics in the targeted populations or indirectly by gradually influencing the population's heritable characteristics (discussed below). Gear or run timing selectivity may influence the annual productivity of the population by removing the older, larger individuals, too many of one sex, or the larger females carrying the most eggs. Fishing-influenced changes in the average sizes and ages of salmon populations have been well documented (Ricker 1981). For example, body size is related to redd digging success (Beacham and Murray 1987) and/or fecundity -- larger fish usually carry more eggs (Sandercock 1991). When too many individuals with the most reproductive potential are removed, the population's productivity is reduced.

Box 3-14 Fishing Limiting Factors

- Reduce spawner numbers,
- Reduce the number of carcasses in freshwater ecosystems,
- Alter the size and age of returning spawners,
- Alter the run timing of spawners,
- Alter the fecundity of spawners,
- Change genetic characteristics of spawners, and/or
- Alter the population structure or diversity.

Genetics — As fisheries are continually prosecuted, the genetics of the target populations can be gradually changed, especially if there is selection for certain sizes of fish or portions of the run timing (Reisenbichler 1997). Because of their tendency to home to their natal streams, Pacific salmon have evolved a diversity of genetic and phenotypic population characteristics (Waples 1991a). Every spawning population is potentially a unique genotype (Healey and Prince 1995). There is even evidence of genetically controlled divergence within a single, relatively small spawning area (Woody et. al. 2000). Examples of apparently heritable ecological strategies for success include variations in body size correlated with differences in stream flows (Beacham and Murray 1987), run timing for spawning and incubation survival (Smoker et al. 1998), duration of egg incubation (Woody 1998), and a variety of freshwater rearing strategies (e.g., Wood et al. 1987, Bisson et al. 1997). Lastly, as numbers are reduced by harvest, especially in small populations, all the attributes controlled by genetic diversity are threatened by inbreeding and/or genetic drift (Reisenbichler 1997).

Population Structure and Diversity — Reduced abundance also affects the structure and biodiversity of populations. Salmon populations are generally structured hierarchically with genetic relatedness usually corresponding to geographical distance (Allendorf and Waples 1995). Independent populations are defined as a group of the same species that spawns in a particular location and season and which, for the most part, do not interbreed with other spawning groups (Myers et al. 2003). Each independent population evolves characteristics of productivity, body size, run timing, fecundity, etc. that correspond with the habitat features it experiences throughout its life history. The combination of these features across populations constitutes the biodiversity of a group of populations, commonly referred to as a stock when mixed together for harvest management purposes. As harvest usually occurs at the stock level, a similar harvest rate is applied to the mixture of populations, some having higher production potential than others. Heavy harvest rates, especially when combined with habitat problems and natural variation, can therefore drive the weaker populations to low levels, even to extinction (e.g., Walters and Cahoon 1985). As weaker populations are diminished or eliminated, the total biodiversity and genetic variation within and between the hierarchical populations is reduced (Riddell 1993). Setting harvest rates to maximize use of high productivity hatchery populations is particularly troublesome for intermingled wild populations that cannot withstand the hatchery harvest rate (NRC 1996, Knudsen 2002). The use of selective fisheries for marked hatchery fish is expected to ameliorate this effect on lower Columbia Chinook, coho, and steelhead.

3.5.3. Threats

There are a number of ongoing harvest-related threats to salmon and steelhead viability and productivity. Many fishing threats are species-specific and they will be addressed below accordingly. Other fishing-related threats apply across all or most species and can be characterized generally as:

- Unmet (or unidentified) escapement goals,
- Technical inability to identify the optimal carrying capacity of spawners,
- Social/political inability to further constrain fishing,
- Complexity of management institutions causing an inability to get agreement, and
- Complexities of managing fisheries to stay within the allowed exploitation rates.

Spring Chinook Fishery

Most wild spring Chinook escapements are extremely low and are based primarily on strays from hatchery programs. The exploitation rate of spring Chinook has fluctuated over time, ranging from 20 to 65%. Currently, most of the harvest of lower Columbia wild spring Chinook occurs in the ocean incidental to target fisheries for Alaskan, Canadian, Columbia River hatchery, and California hatchery

Chinook stocks. The mortality of wild spring Chinook in Columbia River fisheries is now incidental to target fisheries for fin-clipped Willamette, lower Columbia, and upper Columbia hatchery fish. There is likely unreported retention of wild spring Chinook in the fisheries. Furthermore, catch and release fishing is known to result in unseen mortalities, including the increased incidence of spawners that die before depositing eggs into the gravel. Fishing-induced threats to sufficient escapements of wild spring Chinook include:

- Harvest in ocean fisheries,
- Incidental in-river harvest,
- Release mortalities from hatchery-selective fisheries,
- Unaccounted-for sea lion mortality, and
- Illegal harvest.

Fall Chinook Fishery

Fisheries on lower Columbia River (LCR) fall Chinook have been regulated for impacts of 38-49% from 2002-2009, approximately half of the 70-80% rate prior to the 1990s. Columbia River tule fall Chinook are harvested in ocean commercial and recreational fisheries from Oregon to Alaska, as well as the Columbia River commercial gill net and sport fisheries. Lower Columbia tule fall Chinook are an important contributor to Washington ocean troll and sport fisheries as well as the Columbia River estuary sport fishery. Fishing rates are generally greater on fall tule than late fall bright Chinook. Recent implementation of full marking of hatchery fall Chinook will provide increased management flexibility for use of mark-selective fisheries. By 2011, all returning LCR hatchery fall Chinook should be marked. Columbia River and tributary fisheries quotas have recently been set for tules according to rebuilding exploitation rate (RER) established for Coweeman fall Chinook and for lower river brights by an escapement target of 5,700 to the North Fork Lewis River. Coweeman fall Chinook are one of the strongest remaining populations, hence, there is some question whether exploitation rate limits based on Coweeman Chinook provide adequate protection for weaker populations of fall Chinook. More recent analyses used in making harvest management decisions have begun to evaluate impacts of harvest on other populations (e.g. Appendix E Ch. 14; Ford et al. 2007; NFWSC 2010). Fishing-related threats to wild fall Chinook include:

- Harvest in ocean and freshwater fisheries,
- Inability to distinguish wild from hatchery fish in fisheries, and
- Illegal harvest.

Coho Fishery

The primary fisheries targeting Columbia River hatchery coho salmon occur in West Coast ocean and Columbia River mainstem fisheries. Most of these fisheries have hatchery-selective harvest regulations or time and area strategies to limit impacts to wild coho. The exploitation rate of coho prior to the 1990s fluctuated from approximately 60% to 90% but now the aggregate annual exploitation rate of wild coho is about 20% or less, while the exploitation of hatchery coho is significantly greater because of mark-selective fisheries. It is unclear whether current exploitation rate limitations for wild coho provide adequate protection for the weak populations included in the aggregate. Wild coho are harvested in Washington, Oregon, California, and Canadian Ocean commercial and sport fisheries (about 9% of the total run), and in Columbia River sport, commercial, and treaty Indian fisheries and tributary sport fisheries (about 9% more). Regulations in most fisheries specify the release of all wild (non-fin clipped) coho but some coho are likely retained and others die after release. Fishing-related threats to wild coho salmon escapements include:

- Ocean and in-river harvest,
- Release mortalities from hatchery-selective fisheries, and
- Illegal harvest.

Chum Fishery

Chum salmon were once very abundant in the Columbia River Basin, with commercial landings ranging from 1 to 8 million pounds (80,000 to 650,000 fish) in most years before the early 1940s. Chum escapements have been extremely small since the late 1950s, but improved somewhat recently. The total estimated escapement in 2002 was just under 20,000. NMFS biological opinions now limit the incidental impact of Columbia River fisheries targeting other species to an expected 2% and not to exceed 5% of the annual return of chum listed under the ESA. No sport or commercial fisheries specifically target chum salmon and the current impacts of 3% or less are incidental to fisheries for other species. Numbers incidentally taken in current freshwater or ocean fisheries are not significant. Even though no fisheries target chum salmon, fishing activities result in the following threats:

- Incidental catch in sport and commercial fisheries, and
- Illegal harvest.

Steelhead Fishery

Fishery impacts on wild summer steelhead are currently limited to incidental mortality in freshwater fisheries. Populations above Bonneville are also subject to treaty tribal subsistence and commercial fisheries. Interception of steelhead in ocean salmon fisheries is rare. Fishing rates on wild steelhead have been reduced from their historical peaks in the 1960s by over 90% following prohibition of commercial steelhead harvest in the mainstem (1975), hatchery-only retention regulations in the Columbia River mainstem starting in 1986, and hatchery-only retention regulations in the tributaries during the late 1980s and early 1990s. Current fisheries targeting steelhead in the Columbia River mainstem and tributaries focus primarily on hatchery fish. Wild steelhead mortality is incidental (less than 10% of the wild run). Ongoing threats to wild steelhead populations from fishing include:

- Incidental handling in fisheries targeting other species, and
- Illegal harvest.

Bull Trout Fishery

Abundance data for lower Columbia bull trout is very limited. The primary populations for which there is any significant data are in Yale and Swift reservoirs and their tributaries in the Lewis River system. Fishing for bull trout is closed in Washington. Hooking mortality may occur from catch and release of bull trout in fisheries targeting other fish, particularly the coho and kokanee fisheries in Merwin and Yale reservoirs. Incidental catch of bull trout is thought to be low, however. In the Lewis River system, incidental take of bull trout is thought to be greater above Swift Reservoir. WDFW has actively set fishery regulations to protect bull trout in reservoirs and tributaries in the Lewis River basin. Ongoing threats to bull trout from fishing include:

- Incidental handling in fisheries targeting other species,
- Illegal harvest.

3.5.4. Impact Assessment

Fisheries are unique among listing factors in that impacts are estimated annually for all ocean and freshwater sport, commercial, and tribal fisheries where harvest of listed species is significant. Data on direct harvest and catch-and-release mortality are available from Federal and State fishery regulatory agencies and Indian Tribes. Prior to the first listing of most lower Columbia ESUs, fishing impact rates on naturally-spawning fish ranged from <5% for chum salmon to 65% for tule fall Chinook (Table 3-6). In most cases, estimates represent aggregate stock rather than population-specific assessments although numbers are often based on representative index populations. Hatchery and wild stocks were often not historically distinguished by fishery regulation or in harvest assessments, but current impact estimates are based on wild stocks.

Spring Chinook: Impacts on wild fish including harvest and incidental fishing mortality averaged about 50% per year prior to first listing (Figure 3-27). During the 1970s and 80s, impacts were as high as 65%. Harvest rates have been reduced to around 20% or less since listing by restrictions of ocean fisheries and implementation of mark-selective fisheries for hatchery spring Chinook in freshwater.

Fall Chinook: Impacts on wild fish including harvest and incidental fishing mortality regularly reached or exceeded 65% for tule fall Chinook and 50% for bright fall Chinook prior to first listing. Target fishery impacts were reduced from the pre-listing baseline of approximately 65% to 49% starting in 2002 and to 38% in 2009. The 2009 impact of 38% included approximately 20% in Canada and SE Alaska ocean, 5% in ocean Treaty Indian, 5% in ocean sport, 4% in Columbia commercial and 4% in Columbia sport fisheries.

Chum: Increasing restrictions of late fall commercial seasons since the 1950s have reduced impacts to less than 5% per year since 1993. In many years, impacts are less than 2%.

Coho: Average impacts on wild fish including harvest and incidental fishing mortality averaged about 50% prior to first listing. During the 1970s, fishery impacts on coho approached or exceeded 80%. More recent fishery impact rates on wild coho have been reduced by half or more.

Steelhead: Impacts generally averaged about 10% or less around the time of first listing which are considerably reduced from historical peaks that regularly exceeded 70%.

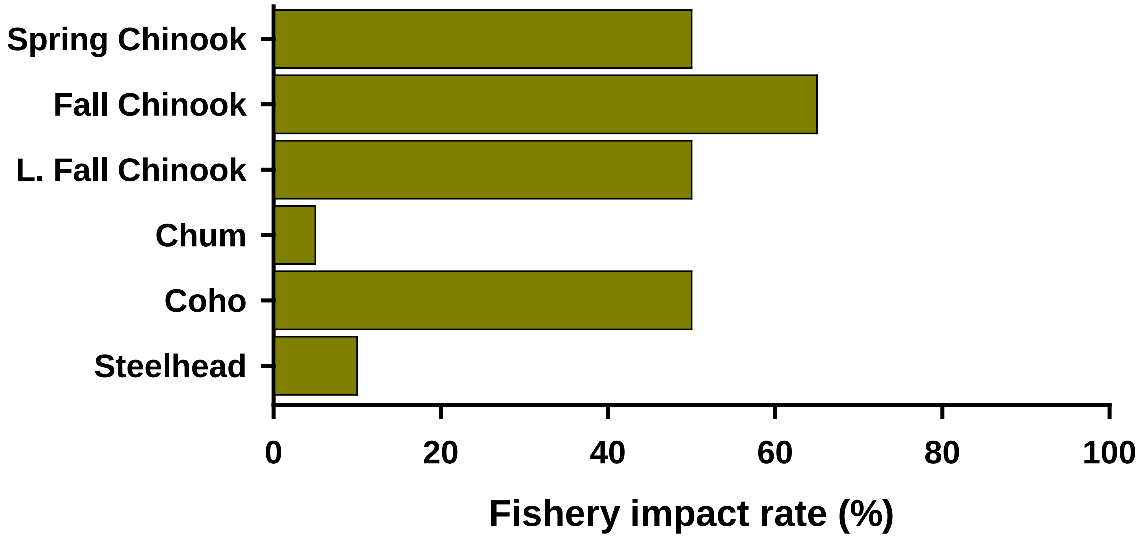

Figure 3-27. Species-specific fishery impact rates in combined ocean and freshwater fisheries during the late 1990s baseline reference period coinciding with first listing of most lower Columbia River ESUs.

Fishery impact rates vary for each year depending on annual stock status of multiple west coast salmon populations including lower Columbia salmon and steelhead (Table 3-6). Annual numbers generally average less than the current ESA take limits identified by NMFS. While weak stock management had significantly reduced fishery impacts by the time of first listing in the late 1990s, further reductions have subsequently been implemented in the interim. Selective fisheries for adipose fin-clipped hatchery spring Chinook (since 2001), coho (since 1999), and steelhead (since 1984) have substantially reduced fishing mortality rates for naturally-spawning populations and allowed concentration of fisheries on abundant hatchery fish. Selective fisheries occur in the Columbia River and tributaries, for spring Chinook and steelhead, and in the ocean, Columbia River, and tributaries for coho. Columbia River hatchery fall Chinook have recently been marked in order to provide for implementation of selective fisheries over the next few years. In addition, fishery impact limits have been reduced since 1999 by NMFS for fall Chinook and coho.

Table 3-6. Recent fishery impacts (%) in combined freshwater and ocean fisheries for listed lower Columbia River species and annual fishery impact limits adopted by the NMFS.

Year	Sp. Chinook		Fall Chinook		L. Fall Chinook		Chum		Coho		Steelhead	
	Lim.	**Est.**	**Lim.**	**Est.**	**Lim.**	**Est.**	**Lim.**	**Est.**	**Lim.**	**Est.**	**Lim.**	**Est.**
1985		43		66		54				66		
1986		52		82		64				73		
1987		45		82		65				79		
1988		49		81		68				77		
1989		50		59		44				78		
1990		57		60		38				76		
1991		54		63		57				65		
1992		46		65		57				60		
1993		48		61		51				53		
1994		45		33		38				10		
1995		10		36		36				12		
1996		11		26		16				12		
1997		16		35		25				14		
1998		12		33		23				8		
1999		38		42		19				28		
2000		38		48		24				24		
2001		21		51		31				13		
2002		43	49	51		41				14		
2003		34	49	47		50				23		
2004		31	49	45		40				24		
2005		36	49	51		50				18		
2006		34	49	51		32			15	13		
2007			42	47					20	19		
2008			41	35					8	7		
2009			38									

3.6. Hatcheries

3.6.1. Background

Salmon and steelhead production in the lower Columbia region is currently dominated by fish produced in over 20 salmon and steelhead hatcheries in the region. These hatcheries produce fish for sport and commercial harvest, supplementation of natural production, and conservation banks for severely depleted populations. Fisheries currently depend on hatchery production as few wild stocks are healthy enough to support significant harvest. However, hatcheries can also severely impact wild populations through both direct and indirect effects (Figure 3-28). By both design and happenstance, fish produced in hatcheries sometimes spawn in the wild with naturally-produced fish. Numbers and effects of naturally-spawning hatchery fish vary widely among species and populations depending on hatchery proximity and practices. Some natural spawning populations include large fractions of hatchery fish. Other populations are largely free of hatchery influence. In the lower Columbia River, most tule fall Chinook and coho have been heavily hatchery influenced, spring Chinook populations rely on hatchery production, steelhead have been variously affected, and chum, bright fall Chinook, and bull trout are largely free of hatchery effects.

To set the stage for a discussion of hatcheries and their role in past, present, and future lower Columbia salmon production and restoration, requires some basic definitions of the various types of hatchery programs. These range on a continuum from major production facilities to small genetic conservation programs and can be organized according to the programs’ history and purpose. Multiple programs with different or complimentary purposes may be found at a single facility.

Production hatcheries are used primarily to rear and release large numbers of fish that support fisheries. These are usually characterized by large physical plants and may incorporate satellite rearing and acclimation facilities. Many production hatcheries were originally constructed to mitigate for lost habitat upstream of dams.

Augmentation programs are usually more closely tied to local natural production but are primarily oriented to producing fish for harvest (Kapuscinski 1987). In most cases, the differences between the hatchery and natural fish are difficult to discern and natural reproduction is largely supported by hatchery fish. These programs are often associated with large production hatcheries and incorporate satellite rearing and acclimation facilities.

Supplementation programs use artificial propagation in an attempt to maintain or increase natural production, while maintaining the long-term fitness of the target population and keeping the ecological and genetic impacts on non-target populations within specified biological limits (RASP 1992).

Conservation hatcheries use artificial propagation techniques to maintain populations when they are at critically low numbers. They may include the use of captive broodstock but ultimately are aimed at rebuilding wild populations through supplementation strategies (Waples et al. 1991a). There are currently no true conservation hatchery programs in the lower Columbia planning area.

Many hatcheries were initially built as mitigation to offset the detrimental effects of development on salmon habitat and access. Hatchery programs provide one of the few alternatives for mitigating the large losses of salmon habitats and natural populations. Initial successes of artificial production practices in the early 1900s led hatcheries to be seen as an inexhaustible source of fish for harvest. The historical view was that hatchery fish could be substituted for naturally spawning fish without lasting consequences and that there was little need to protect remaining naturally spawning populations and the habitats that supported them. While the first hatcheries were operated long before mainstem dams were built, most lower Columbia River hatcheries were built to compensate for dam construction that blocked access to spawning grounds in the upper Lewis and Cowlitz rivers or reduced production from the upper Columbia and Snake rivers. Much of the mitigation hatchery program for the Columbia basin was concentrated in the lower river where hatchery water sources were abundant, fish avoided upstream and passage problems at mainstem Columbia River dams, and returns were readily available to lower basin fisheries which controlled most of the historical harvest.

The view of hatcheries has undergone a fundamental paradigm shift over the last 30 years as risks to naturally spawning populations have become better understood. We now know that poorly designed hatchery programs are often detrimental to wild salmon production (Cone and Ridlington 1996, Walters et al. 1988, NRC 1996, Lichatowich 1999). Hatcheries substantially increase net productivity by increasing egg-to-smolt survival relative to that realized in the natural environment. Because hatcheries allow greater than normal survival, individuals that would have died in the natural environment often survive to increase competition, predation, genetic effects, disease proliferation, and mixed stock fisheries effects among each other and their wild counterparts. Hatchery fish have also exhibited reduced fitness and survival per individual compared to wild fish (NRC 1996, Reisenbichler 1997). When hatchery fish stray and spawn in the wild, the fitness of natural offspring populations can likewise be reduced (Waples 1991, Reisenbichler 1997). Historical programs failed to understand the significance of local adaptation to population health which led to hatcheries regularly mixing stocks from different basins thus further exacerbating the effects of hatchery selection practices and domestication.

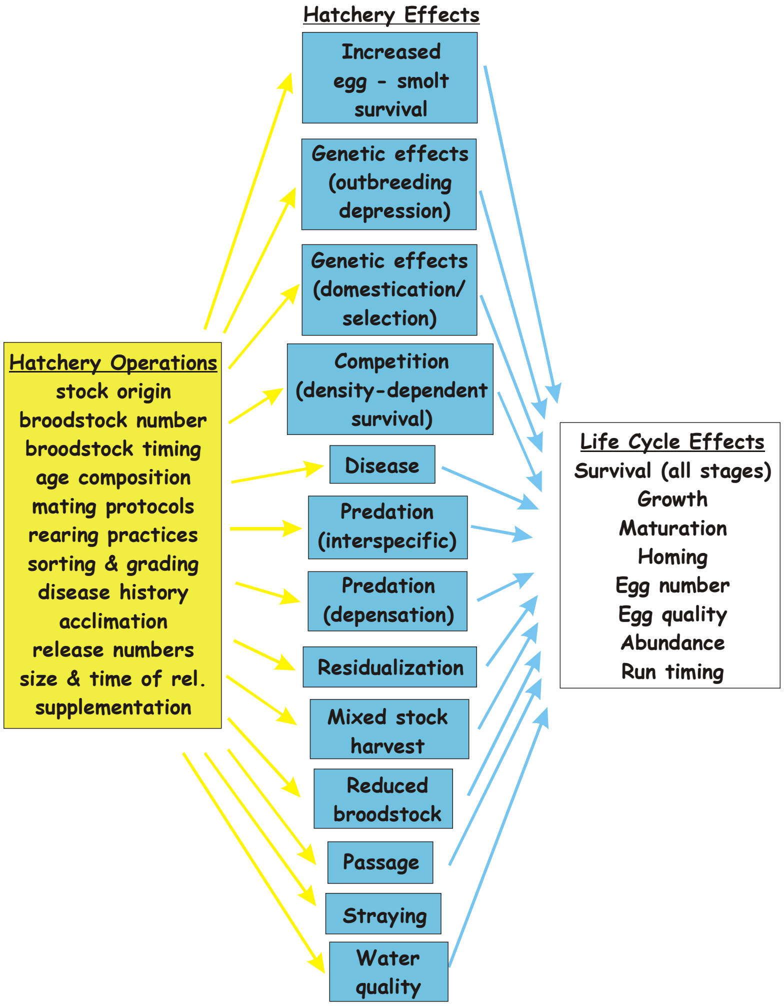

Figure 3-28. Potential links between hatchery operating procedures and effects on salmonids.

Hatchery fish can also mask declines in status of wild populations due to habitat loss or hatchery effects on fitness. It is difficult to observe a decline in natural productivity in basins where continuing hatchery subsidies mask the true productivity of the wild populations. Hatchery subsidies of wild populations have led to a reduced imperative for protection and restoration of habitats critical to natural production. Gradual erosion of adaptive population diversity in the hatchery and coincident declines in natural population productivity are a formula for species extinction over the long term. Populations maintained through a continuing influx of hatchery fish are not sustainable if they might become extinct whenever the hatchery subsidy is removed. No hatchery has demonstrated the ability to preserve a full spectrum of wild population diversity and life history traits in the long term over multiple generations. Hatcheries also depend on a continuing commitment of funding and other resources which places the long term viability of a hatchery-supported stock at the whims of political processes and competing funding priorities.

While hatcheries can pose serious risks to wild populations, benefits can also be significant. The production and mitigation benefits for fisheries are obvious. Hatcheries can provide demographic benefits to wild populations by increasing production when natural abundance is very low. Remnants of some lower Columbia River salmon currently exist only in or depend on hatcheries. Many lower Columbia River Chinook and coho populations would likely have been extirpated by habitat changes and by high harvest rates without continuing subsidies of hatchery fish. Hatcheries will continue be a critical tool for preservation, reintroduction, and supplementation over the short term. Conservation values include preserving genetic stocks where habitat is gone, reintroducing fish in areas where habitat has been restored, and bolstering survival to offset survival bottlenecks.

Recovery will ultimately depend on naturally-produced fish reproducing naturally. Natural habitats and wild populations are the only demonstrated alternative for guaranteeing long term sustainability. This biological fact is unchanged regardless of how hatchery controversies play out or how NMFS classifies the significance of hatchery salmon stocks in salmon recovery. While significant progress has been made in reducing hatchery impacts on wild fish, many hatchery populations continue to be a significant limiting factor for wild population viability. However, the long history of hatcheries in the lower Columbia, and their associated effects on wild fish, cannot be erased simply by closing all hatcheries. To do so would eliminate important hatchery-based fisheries and likely some populations of tule fall Chinook and coho which are now largely supported by hatchery augmentation. Instead, hatchery programs that produce fish for harvest should be modified to meet criteria for either integrated or segregated programs, support a comprehensive all-H approach to rehabilitating depleted populations, and minimize impacts to wild fish (NRC 1996).

This Plan identifies a recovery strategy for reform of hatchery programs to find an effective balance between hatchery facilities that can; 1) produce fish for harvest, 2) augment natural production, 3) help to rebuild depleted wild populations, and/or 4) serve as conservation banks for severely reduced populations, all while minimizing impacts on natural production. Hatcheries will continue to be operated in the foreseeable future for both conservation and fishery enhancement purposes and hatchery fish will continue to spawn naturally in some watersheds. Hatchery programs will need to be shaped to minimize risks while taking advantage of very real benefits. Conservation hatchery programs will be a key component in ongoing attempts to preserve and rebuild several listed Columbia basin salmon stocks (Waples and Do 1994). Some populations will consist entirely of naturally-produced fish segregated from significant hatchery influences. Other populations will include natural and hatchery-produced fish from carefully integrated hatchery programs. Hatchery managers have numerous operational choices that affect the biology and productivity, and thereby influence the life cycle, of both the hatchery fish and the wild fish with which they interact. Integrated hatchery programs will be particularly important for preservation, reintroduction, and supplementation in the interim period until habitats that can sustain viable natural populations are restored. NMFS hatchery policies will provide guidance on the role specific hatchery stocks may play in salmon recovery.

Even after viable ESUs of salmon are recovered, hatcheries will also be needed to provide fish for fisheries as mitigation for permanent loss of habitat and hydro system mortality. Fish populations in some areas will continue to include significant numbers of hatchery fish. It will not be necessary to exclude hatchery fish from every population in order to meet ESU recovery goals or to demonstrate individual population viability. Not every population needs to be restored to a high level of viability for ESU recovery. Viable populations capable of being naturally self-sustaining can also be restored in selected areas even when hatchery fish spawn in the wild. Natural fish population accounting practices will need to make the necessary adjustments to accurately represent the wild component independent of significant hatchery fish effects, thus providing an accurate assessment of the ability of the habitat conditions to support wild populations (Appendix C of NMFS 2008a).

History

Hatchery production in the lower Columbia River watershed began in the late 1800s. The first Washington hatchery was built on Baker's Bay near the mouth of the Columbia River in 1894 (Figure 3-29) (Wahle and Smith 1979). Soon after, state and federal hatchery operations began to enhance commercial fisheries. By the 1890s, many hatchery and egg-take stations were operating between the Chinook River (near the Columbia River mouth) and the Little Spokane River (upper basin).

In 1895, the first state-operated hatchery in Washington was built on the lower Kalama River and is still in operation. The first federal Chinook salmon hatchery on the lower Columbia River was built on the Little White Salmon River in 1897 (Nelson and Bodle 1990). Hatchery production exploded during the early 1900s. By 1905, approximately 62 million fry were released annually.

Throughout the 1900s, the negative effects of agricultural development, timber activities, and other land use practices, and the development of the Columbia River dam complex increased the need to mitigate for reduced natural production. Artificial production appeared to be the only means available to fishery managers to compensate for fish losses and the resulting decline in fish available for harvest.

The first half of the twentieth century witnessed an explosive increase of hatcheries and hatchery production. From 1913 to 1930, about 320 million Chinook salmon fry were released into the lower Columbia River by Washington state hatcheries alone; similar production numbers are estimated for Oregon and federal hatchery efforts. Hatchery operations dropped during the Great Depression and were temporarily interrupted during World War II, when production declined to one-tenth of that seen during pre-war years at Washington state hatcheries.

In response to the construction of Bonneville and Grand Coulee dams, Congress passed the Mitchell Act in 1938, which required the construction of hatcheries to compensate for fish losses caused by the dams as well as by logging and pollution. A 1946 amendment to the Mitchell Act led to the development of the Lower Columbia River Fishery Development Plan, which initiated the major phase of hatchery construction in the Columbia River basin. The plan was later expanded to include the upper Columbia River and the Snake River.

Although most of the lost natural salmonid production was located in the upper Columbia and Snake River basins, only four of the 39 propagation facilities authorized by the Mitchell Act were constructed above The Dalles Dam in the mid-Columbia River. Facilities were not constructed in the upper basin because of concerns with the ability of fish to bypass dams in the upper watershed and because the primary goal of the program was to provide fish for harvest in the ocean and lower river fisheries (Myers et al. 1998).

By 1990, total annual hatchery juvenile production (202.5 million) plus estimated wild production (about 145.2 million) equaled about 347.7 million juveniles in the Columbia River, while historical wild juvenile abundance equaled about 264.5 million (Kaczynski and Palmisano 1992). However, the number of juveniles effectively migrating to the lower Columbia and successfully reaching the estuary is likely still less than historical numbers after adjusting for modern-day passage mortality through dam structures and post-release mortality suffered by the hatchery fish.

Hatchery programs in the lower Columbia basin have included all salmonids native to the region. (Species-specific hatchery program information is presented in the Program section below.) Salmonids often have been transferred among watersheds, regions, states, and countries, either to initiate or maintain hatchery populations or naturally spawning populations. The transfer of non-native fish into some areas has shifted the genetic profiles of some hatchery and natural populations so that the affected population is genetically more similar to distant hatchery populations than to local populations (Howell et al. 1985, Kostow 1995, Marshall et al. 1995). Until recently, the transfer of hatchery salmon between distant watersheds and facilities was a common practice (Matthews and Waples 1991, WDF et al. 1993, Kostow 1995). However, agencies recently have initiated policies to reduce the exchange of non-indigenous genetic material among watersheds. For example, Washington Chinook salmon managers adopted a statewide plan in 1991 to reduce the number of out-of-basin hatchery-to-hatchery transfers. However, the plan did not explicitly prohibit introductions of non-native salmonids into natural populations; rather, the plan included genetic guidelines specifying which transfers between areas were acceptable.

The balance of hatchery and natural fish is currently dominated by hatchery fish as was expected when the hatchery mitigation programs were developed. For perspective on the role of Columbia River hatchery fish, by 1987, hatchery-origin fish dominated returns: 95% of coho, 70% of spring Chinook, 80% of summer Chinook, 50% of fall Chinook, and 70% of steelhead were produced by hatcheries (NRC 1996). As natural population recovery is implemented, the fish balance should begin to swing back towards natural production over time, although the rate and magnitude of the swing will depend on the relative success in rebuilding natural populations, with consideration given to total adult production and the public’s demand for harvest opportunities, now principally provided by hatchery production.

Recent Programs

Around the time of initial listings, there were 20 salmon and steelhead production hatcheries in the Washington lower Columbia basin (Figure 3-29) as well as a number of associated rearing facilities and acclimation sites. Hatcheries were releasing over 50 million salmon and steelhead per year in Washington lower Columbia River subbasins (Table 3-7). Two-thirds (34 million) were tule fall Chinook, 9.6 million were coho, spring Chinook totaled 5.4 million, steelhead 2.5 million, and chum 0.5 million. Numbers were subsequently reduced as several programs were modified or terminated, and additional reductions are currently underway. Fall Chinook and chum were released as subyearlings; other species were released primarily as yearlings. Subyearling survival rates are much lower than those of yearlings, so release numbers are not directly comparable among species. Oregon also releases significant numbers of fall Chinook, spring Chinook, coho, and steelhead from lower Columbia and Willamette Basin hatcheries.

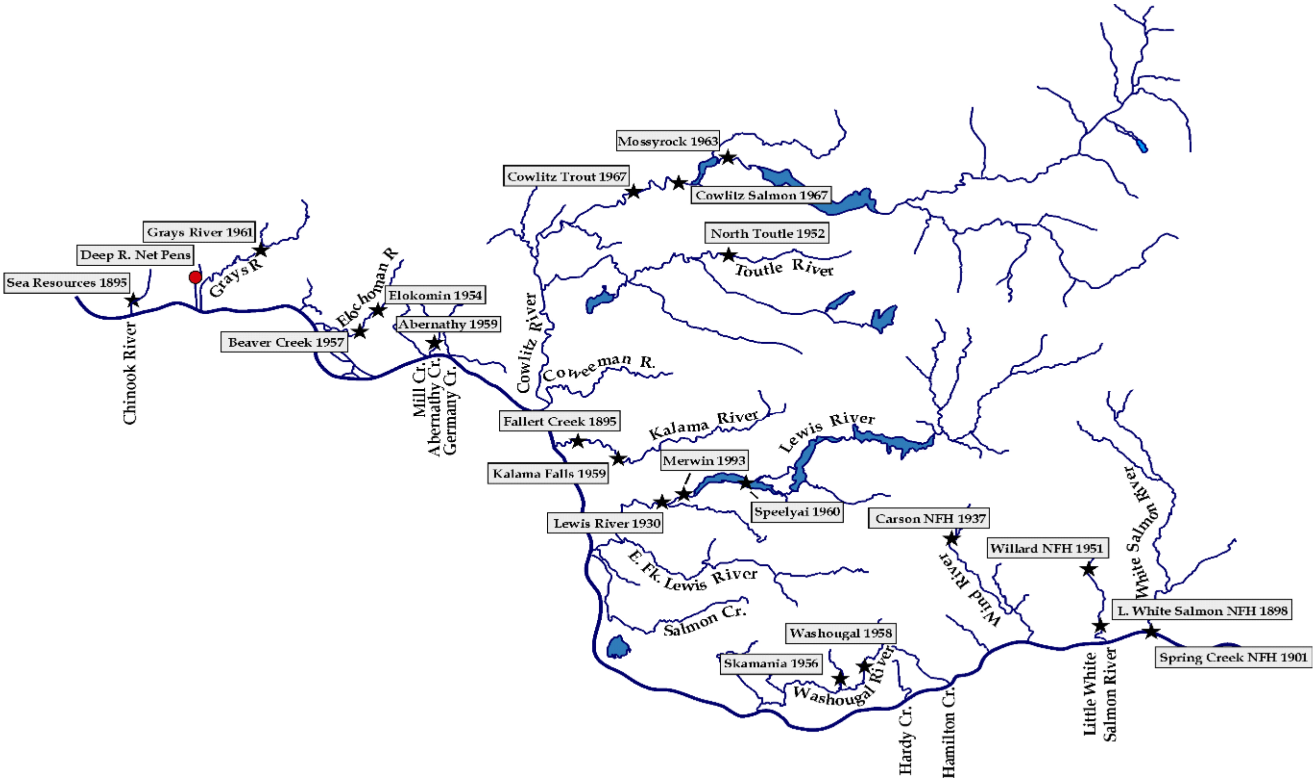

Figure 3-29. Lower Columbia production fish hatcheries and beginning dates of operation.

Table 3-7. Summary of lower Columbia River salmonid release numbers (thousands) in Washington subbasin hatchery programs as of 2004.

	Chinook					Steelhead	
Subbasin	**Spring**	**Fall (tule)**	**Fall (bright)**	**Chum**	**Coho**	**Winter**	**Summer**
Deep	200	0	0	0	400	0	0
Chinook	0	107.5	0	147.5	52	0	0
Grays	0	0	0	300	150	40	0
Eloch/Skam	0	2,000	0	0	930	90	30
Mill/Ab/Ger	0	0	0	0	0	0	0
L. Cowlitz	967	5,000	0	0	3,200	652.5	500
U. Cowlitz	300	0	0	0	0	287.5	0
Tilton	0	0	0	0	0	100	0
NF Toutle	0	2,500	0	0	800	0	25
SF Toutle	0	0	0	0	0	0	25
Coweeman	0	0	0	0	0	20	0
Kalama	500	5,000	0	0	700	90	90
NF Lewis	1,050	0	0	0	1,695	100	225
EF Lewis	0	0	0	0	0	90	25
Salmon	0	0	0	0	0	20	0
Washougal	0	4,000	0	0	500	60	60
Steamboat Slough	0	0	0	0	200	0	0
L. Gorge	0	0	0	100	0	0	0
Wind	1,420	0	0	0	0	0	0
Lit. White Salmon	1,000	0	2,000	0	1,000	0	0
White Salmon	0	0	0	0	0	0	0
Spring Creek	0	15,100	0	0	0	0	0
Totals	5,437	33,707.5	2,000	547.5	9,627.5	1,550	980

Throughout the twentieth century, the primary purpose for construction of lower Columbia basin production hatcheries was to enhance fisheries and to mitigate for reduced ability of the habitat to produce natural fish at historical levels (Lichatowich 1999). Almost all hatchery program production of salmon and steelhead in the lower Columbia basin is funded by federal monies as mitigation for fishery losses associated with the development of mainstem Columbia River federal dams, or from licensed operators of the tributary dams in the Cowlitz and Lewis rivers (Radtke and Davis 2000). As efforts move forward to restore those same natural populations that the hatchery programs were intended to replace, hatchery programs are being carefully reevaluated for compatibility with natural populations (ISAB 2003).

Columbia River hatchery programs have recently been the subject of an intensive review and reform effort. This evaluation is occurring through several processes with one of the most ambitious being undertaken under the auspices of the congressionally mandated Hatchery Scientific Review Group (HSRG). The HSRG is an independent scientific review panel of the Pacific Northwest Hatchery Reform Project established by Congress in 2000 in recognition that while hatcheries play a legitimate role in meeting harvest and conservation goals for Pacific Northwest salmon and steelhead, the hatchery system was in need of comprehensive reform. The HSRG has reviewed all state, tribal and federal hatchery programs in Puget Sound, Coastal Washington, and the Columbia River Basin (HSRG 2009).

NMFS is in the process of preparing an Environmental Impact Statement (EIS) to inform Columbia River basin hatchery operators and the funding of Mitchell Act programs. Currently, funds are provided to the Washington Department of Fish and Wildlife (WDFW) and Oregon Department of Fish and Wildlife (ODFW), U.S. Fish and Wildlife Service (USFWS), and Confederated Tribes and Bands of the Yakama Nation (Yakama) for the operation and maintenance of 18 hatcheries, which stock the mainstem Columbia River and its tributaries with close to 65 million salmon and steelhead annually. These funds also provide for the marking of hatchery fish and support associated monitoring, reform, and scientific investigations. The EIS will address the following questions: (1) How will hatchery operations positively or negatively affect the distribution, diversity, and abundance of the various populations of steelhead, Chinook, chum, and coho salmon found within the project area? (2) How will hatchery operations affect the other fish and wildlife species in the region? (3) What are the impacts of hatchery water withdrawals and releases of water used for fish rearing? (4) How are tribal fisheries affected?; and (5) Will hatchery operations have a disproportional impact on lower income groups? The draft EIS is expected to be made available for public comment in mid 2010.

3.6.2. Limiting Factors

Genetic Effects

Genetic effects of hatchery practices can influence wild fish populations because hatchery fish become genetically different from local wild fish within a few generations (Reisenbichler 1997). In general, the genetic effects of hatcheries and hatchery fish can be grouped into three major categories (Waples 1991, Krueger and May 1991): 1) the genetic effects of artificial propagation on the hatchery fish, 2) the direct genetic effects of hatchery fish spawning with wild fish in the natural habitat, and 3) the indirect genetic effects of hatchery fish on wild populations due to competition, predation, disease transfer, changes in fishing mortality, or any other factor that affects the abundance or effective population size of the wild population (Campton 1995). Here we will discuss direct genetic effects; the third point is addressed under subsequent headings.

The reasons for genetic differences in hatchery fish are attributable to:

- Taking broodstock from a non-local population,
- Random effects (genetic drift or founder effects) of small hatchery population size,
- Artificial selection by hatchery personnel,
- Increased survival of individuals poorly suited to natural habitat (relaxed selection), and
- Natural selection of fish that are well adapted to hatchery survival (domestication selection).

The loss of genetic variability to genetic drift has been documented for salmonids (Allendorf and Phelps 1980, Ryman and Stahl 1980; Waples and Teel 1990) and is commonly discussed in hatchery manuals regarding spawner numbers and sex ratios (Hershberger and Iwamoto 1983, Kapuscinski and Jacobsen 1987). Genetic drift is most commonly identified by the loss of infrequent alleles and a resulting increase in homozygosity in small populations. The rate of genetic drift is governed by the effective population size (i.e., the number of spawners that effectively contribute gametes to the next generation). Simon et al. (1986) found that post-release smolt survival was significantly and positively correlated to effective population size. Effective population size can be artificially reduced by using males to fertilize multiple females. For instance, Waples and Teel (1990) found effective population sizes of Chinook salmon in some hatcheries to be less than 100 even when returns were greater than 1,000 fish.

Box 3-15. Hatchery-related Genetic Limiting Factors

- Genetic drift and selection in hatchery populations,
- Domestication of hatchery populations (loss of fitness for survival in the wild), and
- Hatchery-produced strays intermingling with and outnumbering wild fish, including loss of between-population identity or variation, decreases in within-population genetic variation, and decreased fitness.

Selection can be either purposeful or inadvertent, but its consequences are the same in either case. Genetic variability is lost when only a segment of the population, not representative of the whole, is selected for broodstock. This effect was widespread among historic hatchery programs (e.g., see Cramer et al. 1991 regarding coho hatcheries). Most commonly, it results from the practice of taking eggs from the first fish arriving at the hatchery and then ceasing the egg take once the egg-incubation capacity of the hatchery is reached. Furthermore, because predictions are not possible on how the entire gene complex of a population will be affected by selection for a specific trait, selection should be avoided where enhancement of natural populations is desired (Krueger et al. 1981). Several studies have demonstrated that selective breeding in hatcheries has reduced viability as a result of the loss of genetic variability (Ryman 1980, Kincaid 1976, Allendorf and Utter 1979, Allendorf and Phelps 1980, Ryman and Stahl 1980).

Domestication selection results from unintentional selection for survival in a hatchery environment (Reisenbichler 1997). This selection may result from culling the slow growing fish, from disease treatments, or from the effects of growth differences in the hatchery on survival to maturity. A particular type of domestication selection that is difficult to eliminate relates to how hatchery practices can provide selective advantages to fish that spawn during a specific time of the spawning season. For example, the earliest spawning fish in a hatchery also produce the earliest emergent fry and therefore the largest smolts at release. Numerous studies have demonstrated that survival to adulthood increases as smolt size at a given time increases for every salmonid species. Thus, when a hatchery eliminates the environmental perils of early spawning, a new selective advantage is provided to early spawning fish.

Spawning of hatchery salmonids in the wild with naturally produced fish has the potential to adversely affect genetic characteristics of natural populations (Campton 1995, Reisenbichler 1997). For hatchery fish to have a genetic impact on naturally spawning fish, two conditions must be true: 1) the hatchery fish must be genetically different from the natural fish, and 2) the hatchery and natural fish (or their descendants) must interbreed. The magnitude of genetic impact will depend on the extent to which these two conditions are true (see discussion on straying below).

Three types of genetic risks have been identified which may impact the long-term productivity of wild populations, including:

- Loss of between-population identity or variation,
- Decreases in within-population genetic variation, and
- Decreased fitness (Campton 1995).

The loss of between-population variation or diversity is a primary genetic risk of introducing non-indigenous fish to wild populations. When populations having different genetic profiles interbreed, they may tend toward homogeneity (Campton 1995). For example, populations of wild steelhead on the northwest coast of Washington, where nonnative hatchery steelhead had been extensively stocked since the 1940s, were genetically more homogenous than wild, unstocked steelhead in British Columbia (Reisenbichler and Phelps 1989). Lower Columbia River wild coho salmon are now genetically indistinguishable from hatchery fish stocked for a number of years in large numbers (Flagg et al. 1995). In the long run, this potential loss of diversity weakens the biological resiliency essential to the variable structure required for a healthy salmon ESU.

The loss of within-population variation results when hatchery populations with reduced genetic variation, as described above, spawn naturally with local populations (genetic swamping). The genetic variation of the local populations is subsequently reduced, especially when the number of hatchery fish is large (high stray rates or widespread dispersal of hatchery juveniles). For example, an introduced stock of coho salmon that is substantially different from the native stock might survive at roughly 20%

the rate of the native stock, while a similar stock introduced from a nearby stream might survive at roughly 80% of the rate of the native stock (Reisenbichler 1986).

Loss of fitness, as expressed by reduced reproductive success and survival, occurs from the interbreeding of two genetically diverged populations, such as hatchery fish and wild fish, and is referred to as outbreeding depression (Campton 1995). A number of studies have revealed that feral hatchery fish spawning in the wild, either with each other or with wild fish, clearly have reduced reproductive success, lower juvenile growth and survival, and lower marine survival than their wild counterparts (Reisenbichler and McIntyre 1977, Nickelson et al. 1986, Leider et al. 1990). In particular, naturally spawning Skamania stock steelhead introduced into the Kalama River (1- to 2-month differences in time of spawning) were only 28% as successful at producing smolt offspring as the native fish (Chilcote et al. 1986). Survival of wild Kalama steelhead was reduced to 43% of normal when a wild fish mated with a Skamania stock hatchery steelhead (Chilcote et al. 1986). Also, studies with hatchery releases have indicated hatchery fish derived from local populations perform much better in their native environment than do hatchery fish from other populations (Bams 1976, Altukhov and Salmenkova 1986).

Population Mixing

Populations can be mixed, and result in genetic and life history effects, through a number of management activities. Obviously, massive releases of smolts from hatcheries and widespread outplanting from production hatcheries have the single most dramatic effect. Hatchery transfers, intentional augmentation and supplementation of natural production, and straying from hatchery programs all contribute to negative impacts on wild populations. The ISAB (2003) concluded that hatchery programs based on hatchery broodstock lines, and which allow the hatchery products to interact intensively with natural populations, almost certainly impose a large cost on the affected natural populations.

Hatchery Transfers — Most hatchery populations have been affected to some degree by transfers between hatcheries to fill egg-take goals in years of low return. Examples within the Columbia basin of hatchery populations that have undergone substantial transfers are early-type coho (Cramer et al. 1991) and tule fall Chinook. Many hatcheries have been founded with broodstock from other hatcheries. As examples, Skamania steelhead, Carson spring Chinook, and Cowlitz coho have been used at a number of hatcheries.

Box 3-16. Hatchery-related Mixing Limiting Factors

- Increasing the likelihood of deleterious genetic effects,
- Reduced population diversity and fitness,
- Low-mortality conditions that can favor maladaptive traits, and
- Increasing straying of hatchery fish.

Populations are also mixed when brood fish are taken at a dam where more than one population must pass. For example, the Bonneville upriver bright stock of fall Chinook was developed at Bonneville Hatchery by taking their broodstock from bright fall Chinook trapped out of the fish ladder at Bonneville Dam. These fish were a mixture of fall Chinook that originally spawned throughout the Columbia basin above Bonneville Dam. Similarly, Carson stock spring Chinook were developed at Carson National Fish Hatchery by trapping spring Chinook at Bonneville Dam as broodstock.

Supplementation — Although the original purpose of most Northwest hatcheries was to provide harvest opportunities in the face of declining salmonid abundance, augmentation and supplementation of natural production have become the focus of some recent salmonid recovery efforts (RASP 1992, Cuenco 1993, ISAB 2003). Augmentation and supplementation are generally aimed at either enhancing existing stocks of anadromous fish or reintroducing stocks formerly present in particular subbasins. Hatchery programs designed to supplement endangered or exploited salmonid populations, like more traditional hatchery programs, can reduce population fitness because the animals are reared under low-mortality conditions that can favor maladaptive traits. The scale of hatchery operations and practices employed in smaller supplementation programs can often be considerably less than those at hatcheries designed to provide for harvest opportunities. However, supplementation programs have similar concerns regarding genetic and ecological effects as other hatchery programs (ISAB 2003). In the extreme case of continual, large-scale augmentation, where the hatchery and natural populations are integrated, the empirical basis is inadequate for determining the cost to the natural population (ISAB 2003). The ISAB (2003) recognized that Columbia Basin supplementation occurs at a number of intentional and unintentional levels:

”Most of the hatchery programs are not integrated with natural production because they rely extensively on fish of hatchery origin for their broodstock. Nevertheless, the hatchery productions from these programs are present in large numbers on the breeding grounds of many natural spawning stocks. In some cases this is deliberate, in others it is inadvertent. Either way, this constitutes a supplementation action.”

Straying – For hatchery and wild fish to interbreed, they must spawn in the same place at the same time. The degree of genetic mixing and the effects on life history that occurs when hatchery fish are released in a wild population varies dramatically, depending on the ability of the hatchery fish to survive to maturity and on temporal isolation mechanisms. Leider et al. (1986) found that 36% of all wild summer steelhead in the Kalama River mated with hatchery fish, even though spawning by hatchery fish peaked one month earlier than wild fish. The high rate of interbreeding in the Kalama River resulted from the much greater abundance of hatchery fish than wild fish. Evidence indicates that straying is more likely among some races of salmon than others (Quinn and Fresh 1984, Chapman et al. 1994).

Hatchery or fish management practices that lead to straying of hatchery fish at the time of return are key factors governing the risk of reduced diversity and fitness in locally adapted populations. Management practices which may increase the straying rate are: 1) broodstock transfers, 2) mixed broodstock origins, 3) releasing hatchery fish close to the mouth of the stream to which adults are intended to return, 4) off-station releases of fish, 5) not acclimating fish prior to releases, and 6) rearing juveniles in other basins/water sources prior to release. Environmental conditions affecting straying rates include protracted periods of low flow and high water temperatures at the time and place adult fish are targeted to return.

Competition

The potential for intra- and inter-specific competition for food or space between hatchery and wild stocks depends on the degree of spatial and temporal overlap in resource demand and supply (Steward and Bjornn 1990, McMichael et al. 2000). The capacity for hatchery fish to significantly alter the behavior and survival of wild fish via competition remains a controversial subject (Steward and Bjornn 1990). There are five areas where competition and crowding may occur between hatchery and natural fish: in rearing streams, during downstream migration, in mainstem reservoirs, in the estuary, and in the ocean.

Rearing Stream — Streams in which juvenile salmonids rear have a limited amount of the resources necessary for survival and growth. Competition for food and space can occur when hatchery fish are released into streams where wild fish are present (McMichael et al. 2000). Competition is most likely to occur if the fish are of the same species and they share the same habitat and diet. Juvenile salmon establish and defend foraging territories through aggressive contests (Nielsen 1992). Hatchery fish may be more aggressive, disrupting natural social interactions (Nielsen 1994). Often hatchery-reared individuals may be larger than wild fish in the same stream, and occupy the best feeding territories, placing their wild counterparts at a disadvantage and reducing the number of wild fish in the natural habitat (McMichael et al. 1997). Because carrying capacity of many streams and watersheds has been degraded by contamination, development, logging, and other causes, the effects of competition on wild salmonids may be further exacerbated.

Downstream Migration — Few studies have directly addressed the possibility of density dependent competition during juvenile emigration (Hard 1994). Since salmonid smolts actively feed during their downstream migration (Becker 1973; Muir and Emmett 1988, Sagar and Glova 1988), it is reasonable to conjecture that increased density from hatchery releases could increase competition for wild smolts.

Reservoirs —Muir and Coley (1994) hypothesized that smolts passing through reservoirs were negatively affected by starvation and that increased hatchery production could further deplete food resources. Neither Chapman et al. (1994) nor Witty et al. (1995) found documentation of density-related interaction in Snake and Columbia River reservoirs. Ultimate impacts on adult fish production would vary greatly in any one year as a result of multiple additional influences on smolt-to-adult survival, including flow-related passage time through the reservoirs and on to the estuary.

Box 3-17. Hatchery-related Competition Limiting Factors

- Reduced survival of juveniles,
- Exacerbation of poor food availability in reservoirs,
- Exceeding the carrying capacity of the estuary,
- Reduced size fish upon ocean entry,
- Lower marine survival, and
- Reduced numbers of wild adults returning to spawn.

Estuarine Conditions —Extensive hatchery production programs may have at times exceeded the carrying capacity of the Columbia River estuary, resulting in competition between natural and hatchery fish. The potential exists for large-scale hatchery releases of fry and fingerling ocean-type Chinook salmon to overwhelm the production capacity of estuaries (Lichatowich and McIntyre 1987). Furthermore, the productivity of the Columbia River estuary likely has decreased over time as a result of habitat degradation, which would increase the likelihood for competition in the estuary. Simenstad et. al. (1984) cautioned that the estuary condition may limit rearing production of juvenile Chinook, and many other studies have demonstrated the importance of the estuary to early marine survival and population fitness (Healey 1991; Miller et al. 2003). However, rivers such as the Columbia, with well-developed estuaries, are able to sustain larger ocean-type populations than those without (Levy and Northcote 1982). Although research has demonstrated possible density-dependent competition mechanisms in other estuarine environments (Skagit River, WA, Sixes River, OR), the importance of density dependence in the lower Columbia River and estuary has not been determined.

Estuaries may be “overgrazed” when large numbers of ocean-type juveniles enter the estuary en masse (Reimers 1973, Healey 1991). The intensity and magnitude of competition in estuaries depends partially on the residence time of hatchery and natural juvenile salmonids. Duration of estuary use probably depends partially upon fish size at arrival (Chapman et al. 1994). Some workers (Reimers 1973, Neilson et al. 1985) have suggested that the amount of time spent in estuaries may relate to competition for food; that estuarine residence time increases with increased competition, because fish take longer to reach the threshold size needed for successful ocean entry. Thus, if large numbers of hatchery fish are present in the estuary, growth and survival of wild fish could be reduced (Chapman et al. 1994). In contrast, Levings et al. (1986) reported that the presence of hatchery Chinook salmon did not affect residency times and growth rates of wild juveniles in a British Columbia estuary and that hatchery fish used the estuary for about half the time that wild fry were present (40-50 days).

Natural populations of salmon and steelhead migrate from natal streams over an extended period (Neeley et al. 1993, Neeley et al. 1994); consequently, they also enter the estuary over an extended period (Raymond 1979). Hatchery fish are generally—but not always—released over a shorter period, resulting in a mass emigration into natural environments. In recent years, managed releases of water, commonly called water budgets, have been used to aid mass and fast migration of hatchery and wild smolts through the migration corridor. Decisions regarding the mode of travel in the migration corridor (i.e., in-river migration or collection/transportation) are made by managers to expedite movement of smolts to the estuary (Williams et al. 1998). Water budget management, combined with large releases of hatchery fish, result in large numbers of juvenile salmon and steelhead in the estuary during spring months when the estuary productivity is low.

Ocean Conditions — There has been a general consensus that most density-dependent mechanisms at sea, if they occur, probably take place within the first few weeks after smolts enter the ocean (Gunsolus 1978, Peterman 1982, 1987, Fisher and Pearcy 1988, Beamish et al. 2004). Factors which may contribute to competition in the ocean include: hatchery-reared fish that successfully forage upon reaching the ocean (Paszkowski and Olla 1985a, 1985b), food production in the ocean varies in time and space (Healey and Groot 1987), migratory salmonids remain in fairly cohesive groups (Pearcy 1984), and migration routes of different stocks and species may overlap (Steward and Bjornn 1990). Therefore, competition is possible between hatchery and wild fish in the ocean, particularly in nearshore areas (Peterman and Routledge 1983, Peterman 1989, and Emlen et al. 1990) and especially during periods of low ocean productivity (Steward and Bjornn 1990). McCarl and Rettig (1983) found evidence for density-dependent mortality in the area referred to as the Oregon Production Index Area (OPIA) which includes the Pacific coastal water bounded on the north by Leadbetter Point, Washington, south to Monterey Bay, California. They suggested that variability in smolt survival increased with the number of smolts, and hatchery smolts should be limited if the stability of fisheries was an important goal. However, Nickelson (1986) challenged these claims, suggesting that wild and hatchery fish do not occur together at sea and that there is no evidence supporting density-dependent mortality at sea. Witty et al. (1995) suggest that nearshore density-dependent mortality may occur when large numbers of hatchery juveniles are present during years of low ocean productivity.

Density interactions also may occur at sea away from nearshore areas. Several researchers have reported indications that oceanic carrying capacity can be taxed, with feed-back density effects in salmon populations (Chapman and Witty 1993). Adult size tends to decline in large populations of Fraser River pink salmon. Peterman (1987) noted that the average weight of pink salmon was less during years of larger hatchery populations. Chum salmon culture programs in Japan suggested the presence of density-dependent production limitations, expressed in mean size of adult fish produced as mass enhancement efforts proceeded (Kaeriyama 1989). Eggers et al. (1983) found that mean length of sockeye in Bristol Bay related inversely to magnitude of the return. Eggers et al. (1983) noted that the effect of density-dependent growth was reduced in years of higher ocean temperatures, suggesting that temperature effects moderated depression of growth in years of high fish density. Peterman (1987) reported that density-dependent processes, associated with available food during early ocean rearing, can reduce fish size. Taken together, these studies indicate a strong potential for oceanic competition between hatchery and wild salmon.

Disease

Hatchery programs often succeed or fail depending upon success in controlling pathogens. Types, abundance, and virulence (epidemiology) of pathogens and parasites in hatchery fish are generally known, but less is known about diseases and parasites in natural fishes of the Columbia River basin or the vectors and amounts of disease transmitted from hatchery to wild fish (Steward and Bjornn 1990). Hatchery fish are always confined to some degree, which creates opportunities for epizootic outbreaks. Often, but not always, hatchery fish are infected by pathogens in the hatchery water supply or by natural fish entering the hatchery. Regardless of control measures, hatcheries release some fish infected with pathogens and parasites although every attempt is made by hatchery managers and biologists to minimize release of impaired fish to the natural environment.

Disease is thought to result in significant post-release mortality among hatchery fish, being either directly responsible for mortality or predisposing fish to mortality from other causes (Steward and Bjornn 1990). Steward and Bjornn (1990) found little evidence to suggest that the transmission of disease from infected hatchery fish to wild salmonids is widespread. However, there has been little research on this subject, and since most disease-related losses probably go undetected, researchers have concluded that the full impact of disease on stocks is probably underestimated (Goede 1986, Steward and Bjornn 1990). Increasing fish abundance through the release of large numbers of hatchery fish could alter normal population mechanisms and trigger outbreaks of pathogens in natural fish, both in tributary rearing areas and in mainstem migration corridors. McMichael et al. (2000) reported that disease incidence in cohabiting hatchery and wild fish increased with temperature and was likely influenced by the stress of interaction. Disease management practices as outlined bythe Integrated Hatchery Operations Team (IHOT) and the Pacific Northwest Fish Health Protection Committee have reduced the abundance and virulence of pathogens in hatchery populations.

Box 3-18 Hatchery-related Disease Limiting Factors

- Disease spread within hatchery fish and to wild fish,
- Increased likelihood and virulence of epizootics, and
- Altered population mechanisms and increased stress.

Predation

The two primary predator-prey relationships that can result from hatchery and wild fish interactions include predation by hatchery fish on natural fish and the functional response of non-salmonid fish preying on natural fish as a result of increased numbers of hatchery and natural salmonids. Predator-prey interactions between hatchery steelhead and naturally produced salmon has been identified as a concern (Chapman and Witty 1993). Hatchery Chinook salmon predation on wild Chinook salmon has been reported by Sholes and Hallock (1979). Fresh (1997) cited several studies that indicated hatchery coho, steelhead, and Chinook preyed on wild fry of conspecifics as well as pink and chum fry.

Residualism of hatchery salmon and steelhead is common (McMichael et al. 2000). Cannamela (1992) assumed total residualization rates of 10-25% based on Partridge (1985, 1986) and Chrisp and Bjornn (1978). Residual steelhead commonly exceed 10 in (250 mm) TL in Columbia River basin migration corridors, a threshold size at which piscivorous behavior of steelhead or rainbow trout increases markedly (Ginetz and Larkin 1976, Parkinson et al. 1989, Horner 1978, Partridge 1985,1986, Beauchamp 1990). Recent hatchery management practices to address residualism concerns include targeting the size at release of steelhead to a range of 185-220 mm. The construction of dams and associated fish handling facilities and hatcheries have established places in the migration corridor where hatchery and wild smolts concentrate, thus greatly increasing the opportunity for predation. Creating reservoirs has increased the area of the river’s cross-section and decreased the velocity and turbidity of the flow, thus enhancing the efficiency of the predators (Junge and Oakley 1966).

Large concentrations of hatchery fish may adversely affect wild juveniles by stimulating functional responses from bird and non-salmonid fish predators (Steward and Bjornn 1990). In the Columbia basin migration corridor, this response is likely to occur at the head of reservoirs, at the face of dams, and at turbine spillway and bypass discharge areas. There is evidence that prey availability immediately below mainstem dams on the Columbia River affects predation rates by northern pikeminnow on juvenile salmonids (Petersen and DeAngelis 1992). Below McNary Dam, Vigg (1988) demonstrated that the predation rate of northern pikeminnow on juvenile salmonids increased with increased salmonid density to an asymptote at higher salmonid densities. Conversely, Cada et al. (1994) note that the importance of predation by northern pikeminnow and other predators at the Columbia River hydroelectric projects may be lessened by the possibility that many fish being consumed are hatchery smolts; they speculate that hatchery fish are more vulnerable than wild fish. Large numbers of hatchery fish may provide a swamping effect and reduce the predation on naturally produced salmonids.

Box 3-19. Hatchery-related Predation Limiting Factors

- Direct inter- and intra-specific predation of hatchery fish on wild fish,
- Increasing susceptibility to predators at structures, or
- Increased attraction of predators when large numbers of hatchery fish are mixed with wild fish.

Mixed Stock Harvest

Because hatchery and naturally produced salmon and steelhead are often captured in the same ocean and river fisheries, when hatchery production stimulates harvest effort, the catch of naturally produced fish can be increased as well. Since hatcheries provide an environment where the survival rate to smolting is much greater than in the wild, the proportion of returning adults needed to support the population is much less and, therefore, the targeted harvest rate has been at times much greater than the commingled wild populations can sustain. Thus, stimulating harvest has been a notable impact of hatchery programs on natural production (Hilborn 1992). Harvest managers have grappled with the challenge of regulating the fisheries so that surplus hatchery fish can be harvested without over-harvesting the wild fish that are intermixed in the same fishery.

Harvest management strategies focused on hatchery fish harvest were common practice for several species in the lower Columbia for many years (Flagg et al. 1995). Fishery strategies which maximized harvest of surplus hatchery fish were consistent with the mitigation objectives which established the hatchery programs. Current harvest management strategies have transitioned to minimize harvest of weak wild stocks to meet conservation objectives under ESA (see previous section on Fishing). Seasons are structured and regulated in an attempt to provide reasonable opportunity to harvest hatchery and healthy wild stocks within the limits of the weak stock management focus.

Selective harvest of adipose fin-clipped hatchery steelhead, coho, and spring Chinook, and release of unclipped wild fish, is now required in all lower Columbia and tributary sport fisheries. Full marking of hatchery-origin fall Chinook has recently been implemented and by 2011 all returns will be adipose fin-clipped and provide opportunities for selective fisheries. Wild fish harvest rates are also controlled by an annual structure of fishing seasons (see previous section on Fishing). The lower Columbia commercial fishery now uses tangle-net gear and on-board fish recovery boxes to enable release of wild spring Chinook and retention of adipose fin-clipped hatchery spring Chinook. The commercial fishery is also regulated by time and area restrictions to focus harvest on hatchery coho while minimizing impacts on wild coho (see previous section on Fishing).

Box 3-20. Hatchery-related Harvest Limiting Factors

- Overharvest in mixed populations,
- Incidental catch in selective fisheries targeting hatchery fish, and
- Post-release mortality in selective fisheries targeting hatchery fish.

Passage

Hatchery collection facilities use weirs, ladders, and screens to block fish passage, capture fish for the collection of broodstock, and regulate numbers, stocks, and species of fish entering and passing above hatchery facilities. All weirs cause some degree of migration delay. Most weirs cannot accommodate upstream passage of large fish unless they are staffed to provide passage. Weir effectiveness can be limited by physical and biological constraints such as high water, cold or warm water temperatures, low flow, and/or staffing problems (Witty et al. 1995). Weirs operated to block fish passage for the purpose of collecting hatchery broodstock, or to implement supplementation programs, usually have specific operating criteria that vary facility-to-facility and year-to-year. Estimated production potential above weirs is usually known, and escapement may be allowed accordingly. Operating weirs to meet escapement and hatchery production goals is often a challenge (Witty et al. 1995).

Hatchery fish ladders have the potential to block or delay natural fish passage. These impacts can vary from very significant to insignificant depending on: numbers or proportion of the run affected, quantity and quality of habitat above the ladder, and impacts on life history characteristics (Witty et al. 1995).

Problems with inadequate screening at hatcheries can be divided into two categories: screen systems that fail to keep natural fish out of hatchery facilities and screen systems that fail to keep hatchery fish out of natural environments. The impacts of natural fish entering hatchery facilities are: 1) removing natural fish from their natural environment, 2) exposing natural fish to disease and predation in hatchery environments, 3) introducing disease from natural fish to the hatchery environment, 4) natural fish in environments unsuited for their survival, and 5) releasing natural fish in environments which will result in changing biological balance, changing genetics of endemic stocks, or otherwise upsetting management objectives.

Some possible impacts of hatchery fish escaping into natural environments are: 1) introduction of non-endemic species or stocks, 2) changing biological balance, changing genetics, or upsetting management objectives, 3) exposing natural fish to disease, competition or predation from hatchery fish, and 4) failing to meet hatchery program objectives.

The degree of impact may or may not be directly related to numbers of fish entering or leaving hatchery facilities, but potential impacts are related to fish numbers (i.e. when all hatchery fish escape as compared to a small number of hatchery fish escaping) (Witty et al. 1995).

Box 3-21. Hatchery-related Passage Limiting Factors

- Limitations to migratory access of wild spawners to upstream areas,
- Losses of wild fish into hatchery facilities, and
- Genetic, population, competition, or predation problems resulting from escape of hatchery fish.

Water Quality

General water quality effects resulting from the operation of hatchery facilities include potential impacts from water withdrawal and hatchery effluent. All hatcheries are required to comply with NPDES standards for clean water prescribed by Ecology. Many facilities have incorporated settling ponds that improve water quality discharges. Many fish hatcheries and satellite facilities divert natural stream flows upstream of hatchery facilities and return the water downstream of the hatchery. The volume of water removed varies according to fish production profiles in the hatchery. Withdrawal of natural stream flows results in a stream channel with reduced flow, no flow, or unnatural flow patterns. When evaluating impacts of water withdrawal on natural fish and their environments, one should consider whether fish passage or homing is affected, and/or fish production is significantly affected.

Making these evaluations requires knowledge of life history characteristics and population dynamics of affected natural fish and comparing this information to measured area affected by water withdrawal, time of year when water is withdrawn, percent of flow withdrawn, and location where water is returned. The impact of hatchery water withdrawal requires an examination of past, present, and proposed operations at each hatchery (Witty et al. 1995).

Hatchery effluent may contain organic waste, chemicals, fish pathogens, and warmer or cooler water. The main forms of wastes in hatchery effluent are suspended solids and dissolved nutrients; especially nitrogen and phosphorus (Pillay 1992). In measuring the impacts of effluent one should consider (Witty et al. 1995) pounds of fish produced, effluent treatment facilities, rate of dilution in the recipient waters, quality of water entering the hatchery, and water quality standards set by state and federal regulations.

The nature and extent of chemical use in hatcheries depends on the locality, species of fish reared, nature and intensity of culture operations, and the frequency of disease occurrence (Pillay 1992). There is a potential for harmful effects of chemicals in natural environments. If chemicals used in hatcheries are deemed safe by the Food and Drug Administration, their dispersal into natural environments should be considered safe. The level of impact from discharged hatchery effluent on fish survival is unknown, but is presumed to be small and localized at outfall areas, as effluent is diluted downstream (NMFS 1995). Hatchery facilities that rear greater than 20,000 lbs annually must obtain state and federal pollution discharge (NPDES) permits that set limits on the release of effluent from the facilities.

Hatchery effluent may increase populations and virulence of indigenous pathogens. Virulent pathogens are usually associated with epizootics in natural populations, whereas facultative pathogens tend to emerge as causes of epizootics in cultured populations (Pillay 1992). Despite the absence of conclusive evidence of major infections of wild stocks from aquaculture, very little research has been done to define the role of aquaculture in the outbreak of diseases in natural fish (Pillay 1992). Agencies use guidelines outlined by the Pacific Northwest Fish Health Protection Committee (PNFHPC) to control fish pathogens in hatchery effluent.

Some hatcheries heat or cool water to control embryo development, although the amount of water treated usually is not great. If the water temperature in the natural environment is changed, adverse impacts on natural fish could occur (Witty et al. 1995).

Box 3-22. Hatchery-related Water Quality Limiting Factors

- Withdrawals of stream water, reducing available spawning and rearing habitat,
- Misdirected homing responses at hatchery outfalls, and
- Releases of water that is altered by organic loads, chemicals, pathogens, temperature.

3.6.3. Threats

The impact of hatchery fish on each wild population depends on the variety and extent of hatchery practices implemented in the watershed. The effects can range from simple exposure to a few planted fry mixed with wild fry in a natural stream, to overwhelming releases of millions of fry or smolts. In particular, hatchery programs based on hatchery broodstock lines, and which allow the hatchery products to interact intensively with natural populations, almost certainly impose a large cost on the affected natural populations. Many hatcheries have been founded with broodstock from other hatcheries and most hatchery populations have been affected to some degree by transfers between hatcheries to fill quotas in years of low adult returns. Hatchery or fish-management practices that increase straying of hatchery fish upon return continue to reduce diversity and fitness in locally adapted populations. Hatchery practices have been under scrutiny and study for decades. Many standard, detrimental practices have been curtailed, but others have not. The hatchery practices that continue to threaten the rebuilding, viability, and productivity of wild salmon are:

- Large releases of hatchery fish,
- High survival of less fit individuals (mass production in large hatcheries),
- Numerical predominance of inferior hatchery fish over wild in planned or de facto supplementation/augmentation programs,
- Population mixing (stock transfers),
- Broodstock collection (reducing the number of spawners in the wild),
- Artificial selection by hatchery personnel,
- Disease,
- Fishing effects on wild fish mixed with abundant hatchery fish,
- Lack of diversion screens or screens that do not meet current federal standards, and
- Blocked habitat at hatchery facilities.

3.6.4. Impact Assessment

Hatchery impacts on wild populations can be complex, consisting of a mixture of positive demographic and negative diversity and productivity effects. Effects of many factors are poorly understood and not amenable to quantification. For impact analyses included in this Plan, estimates of hatchery impacts are limited to the negative effects of hatchery domestication and selection on wild population fitness. Fitness is defined here in terms of productivity relative to the inherent value of each wild population in the absence of current or historical hatchery effects. Fitness effects are among the most significant effects of hatcheries and have been estimated for lower Columbia populations in the system-wide hatchery reform review by the Hatchery Scientific Review Group (HSRG 2009).

Estimated impacts of hatchery spawners on productivity of the naturally-spawning population were related to the proportion of the naturally-spawning population comprised of hatchery-origin spawners (pHOS). Population-specific estimates of hatchery fractions are typically based on spawning ground survey data. Hatchery fish may be distinguished from marks (e.g. adipose fin clips) or tags (e.g. coded-wire tags). Future impact analyses will also consider proportionate natural influence (PNI) which reflects the effects of integrating natural-origin broodstock into hatchery programs.

Estimated impacts of hatchery spawners on productivity of the naturally-spawning population were also related to the productivity of naturally-spawning hatchery-origin fish. Fitness effects of naturally spawning hatchery fish are a function of the hatchery stock of origin, degree of domestication, and the number of generations of influence. Source stocks can have a large impact on fitness which is typically less for fish originating from out-of-basin stocks and generally decreases in proportion to distance from the local population. The ability of hatchery fish to spawn successfully and survival of their progeny in nature is also related to the proportion of natural-origin spawner incorporated into the hatchery broodstock on a regular basis. Relative fitness of current natural and hatchery populations reflects the history of hatchery influence of the wild population and of natural influence of the hatchery population.

Direct estimates of the relative fitness of hatchery and wild spawners are not available for most populations but were inferred in the HSRG analysis from local hatchery program practices based on representative values reported in the scientific literature. Published information on relative fitness of hatchery and wild fish is limited (Berejikian and Ford 2003, TOAST 2004) but generally ranges from under 50% for non-local stocks to 50-90% for local stocks depending on the degree of domestication or selection. Reisenbichler & McIntyre (1977) reported relative survival rates of Deschutes wild and Round Butte hatchery steelhead from egg to migration of 78% for H:H pairs, 80% for H:W pairs and 86% for W:W pairs. Differences are equivalent to a 91% relative fitness of Round Butte hatchery fish which were only a few generations removed from the wild. In the Kalama River, Chilcote et al. (1986) reported a 28% relative fitness of Kalama wild summer and Skamania hatchery summer steelhead based on smolt production. This large reduction in fitness was likely driven by the high degree of domestication in the Skamania hatchery steelhead stock. Even larger differences become apparent where the hatchery stock is substantially different than the wild stock. For instance, a relative fitness of 0% was reported by Kostow et al. (2003) for a Skamania summer steelhead in Clackamas River relative to the native winter run. Finally, Oosterhout & Huntington (2003) assumed a 70% relative fitness for coastal Oregon hatchery and wild coho based on a recommended range of 0.5 to 0.9 by a technical scientific panel.

The HSRG analysis distinguished between two general hatchery management strategies for reducing wild population risk. An integrated program is intended to maintain the genetic characteristics of a local, natural population among hatchery-origin fish by minimizing the genetic effects of domestication (HSRG 2009). This is expected to reduce the genetic risks that the hatchery-origin fish may pose to the naturally spawning population. The intent of a segregated hatchery program is to reduce genetic and ecological risk by maintaining a genetically distinct hatchery population. For instance, population segregation might be achieved with differences in spawn timing which reduce the potential for interbreeding. Respective impacts of integrated versus segregated hatchery programs may be evaluated based on proportionate natural influence (PNI) and proportion hatchery origin spawners (pHOS).

Because this Recovery Plan was primarily concerned with risk, the impact assessment did not consider positive demographic benefits. The assessment also did not consider the effect of ecological interactions between hatchery and wild fish because of the large degree of uncertainty in the nature and scale of these interactions. The net effect of direct and indirect ecological interactions may be either positive or negative and the occurrence and significance of each interaction difficult to determine. Consequently, total hatchery impacts including benefits and detriments may be greater or less

Hatchery contributions to natural spawners and associated impacts vary substantially from species to species and population to population (Figure 3-30, Table 3-8). Impacts are most pervasive for spring Chinook, fall Chinook, and coho with natural productivity estimated to have been reduced by 40-50% for the majority of the populations. Hatchery-origin spawners may comprise 30-100% of the natural spawners for many of these populations. Hatchery-origin natural spawners and hatchery impacts were low for most chum populations and the single late fall Chinook population in Washington. Hatchery impacts on summer and winter steelhead populations varied from very low to high. Maximum impacts due to a high incidence of hatchery-origin natural spawners and significant domestication of the hatchery stock were limited to 50% by the HSRG analysis except in a few populations with a high incidence of out-of-basin strays (e.g. upper gorge coho). Long term effects of even a relatively low hatchery contribution were estimated by the HSRG to significantly depress natural population productivity where the hatchery stock had significantly diverged from the wild population over time. For instance, a 3% incidence of hatchery-origin spawners in the Coweeman fall Chinook population was estimated to reduce natural population productivity by 23%.

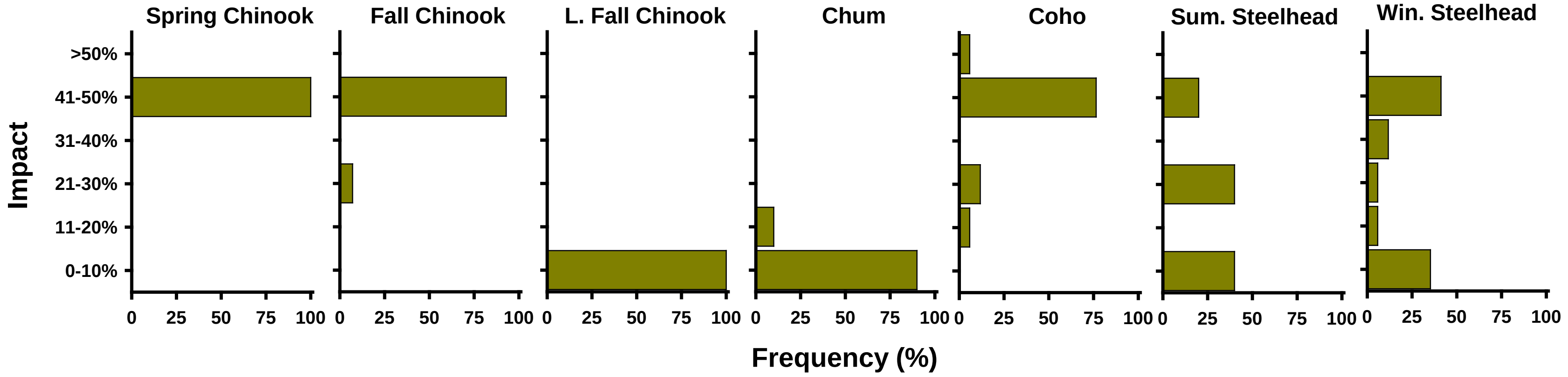

Figure 3-30. Frequency distribution of hatchery impacts by species and life history type for Washington lower Columbia River salmon and steelhead populations.

Table 3-8. Proportion of hatchery-origin spawners in wild production areas (pHOS) and estimated hatchery fitness-related reduction in productivity of natural population (Imp.) for Washington lower Columbia River populations (HSRG 2009).

Populations	Chinook						Chum		Coho		Steelhead			
	Spring		Fall		Late Fall						Summer		Winter	
	pHOS	Imp.	pHOS	Imp.	pHOS	Imp.	pHOS	Imp.	pHOS	Imp.	pHOS	Imp.	pHOS	Imp.
Grays-Chinook	--	--	0.46	0.50	--	--	0.54	0.11	0.25	0.50	--	--	0.01	0.08
Eloch-Skam	--	--	0.61	0.50	--	--	0.03	0.03	0.65	0.50	--	--	0.06	0.34
Mill-Ab-Germ	--	--	0.18	0.49	--	--	0.03	0.03	0.03	0.50	--	--	0.00	0.01
Cowlitz L	--	--	0.29	0.50	--	--	0.02	0.02	0.59	0.50	--	--	0.18	0.49
Cowlitz U	0.36	0.50	0.29	0.50	--	--	--	--	0.59	0.50	--	--	0.18	0.49
Cispus	0.36	0.50	--	--	--	--	--	--	0.59	0.50	--	--	0.18	0.49
Tilton	0.36	0.50	--	--	--	--	--	--	0.59	0.50	--	--	0.18	0.49
Toutle NF	0.36	0.50	0.35	0.50	--	--	--	--	0.58	0.50	--	--	0.05	0.33
Toutle SF	--	--	--	--	--	--	--	--	0.58	0.50	--	--	0.04	0.24
Coweeman	--	--	0.03	0.23	--	--	--	--	0.03	0.20	--	--	0.02	0.12
Kalama	0.62	0.50	0.67	0.50	--	--	0.00	0.01	0.60	0.50	0.04	0.01	0.08	0.02
Lewis NF	0.34	0.50	--	--	0.01	0.05	0.01	0.01	0.66	0.24	0.12	0.47	0.20	0.49
Lewis EF	--	--	0.41	0.50	--	--	--	--	0.03	0.21	0.04	0.26	0.14	0.48
Salmon	--	--	0.55	0.50	--	--	0.01	0.01	0.63	0.50	--	--	0.30	0.50
Washougal	--	--	0.55	0.50	--	--	0.01	0.01	0.63	0.50	0.05	0.30	0.01	0.08
Gorge L	--	--	0.50	0.50	--	--	0.00	0.01	0.65	0.50	--	--	0.00	0.01
Gorge U (incl. Wind)	--	--	1.00	0.50	--	--	0.00	0.01	0.75	0.75	0.00	0.01	0.00	0.01
White Salmon	--	--	0.81	--	--	--	--	--	--	--	--	--	--	--

3.7. Ecological Interactions

3.7.1. Background

Ecological interactions refer to the relationships of salmon and steelhead with other elements of the ecosystem. These include effects of non-native species, food web relationships, and native predators of salmon. Ecological interactions of hatchery and natural fish populations are addressed in the hatchery strategy chapter.

3.7.2. Limiting Factors

Non-native Species

The nature of non-native species introductions in the lower Columbia River are changing from the historical intentional introduction of game or food fish species to the unintentional introduction of species that have unknown or negative impacts on the ecosystem. Currently, there is an increasing rate of aquatic non-indigenous species introductions in the Columbia River; this increase has been attributed to the increased speed and range of world trade, which facilitates the volume, variety, and survival of intentionally or unintentionally transported species. Altered habitats in the Columbia River estuary and lower mainstem ecosystem as a result of hydrosystem development and water regulation have facilitated the successful establishment of aquatic non-indigenous species.

The current biotic community in the Columbia River estuary and lower mainstem is fundamentally different today than it was historically because of the introduction of exotic species. All exotic species introductions in the lower Columbia River represent permanent alterations of the biological integrity of the ecosystem for numerous reasons: impacts of introduced species are unpredictable, introduced species alter food web dynamics, and introduced species are a conduit for diseases and parasites. Although the list of known exotic species in the lower Columbia River is currently greater than 70, limited information is available regarding the ecological interactions of many of these species.

At least 37 exotic fish species are now found in the Columbia River estuary (Northwest Power and Conservation Council 2004). These include potential competitors with salmonids such as American shad and predaceous species such as smallmouth bass and walleye. American shad (*Alosa sapidissima*) populations have grown substantially since introduction into the Columbia River system in 1885 (Welander 1940, Lampman 1946). In recent years, 2-4 million adults have been counted annually at Bonneville Dam. The transition of the estuarine food web from a macro detritus to micro detritus base (i.e. increased importation of plankton from upstream reservoirs) has benefited zooplanktivores such as shad (Sherwood et al. 1990). While shad do not eat salmonids, they exert tremendous pressure on the estuary food web given the sheer weight of their biomass. Shad and subyearling salmonid diets may overlap, suggesting potential competition effects. Because of the abundance of American shad in the Columbia River system, studies have been launched to investigate species interactions between shad, salmonids, and other fish species such as northern pikeminnow, smallmouth bass, and walleye (Petersen et al. 2003). A pattern is slowly emerging that suggests the existence of American shad is changing trophic relationships within the Columbia River. Because of their abundance, consumption rates, and consumption patterns, American shad may have modified the estuarine food web. One study found that in the Columbia River estuary and lower mainstem, shad diet overlapped with subyearling salmonid diets, which may indicate competition for food. Juvenile shad and subyearling salmonids also utilize similar heavily vegetated backwater habitats (McCabe et al. 1983). Commercial harvest has been considered as a means to reduce the abundance of American shad in the Columbia River, but harvest has been restricted because the shad spawning run coincides with the timing of depressed runs of summer and spring Chinook, sockeye, and summer steelhead (ODFW and WDFW 2010).

Twenty-seven non-native invertebrate species have been observed in the estuary and documented by the Lower Columbia River Aquatic Non-indigenous Species Survey (Sytsma et al. 2004). Recent surveys have documented that the estuarine copepod community is dominated by two newly introduced Asian copepods (Santen 2004). In some cases, the abundance of non-native invertebrates can alter food webs through their wide distribution and key role in the food chain (Northwest Power and Conservation Council 2004).

The introduction of non-indigenous plants such as purple loosestrife, Eurasian milfoil, parrot feather, and Brazilian elodea has altered the estuary ecosystem. Exotic plant species often out-compete native plants, which results in altered habitats and food webs (Northwest Power and Conservation Council 2004). In addition to out-competing native plants, introduced plant species can contribute to poor water quality and create dense, monospecific stands that represent poor habitat for native species (Northwest Power and Conservation Council 2004). In turn, these new plant communities may alter insect and detritus production in and around vegetated wetlands. Exotic and/or invasive plants, such as reed canary grass, scotch broom, Japanese knotweed and Himalayan blackberry can out-compete native plants in riparian and wetland areas and significantly alter habitat-forming processes.

There is often little that can be done to eradicate exotic species once a population has been established. Future prevention of exotic species introductions is vital to maintaining the current balance of ecological relationships in the Columbia River estuary and lower mainstem.

Box 3-23. Non-native Species Limiting Factors

- Displacement of native prey species,
- Alteration of food web dynamics,
- Competition from non-native species, and
- Introduction of disease and parasites.

Food Web Effects

Salmon are a single part to a complex ecosystem; they provide a food source for other species, contribute nutrients to freshwater ecosystems, and effect habitat forming processes in freshwater systems. Salmon abundance affects, and is affected by, significant salmon predators and scavengers, such as bull trout and eagles. Large numbers of salmon returning to spawning streams introduce significant amounts of marine-derived nutrients into nutrient-poor freshwater systems. These nutrients stimulate primary and secondary productivity that in turn increases food abundance in the entire stream system, particularly for juvenile salmon. Additionally, salmon can affect physical habitat conditions, such as fine sediment removal during digging of salmon redds.

Box 3-24. Food Web Limiting Factors

- Reduction of marine-derived nutrients delivered to freshwater ecosystems via salmon carcasses.

Predation

Significant numbers of salmon are lost to fish, bird, and marine mammal predators during migration through the mainstem Columbia River. While some predation by fish occurs at dam tailraces and juvenile bypass outfalls, by far the greatest numbers of juveniles are consumed in other portions of the river. Predation likely has always been a significant source of mortality but has been exacerbated by anthropogenic habitat changes. Piscivorous birds congregate near dams and in the estuary around man-made islands and consume large numbers of emigrating juvenile salmon and steelhead (Roby et al. 1998). Caspian terns, cormorants, and gull species are the major avian predators (NMFS 2000a). Native fishes, particularly northern pikeminnow, prey on juvenile salmonids. Habitat and predation losses for piscivorous fishes including northern pikeminnow have increased as a result of habitat changes. Marine mammal's predation on adult salmon has become an increasing source of concern with increasing numbers and concentrations below Bonneville Dam in recent years.

Birds: As a result of estuary habitat modifications, the number and/or predation effectiveness of Caspian terns, double-crested cormorants, and a variety of gull species has increased (Fresh et al. 2005). These birds congregate near dams and in the estuary around man-made islands where they consume large numbers of out migrating juvenile salmon and steelhead (Roby et al. 1998). In 1997 it was estimated that avian predators consumed 10 to 30 percent of the total estuarine salmonid smolt production in that year (Northwest Power and Conservation Council 2004). Collis and Roby (2006) estimated that 3.6 million juvenile salmonids were consumed by terns in 2005. Stream-type juvenile salmonids are most vulnerable to avian predation by Caspian terns because the juveniles use deep-water habitat channels that have relatively low turbidity and are close to island tern habitats. Double-crested cormorants consume a similar number of juvenile salmonids (approximately 3.6 million juveniles) from their East Sand Island nesting grounds (Collis and Roby 2006).

Caspian terns are native to the region but were not historically present in the lower Columbia River mainstem and estuary; they have recently made extensive use of dredge spoil habitat and are a major predator of juvenile salmonids in the estuary. The terns are a migratory species whose nesting season coincides with salmonid outmigration timing. Since 1900, the tern population has shifted from small colonies nesting in interior California and southern Oregon to large colonies nesting on dredge spoil islands in the Columbia River and elsewhere (NMFS 2000c). Many of these Columbia River dredge spoil islands were created as a result of dredging the navigational channel after the eruption of Mt. St. Helens in 1980 although Rice Island was initially constructed from dredge spoils around 1962 (Geoffrey Dorsey, USACE, personal communication). Caspian terns did not nest in the estuary until 1984 when about 1,000 pairs apparently moved from Willapa Bay to nest on East Sand Island. Those birds (and others) moved to Rice Island in 1987 and the colony expanded to 10,000 pairs. Diet analysis has shown that juvenile salmonids make up 75% of food consumed by Caspian terns on Rice Island. Roby et al. (1998) estimated Rice Island terns consumed between 6.6 and 24.7 million salmonid smolts in the estuary in 1997, and that avian predators consumed 10-30% of the total estuarine salmonid smolt population in that year. However, there are no data to compare historical and modern predation rates or predator populations. Further, current predation studies are limited because of the unknown effects hatchery rearing and release programs have had on salmon migration behavior and predator consumption. Nevertheless, evidence suggests that current predator populations could be a substantial limiting factor on juvenile salmon survival (Bottom et al. 2005). Ryan et al. (2003) estimated species-specific predation by Caspian terns from 1988-2000; predation by Caspian terns was consistently highest on steelhead (9.4-12.7%) and consistently lowest on yearling Chinook salmon (1.6-2.9%) while predation on coho salmon was intermediate (3.6-4.1%).

Recent management actions have been successful in discouraging Caspian tern breeding on Rice Island while encouraging breeding on East Sand Island, which may decrease predation on juvenile salmonids. However, estimates of potential decreases in salmonid mortality from reduced tern predation assume that there is no compensatory mortality later in the life cycle (Fresh et al. 2005). This assumption may not be realistic; as Roby et al. (2003) hypothesized that tern predation was 50% additive. Thus, actual improvements in juvenile salmonid survival resulting from management actions that reduce tern predation would likely be lower than current estimates (Fresh et al. 2005).

Fishes: Fishes, including northern pikeminnow, walleye, and smallmouth bass, prey on juvenile salmonids. In the lower Columbia mainstem, pikeminnow have been estimated to consume up to 9.7 million juvenile salmon per year (Table 3-9).

Table 3-9. Projected abundance of northern pikeminnow, salmonid consumption rates, and estimated losses of juvenile salmonids to predation (NMFS 2000b).

Location	Length (km)	Number of pikeminnow	Consumption Rate (smolts/predator day)	Estimated Losses (millions/year)
Estuary to Bonneville Dam	224	734,000	0.09	9.7
Bonneville Reservoir	74	208,000	0.03	1.0

Pikeminnow numbers likely have increased as favorable slack-water habitats have been created by impoundment and flow regulation. Although pikeminnow have always been a significant source of mortality for juvenile salmonids in the Columbia River, changes in physical habitats may have created more favorable conditions for predation (Northwest Power and Conservation Council 2004). In unaltered systems, for example, salmonid smolts are suspended in the water column away from the bottom and shoreline habitats preferred by pikeminnow. However, dam passage has disrupted juvenile migratory behavior and provided low-velocity refuges below dams where pikeminnow now gather and feed on smolts (Friesen and Ward 1999). The diet of the large numbers of pikeminnow observed in the forebay and tailrace of Bonneville Dam is composed almost entirely of smolts. Pikeminnow also concentrate at dam bypass outfalls and hatchery release sites to prey on injured or disoriented fish, and pikeminnow eat many healthy smolts as well. Predation rates on salmonids are often much lower in areas away from the dams, although large numbers of predators in those areas can still impose significant mortality.

In 1990, responding to observed predation problems, a pikeminnow management program was instituted that pays rewards to anglers for each pikeminnow caught and retained over a prescribed size. Through 2001, over 1.7 million pikeminnow had been harvested, primarily in a sport reward fishery. Modeling results project that potential predation on juvenile salmonids by northern pikeminnow has decreased 25% since fishery implementation (Friesen and Ward 1999, NMFS 2000a). By paying only for pikeminnow over a certain size, the program takes advantage of their population characteristics—they are relatively long-lived and only the large individuals are fish predators. Relatively low exploitation rates of only 10-20% per year compound over time to substantially reduce pikeminnow survival to large predaceous sizes.

Walleye are voracious predators of fishes, including juvenile salmonids. On a fish-per-fish basis, walleye are as damaging as pikeminnow, but walleye are considerably less abundant and consume fewer juvenile salmonids (e.g. Rieman et al. 1991). Originally introduced into the upper Columbia basin, walleye gradually have spread downstream throughout the lower mainstem since the 1970s. Significant numbers of walleye have become established in Bonneville Reservoir and between Bonneville Dam and the estuary. Walleye population sizes are quite variable and driven by periodic large year classes that occur during warm, low flow springs. Walleye are subject to a small, directed sport fishery but were not included in the sport reward fishery because projected exploitation effects on salmonids were low. Unlike pikeminnow, most walleye predation occurs in smaller individuals not readily caught by anglers and unaffected by the compounding effects of annual exploitation.

Other introduced fishes—including smallmouth bass and channel catfish—also have been found to consume significant numbers of juvenile salmonids. However, these species are more significant problems in upstream areas than in the lower river where their abundance is low.

Marine mammals: Harbor seals, Steller sea lions, and California sea lions all prey on salmon and steelhead in the lower Columbia River mainstem and estuary (Northwest Power and Conservation Council 2004). Seals and sea lions are common in and immediately upstream of the Columbia River estuary and increasing concentrations have been observed below Bonneville Dam in recent years. Large pinniped populations were historically present in the Columbia River. Their numbers were greatly reduced beginning in the late 1800s by hunting (including bounty hunters) and a formal harassment program. These mammals can be troublesome to sport and commercial fishers by taking hooked or net-caught fish before they can be landed. Their numbers have significantly increased since the Federal Marine Mammal Protection Act (FMMPA) was adopted in 1972. Seals and sea lions are regularly reported to prey on adult salmon and steelhead, although diet studies indicate that other fish comprise the majority of their food. Large numbers of pinnipeds might translate into significant salmon mortality despite this occasional use. However, current marine mammal predation may be proportionally more significant, since all sources of mortality on depressed stocks become more important.

Box 3-25 Predation Limiting Factors

- Juvenile losses to birds and fish,
- Adult losses to marine mammals,
- Reduced juvenile salmonid food base,
- Limitations on freshwater productivity,
- Competition for food in freshwater and the estuary,
- Decreased fitness, and
- Reduced survival.

3.7.3. Threats

Non-native Species

Increases in global trade, interstate recreation, and residential aquarium interests have all increased the predominance of aquatic non-indigenous species in lower Columbia River species assemblages. Introductions of aquatic non-indigenous species represent permanent alterations of the biological integrity of the ecosystem for numerous reasons: impacts of introduced species are unpredictable, introduced species alter food web dynamics, and introduced species are a conduit for diseases and parasites. The current biotic community in the Columbia River estuary and lower mainstem is fundamentally different today than it was historically because of the introduction of exotic species. Some species introductions have been intentional, while others have been unintentional. Additionally, habitat changes in the Columbia River estuary and lower mainstem, as a result of hydrosystem development and water regulation, may facilitate the successful establishment of aquatic non-indigenous species. Examples of actions that threaten salmonids are:

- Purposeful game fish introduction for recreational purposes,
- Competition for food and space (American shad/juvenile salmonids), and
- Lack of regulatory control to prevent unintentional introductions via ballast water or other transportation mechanisms.

When ships release ballast water, non-indigenous species can enter receiving waters. In the Columbia River estuary, ship ballast practices have been responsible for the introduction of at least 21 exotic species, many of them from Asia (Sytsma et al. 2004). Populations of the New Zealand mud snail and non-native copepods have established themselves in reaches of the estuary, and the Asian bivalve Corbicula fluminea has expanded its range, with densities of up to 10,000 per m^2 in some areas (Northwest Power and Conservation Council 2004). Ship ballast practices affect salmonids by:

- Introducing invertebrates that disrupt food webs and out-compete juvenile salmonids' native food sources.

Food Web

Salmon serve as both predator and prey in a complex ecosystem. Additionally, decaying adult salmon carcasses provide significant nutrients to freshwater ecosystems. Hatchery practices, such as large releases of hatchery fish over short periods, may increase the likelihood of density-dependent competition among juvenile salmonids in subbasins, the mainstem, and estuary. The significance of density-dependent limitations in the lower Columbia River is not clear. Continuing threats from these ecosystem relationships include:

- Actions that contribute to depressed spawning escapements,
- Decreased fitness from reduced food availability,
- Reduced survival, and
- Reservoir phytoplankton production.

Altered Predator/Prey Relationships

Although predation has always occurred in the estuary ecosystem, the cumulative effect of altered flows, changes in sediment transport processes and food sources, introduced species, hatcheries, upstream habitat impacts, hydroelectric impacts, and contaminants have recast estuary and plume environments such that predator/prey relationships have changed considerably. As a result, significant numbers of salmon are lost to fish, avian, and marine mammal predators during migration and residency in the estuary (Northwest Power and Conservation Council 2004). In addition, degraded conditions (loss of habitat and reduced food web productivity) in the Columbia River estuary and the timing of large hatchery releases may have increased the likelihood of mortality from competition (Northwest Power and Conservation Council 2004).

Pinniped predation on adult spring Chinook and winter steelhead continues to increase. Each spring about 1,000 Stellar sea lion males, 3,000 Pacific harbor seals, and 800 California sea lions take up residence in the lower estuary (Griffin 2006). From these, approximately 80 sea lions congregate at Bonneville Dam and feed on adult salmon, causing an estimated mortality of up to 3.6 percent of all spring Chinook and winter steelhead (USACE 2005). Although predation by pinnipeds in other portions of the estuary and plume has not been estimated, unsubstantiated reports suggest mortality of more than 10 percent of the entire adult spring Chinook and steelhead runs.

Caspian terns and double-crested cormorants in the Columbia River estuary have significantly increased in number, with measurable impacts on stream-type salmonids (Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers 2004). The population increases are attributed to the loss of habitat elsewhere in the world and creation of high-quality bird habitat in the estuary through deposition of dredge materials (Bottom et al. 2005).

Similarly, the new micro detritus-based food web in the estuary has benefited zooplanktivores such as American shad (an introduced species) (Northwest Power and Conservation Council 2004). Shad do not appear to compete directly with salmonids, but their biomass alone—more than 4 million returning adults a year—may have permanently altered food webs in the Columbia River. Catfish, walleye, and other introduced fish species that prey directly on juvenile salmonids also have capitalized on degraded conditions in the estuary, altering food web dynamics through predation and competition for food resources. The numbers of native pikeminnow—another predator of juvenile salmonids—likely have increased as favorable slack-water habitats have been created by impoundments and flow regulation.

Over the past 100 years, horticultural practices and more extensive travel and commerce in the Columbia River have increased the rate of introductions of non-native plants and invertebrates in the estuary. Non-native copepods and four plant species—purple loosestrife, Eurasian water milfoil, parrot feather, and Brazilian elodea—are of particular concern because they alter habitats and food webs in the estuary. Exotic plants can displace native plants to the point that animals that rely on native flora for food, nesting, or cover also are displaced (Northwest Power and Conservation Council 2004). Altered predator/prey relationships affect salmonids by:

- Increasing predation by native birds (Caspian terns, double-crested cormorants, and gull species),
- Increasing predation by native fish (northern pikeminnow),
- Increasing predation by native pinnipeds (Steller and California sea lions and harbor seals),
- Increasing predation by exotic fish (American shad, walleye, smallmouth bass, and catfish), and
- Allowing introduced invertebrates and exotic plants to become established.

3.7.4. Impact Assessment

Effects of non-native species on salmon, effects of salmon on system productivity, and effects of native predators on salmon are difficult to quantify. Strong evidence exists in the scientific literature on the potential for significant interactions, but the complex nature of relationships can confound estimation. Effects are often context- or case-specific. For instance, an introduced species might be a detriment in one area and have no impact in another area. Order-of-magnitude estimates can be derived for some predation impacts. Introduced species and food web effects are treated in this Plan as unquantifiable impacts that warrant consideration with substantive measures despite the inability to estimate the specific magnitude of there effects.

Predation impacts were based on approximate total mortality rates by northern pikeminnow, birds, and marine mammals. Detailed data on predation rates are limited, especially for marine mammals. However, anecdotal information is sufficient to generate approximate estimates that place this impact in perspective relative to other impact factors.

Estimates of pikeminnow predation on juvenile salmonids are available for the Columbia River mainstem (Ward et al. 1995, Friesen and Ward 1999). Pikeminnow are of particular concern because they are among the most common salmonid predators among fish. Current predation by pikeminnow is believed to be greater than historical rates because dams have created favorable habitat conditions for pikeminnow and for predation on salmonids by pikeminnow. Pikeminnow were estimated to consume approximately 9.7 million salmonids per year in the mainstem between Bonneville Dam and the estuary and an additional 1 million salmonids in Bonneville Reservoir (Beamesderfer et al. 1996). Assuming approximately 200 million juvenile salmon and steelhead are available in the lower river per year, pikeminnow predation translates into a rate of about 5% in the lower mainstem. Of this, approximately half occurs in the Bonneville Dam tailrace (Ward et al. 1995). The remainder was apportioned throughout the mainstem based on distance between the tributary mouth and the ocean. Bonneville Reservoir pikeminnow predation rate was calculated in a similar fashion (0.5%) with half assumed to occur in the Bonneville Forebay. The forebay rate was included for salmon populations originating in Bonneville Reservoir tributaries. Data were inadequate to estimate species differences in pikeminnow predation rates. Predation by other fishes, including walleye, was not considered separately, hence, gets subsumed into estimated natural mortality. Walleye are substantially less abundant than pikeminnow and data on predation rates were not available.

Estimates of current tern and cormorant predation were available from Roby et al. (1998), USFWS (2005), NOAA (2006), and Collis et al. (2007). Tern predation on juvenile salmonids on East Sand Island in 2006 ranged from 20% to less than 1%, with steelhead smolts being most susceptible to tern predation (Collis et al. 2007). Overall salmonid predation rates by terns and cormorants were similar but cormorants tended to prey equally on all species (Collis et al. 2007, NOAA 2006). For the purposes of this analysis, we assumed a tern predation rate of 6% for stream-type populations only. We assumed a 6% cormorant predation rate for both stream- and ocean-type populations. Predation by other bird predators or birds in other areas was much less (Collis et al. 2007) and was not addressed in the analysis because of lack of data.

Estimates of marine mammal predation on adult salmonids were based on reported population sizes, literature values for daily ration, and reported diet shares of salmonids as described in the Washington Recovery Plan (LCFRB 2004) and recent monitoring at Bonneville Dam (USACE 2005). Spring and fall predation mortality rates were estimated at 10% and 3% based on the following method. NMFS (2000) reported population sizes of about 2,000 in spring (1,700 harbor seals, 100-200+ sea lions). Fall population sizes were substantially less (1,000 total). Espenson (2003) quoted a daily ration equivalent to 1.2 – 2.0 salmon per day. To generate conservative minimum estimates, diet shares of 20% salmonids in spring NMFS (2000) and 50% salmonids in fall were applied to an assumed daily ration equivalent of 1 salmon per day. Fall diet shares were assumed to be greater than spring because of fewer alternative foods and switching to more abundant salmon. This resulted in per predator consumption rates of 0.2 salmon per day in spring and 0.5 salmon per day in fall. Spring mortality rates were based on 20,000 salmon eaten versus average spring run sizes of 200,000 adult salmonids. Fall mortality rates were based on 30,000 salmon eaten versus average fall run sizes of 1,000,000 adult salmonids. An additional 3% mortality on spring Chinook passing Bonneville Dam was assessed to account for increased vulnerability to predation and correspondingly higher predation rates.

Because of the assumptions required by these calculations, these predation rates should be considered with caution. However, site-specific predation rates suggested that a 3-13% annual loss rate to marine mammals was reasonable. Sea lion predation at Bonneville Dam has ranged from 0.4% in 2002 to 3.4% in 2006 (USACE 2005). These estimates did not account for predation downstream of Bonneville Dam, which have been projected to be as high as 10% (NOAA 2006).

Net effects of predation by birds, fish and pinnipeds were assumed to be multiplicative in nature due to the impact occurring at different salmon life stages:

$$\text{Rate}_{\text{total}} = 1 - ((1 - R_{\text{terns}}) * (1 - R_{\text{cormorants}}) * (1 - R_{\text{pikeminnow}}) * (1 - R_{\text{pinnipeds}}))$$

Where R = predator-specific mortality rate (fraction of the available salmonid population eaten).

Table 3-10. Approximate annual predation mortality rates on anadromous lower Columbia River salmonid populations.[1]

Species	Terns	Cormorants	Pikeminnow	Pinnipeds	Net
Spring Chinook	0.060	0.060	0.0525	0.130	0.272
Fall Chinook	0	0.060	0.0525	0.030	0.136
Chum	0	0	0	0.030	0.030
Coho	0.060	0.060	0.0525	0.030	0.188
Steelhead	0.060	0.060	0.0525	0.100	0.247

[1] Maximum rates – population-specific rates may be less depending on differences in exposure to predation.

3.8. Climate and Ocean Effects

3.8.1. Background

Biologists have only recently come to understand the importance of the ocean in the variation of salmon and steelhead numbers. Salmon management traditionally assumed relatively constant—or at least randomly variable—ocean conditions. After all, how could a water body so vast change from year to year? Anadromy was a tremendously successful life history pattern that traded high mortality over the long migration from freshwater to salt and back, against the large size and fecundity that could be gained in productive ocean pastures.

However, large fluctuations in smolt-to-adult survival over the last three decades have demonstrated that ocean conditions are much more dynamic than previously thought. We now understand that the ocean is subject to annual and longer-term climate cycles just as the land is subject to periodic droughts and floods. Land and ocean weather patterns are related and their combination drives natural variation in salmon survival and productivity as those seen in recent years (Hartman et al. 2000).

3.8.2. Limiting Factors

Ocean Productivity

Fluctuating ocean conditions and regional weather follow large-scale atmospheric pressure gradients and circulation patterns. The El Niño weather pattern produces warm ocean temperatures and warm, dry conditions throughout the Pacific Northwest. The La Niña weather pattern is typified by cool ocean temperatures and cool/wet weather patterns on land. Of the several indices that describe ocean conditions, the most widely known is the ENSO (Figure 3-31). It is based on sea surface temperatures in the Pacific Ocean off the coast of South America. The PDO is a similar index based on conditions in the north Pacific. The PDO often, but not always, tracks with the ENSO. ENSO episodes can have substantial short-term impacts on salmonid production, while the PDO has long term (decadal length) effects (Hare et al 1999).

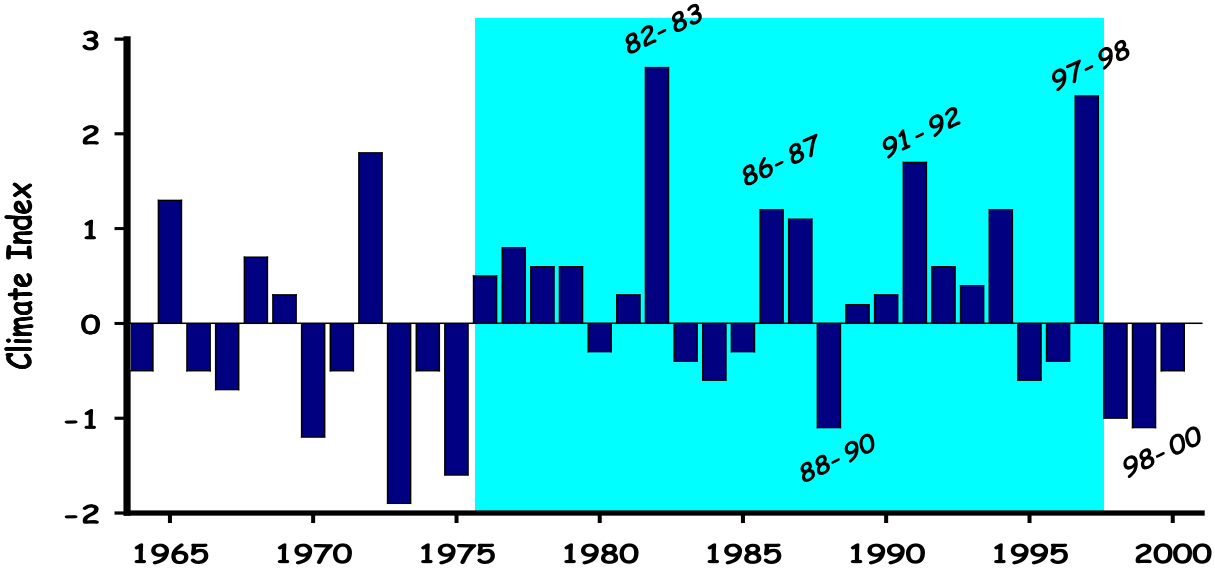

Figure 3-31. Annual variation in the multivariate El Niño southern oscillation (ENSO) index for December. Recent strong El Niño (positive values) and La Niña (negative values) years are labeled.

The PDO is a decadal or longer pattern of climate and oceanic conditions in the North Pacific Ocean associated with the Aleutian low pressure system. The PDO causes shifts in sea surface temperatures and plankton abundance on a decadal time scale (WDFW and PNPTT 2000, Mantua et al. 1997). The most recent shift occurred in 1977 (Ebbesmeyer et al. 1991), resulting in warmer coastal sea surface temperatures, cooler temperatures in the central Pacific Ocean, and more abundant plankton. The PDO regimes have been related to abundance patterns in zooplankton, and subsequent production of Alaskan pink and sockeye salmon (Hare and Francis 1999). The most recent PDO shift has been related to increases in production of pink, chum, and sockeye salmon in the North Pacific Ocean (Beamish and Bouillon 1993). It is possible that PDO effects on salmonid production can be more important than the shorter term ENSO-driven variation.

Annual weather patterns tend to occur in successive years rather than randomly. Thus, warm dry years tend to occur in close association with a higher than average frequency and cool wet years also tend to co-occur. Periods of warm, dry or cool, wet conditions are called regimes; transition periods are called regime shifts. Recent history is dominated by a high frequency of warm dry years, along with some of the largest El Niños on record—particularly in 1982-83 and 1997-98. In contrast, the 1960s and early 1970s were dominated by a cool, wet regime. The historical record reveals a long, irregular series of periodic regime shifts in ocean conditions. Many climatologists suspect that the conditions observed since 1998 may herald a return to the cool wet regime that prevailed during the 1960s and early 1970s.

Significant changes in oceanographic conditions are associated with El Niño/La Niña patterns. During El Niño, deep, warm, nutrient-poor layers of water push northward along the Oregon and Washington coasts. These layers block upwelling of cool nutrient-laden subsurface waters, which in turn reduces primary productivity by phytoplankton and secondary productivity by zooplankton. Juvenile salmon reaching the ocean find limited food resources and this reduces their growth and survival. Unproductive El Niño conditions also affect bird and pinniped survival and productivity. For instance, Welch et al. (1997) noted widespread mortality of northern fulmars (an offshore seabird) from Oregon to Vancouver Island with substantial numbers of starving birds washing ashore in the winters of 1994 and 1995. In addition, warm waters bring large numbers of predaceous mackerel, tuna, and even marlin into Northwest waters to further reduce salmon survival prospects. In contrast, La Niña conditions are associated with strong upwelling of cool nutrient-rich water, high productivity along the Oregon and Washington coasts, and good growth and survival of Northwest salmon stocks.

El Niño produces the opposite effect on productivity in the North Pacific off Canada and Alaska. Northern salmon stocks in Alaska generally appear to benefit from improved ocean productivity and increased smolt-to-adult survival rates during warm, dry periods (Downton and Miller 1998, Hare et al. 1999). Physical and biological domains in the North Pacific are divided by a transition zone called the Subarctic Front (Figure 3-32). Shifts in the location and structure of this front associated with ocean climate patterns drive differences in salmonid predator abundance and food resources in the North and Far North Pacific (NMFS 1996, Percy 1992). High atmospheric pressure along the Pacific Northwest coast during El Niño years is associated with low pressure off the Aleutian Island chain that increases upwelling in the Gulf of Alaska and provides very productive conditions for Alaska salmon. Pacific Northwest and Alaska salmon survival is thus inversely correlated: when ocean conditions are good in the Pacific Northwest, they tend to be poor in Alaska. When Alaska salmon returns are high, Pacific Northwest salmon returns are typically low.

Climate effects on ocean productivity can be compounded by related effects in freshwater. In the Pacific Northwest, cool, wet patterns that improve ocean survival and growth also increase precipitation, increase streamflow, and reduce temperature which provide favorable spawning, rearing and migration conditions for salmonids. Conversely, salmon productivity is reduced by low flows and warm temperatures during drought years that are often associated with El Niño.

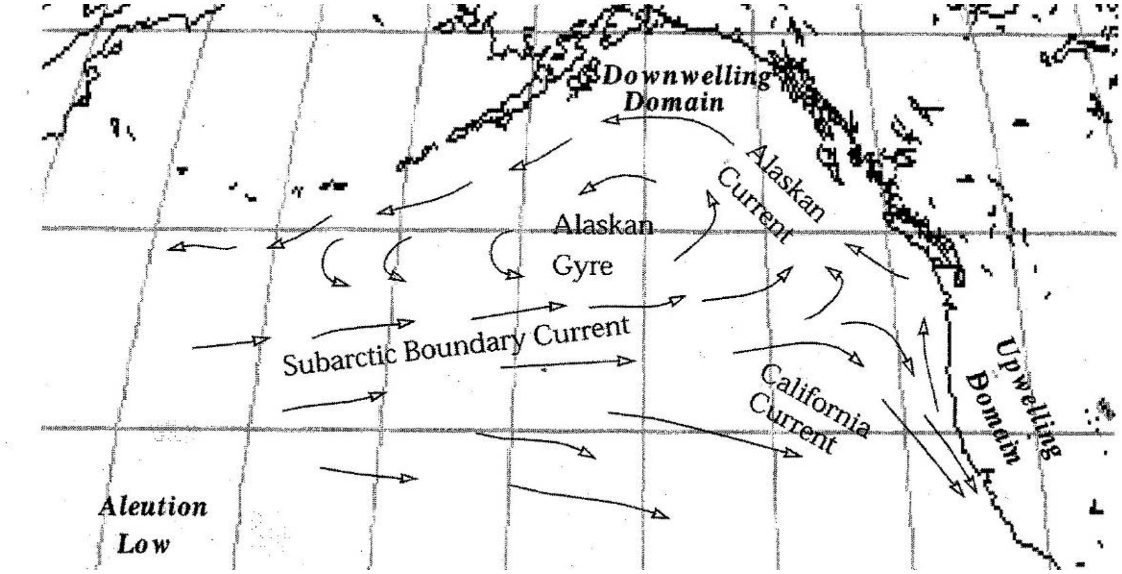

Figure 3-32. North Pacific currents and production domains. Years with an intense winter Aleutian low shift (warm dry in the Pacific Northwest) the subarctic current northward, strengthen the Alaskan current and increase the down welling domain production. Years with a weak Aleutian low (cool wet in the Pacific Northwest) shift the subarctic current southward and strengthen the California current and the upwelling domain production (Anderson 2000).

Effects on Fish Abundance and Survival Patterns

The regime shift to predominantly warm, dry conditions from 1975 to 1998 produced widespread effects on salmon and other ocean fishes throughout the North Pacific (Beamish and Bouillon 1993, McKinnell et al. 2001, Pyper et al. 2001). Abrupt declines in salmon populations coincided with the regime change throughout the Pacific Northwest (Hare et al 1999). Warm, dry regimes result in generally lower survival rates and abundance, and they also increase variability in survival and wide swings in salmon abundance. Some of the largest Columbia River fish runs in recorded history occurred during 1985–1987 and 2001–2002 after strong El Niño conditions in 1982–83 and 1997–98 were followed by several years of cool wet conditions.

Although trends in ocean conditions are a major driving force in the survival and abundance patterns of Pacific salmon and steelhead, the degree of effect varies among species and populations within species. Migration patterns in the ocean may differ dramatically and expose different stocks to different conditions in different parts of the ocean. Some species have broad, offshore migration patterns that may extend as far as the Gulf of Alaska (steelhead, chum, some Chinook). Others have migration patterns along the Washington, British Columbia, Oregon and California coasts (Chinook, coho, and cutthroat). Thus, ocean conditions do not have coincident effects on survival across species or populations.

Oregon and Washington coho stocks are particularly sensitive to El Niño effects because of their local ocean distribution pattern. Coronado and Hilborn (1998) estimated ocean survival rates for marked coho from Pacific Northwest hatcheries during 1971–1990. Trends changed in 1983 toward decreasing survival south of mid-British Columbia and increasing survival north of mid-British Columbia. They noted similar survival trends between hatchery, net pen, and wild coho and concluded that; “the dominant factor affecting coho salmon survival since the 1970s is ocean conditions.” Tschaplinski (2000) found that marine survival of coho smolts from Carnation Creek, British Columbia, varied up to 6-fold between years (0.05 to 0.30). Holtby et al. (1990) found that variation in survival was significantly correlated to early ocean growth rates and sea-surface salinities related to upwelling of nutrient-rich water.

Widespread changes in ocean conditions have had similar dramatic effects on ocean survival of steelhead (Figure 3-33). Cooper and Johnson (1992) showed that variation in steelhead run sizes and smolt-to-adult survival was highly correlated between runs up and down the West Coast. Smolt-to-adult survival rates generally varied 10-fold between good and bad years. Ocean survival rates for three West Coast steelhead populations where good annual index data were available showed high variability and a generally declining trend since the late 1970s (Figure 3-33). Similar survival patterns have been documented for other Pacific salmon species including sockeye (Farley and Murphy 1997, Kruse 1998, Peterman et al. 1998, McKinnell et al. 2001) and pink salmon (Pyper et al. 2001).

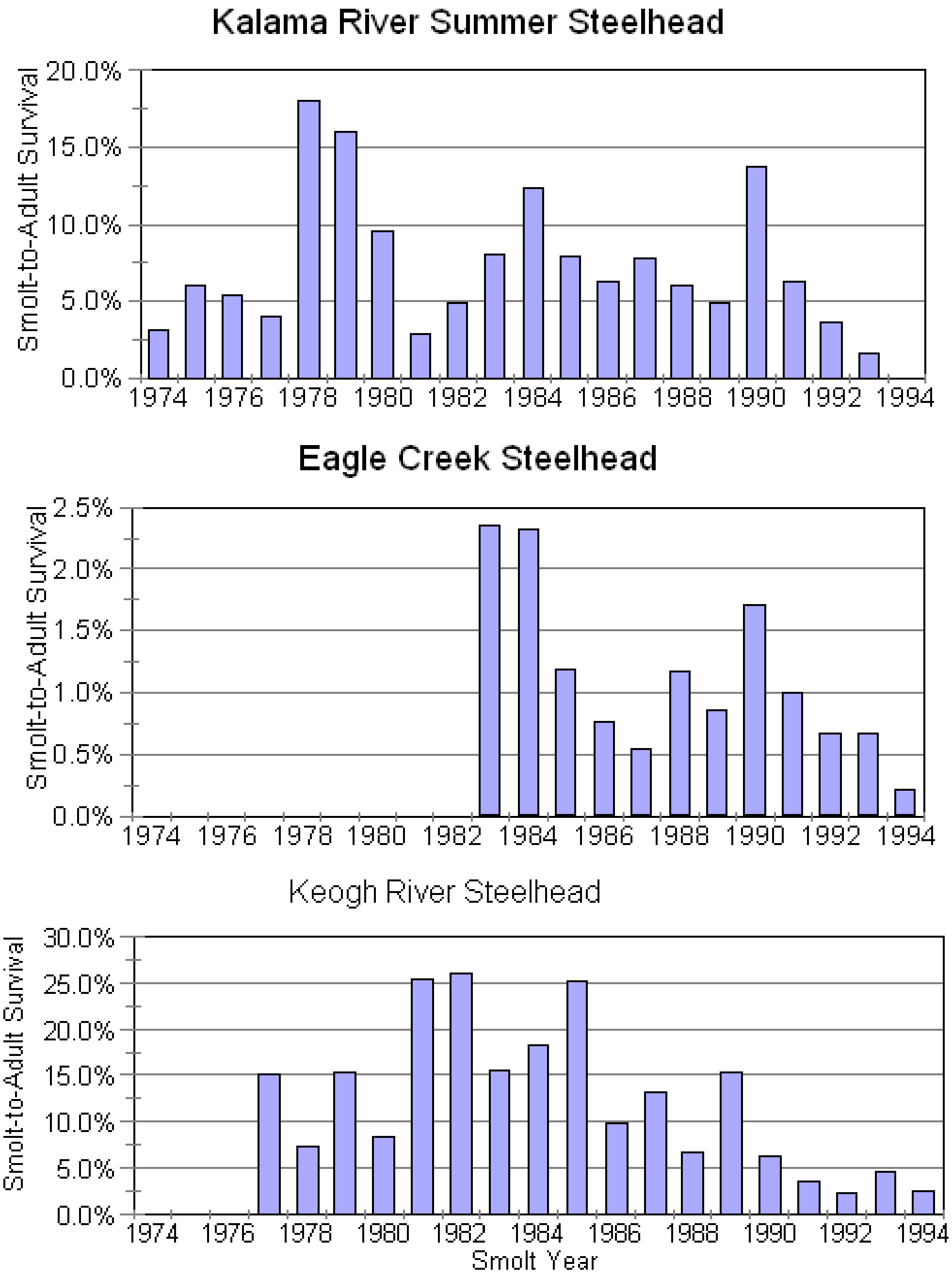

Figure 3-33. Annual means of smolt-to-adult survival rate of winter and summer steelhead from Kalama River Hatchery, winter steelhead from Eagle Creek National Fish Hatchery, and wild winter steelhead from the Keogh River, British Columbia.

Climate Change

The Independent Scientific Advisory Board of the Northwest Power and Conservation Council recently completed a comprehensive review of the available information on climate change and likely effects on Columbia River basin fish and wildlife (ISAB 2007). They concluded that evidence of global warming is unequivocal. Evidence includes increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level. Eleven of the last 12 years (1995-2006) rank among the 12 warmest years since temperatures have been recorded beginning in 1850. The linear warming trend of 0.13°C per decade over the last 50 years is nearly twice the 100 year average.

Climate changes can be attributed to anthropogenic global warming, which over the last century has increased worldwide precipitation over land by about 1% and increased the frequency of extreme rainfall events in much of the United States (U.S. Environmental Protection Agency 2005). Climate records show that the Pacific Northwest has warmed about 1°C since 1900, or about 50% more than the global average. The warming rate for the Pacific Northwest over the next century is projected to be in the range of 0.1-0.6°C per decade. Projected precipitation changes for the region are relatively modest and unlikely to be distinguishable from natural variability until late in the 21st Century. Most models project long-term increases in winter precipitation and decreases in summer precipitation.

The changes in temperature and precipitation will alter the snow pack, stream flow, and water quality in the Columbia basin. Warmer temperatures will result in more precipitation falling as rain rather than snow. Snow pack will diminish and stream flow timing will be altered. Peak river flows will likely increase. Water temperatures will continue to rise.

Climatic fluctuations have a significant effect on the amount and timing of water flowing to the estuary (Fresh et al. 2005). Over the last 100 years, climatic changes have reduced Columbia River average flows by 9% (Jay and Kukulka 2003). These changes are related in part to (1) the Pacific Decadal Oscillation (PDO), which alternates between cold, rainy phases and warm, drier phases approximately every 30 years, and (2) the El Niño/Southern Oscillation (ENSO), a shorter, 3- to 7-year phenomenon that similarly has cold and warm phases that can magnify or reduce the effects of the PDO. PDO and ENSO indicators suggest upcoming changes in ecosystem structure that are unfavorable for salmon and steelhead (Varanasi 2005).

3.8.3. Threats

The reduced productivity that accompanied an extended series of warm dry, conditions after 1975 has, together with numerous anthropogenic impacts, brought many weak Pacific Northwest salmon stocks to the brink of extinction and precipitated widespread ESA listings. Salmon numbers naturally ebb and flow as ocean conditions vary. Healthy salmon populations are productive enough to withstand these natural fluctuations. Weak salmon populations may be severely stressed during periods of poor ocean survival. Weak populations may disappear or lose the genetic diversity needed to withstand the next cycle of low ocean productivity (Lawson 1993).

Looked at over decades, ocean productivity patterns confound our ability to recognize and measure risk factors and the benefits of protection and restoration actions implemented to date. For instance, a favorable climate regime counteracted the detrimental impacts of Columbia River basin hydrosystem development after 1945, while an unfavorable climate regime negated the beneficial effects of salmon mitigation efforts after 1977 (Anderson 2000). Similarly, productive ocean conditions during the 1960s and early 1970s masked declines in wild fish numbers and inflated expectations for increasing hatchery coho production.

Fluctuations in fish run size and studies of ocean conditions over the last 20 years have greatly increased our understanding of the influence of inter-decadal climate patterns on salmon population dynamics, but do not fundamentally alter recent assessments of status and extinction risks. Extinction is most likely during extended periods of poor ocean conditions like those coincident with the ESA listing of many West Coast salmon and steelhead during the 1990s. Large salmon returns in the last few years are a temporary response to improved ocean conditions following the 1997–98 El Niño; they are not likely to represent the average future condition.

Recent improvements in ocean survival may portend a regime shift to generally more favorable conditions for salmon. The large spike in recent runs and a cool, wet climate would provide a respite for many salmon populations driven to critical low levels by recent conditions. The respite provides us with the opportunity to continue protection and restoration to forestall extinction when the ocean again turns sour—as it inevitably will. The risk is that temporary increases in survival and abundance may erode the sense of urgency for salmon recovery efforts.

The Natural Research Council (1996) concluded: "Any favorable changes in ocean conditions—which could occur and could increase the productivity of some salmon populations for a time—should be regarded as opportunities for improving management techniques. They should not be regarded as reasons to abandon or reduce rehabilitation efforts, because conditions will change again."

The bottom line is that, regardless of the marine survival rate that results from the myriad interrelated climate and oceanic patterns, the number of smolts entering the ocean for any given local population directly influences the number of returning adults. In the simplest view, whether marine survival is good or poor, more smolts will produce more adults, assuming the effects of marine competition from neighboring stocks is minimal. In fact, when the ocean is in a low productivity phase, it is even more important to maximize smolt production to ensure sufficient spawners for the future. Because marine survival patterns are difficult to predict, maximizing smolt production under poor survival regimes will also set the stage for a rapid rebound of harvestable surpluses when the regime shifts.

One exception to the notion that additional smolts will result in additional adult returns may be occurring at the broadest scale, as regards massive hatchery releases affecting ocean carrying capacity. Over the years, the oceans were considered to be an endless resource that could support unlimited production of salmon. However, recent research is beginning to detect the possibility of ocean carrying capacity limits. Extensive hatchery fish releases may have implications for overall survival rates. On the local scale, however, the relationship between smolt production and adult production holds true regardless of whether ocean-wide hatchery releases are contributing to pervasive competition. Survival of a given local stock appears to depend on the species, location, and marine conditions the stock encounters.

According to the ISAB (2007), climate change will have a variety of impacts on aquatic and terrestrial habitats in the Columbia Basin. One analysis suggests that temperature increases alone will render 2-7% of current trout habitat unsuitable by 2030, 5-20% by 2060, and 8-33% by 2090. Salmon habitats may be more severely affected because these fishes can only occupy areas below barriers and are thus restricted to lower, warmer elevations in the region. Estimated losses are not available for the lower Columbia region but Washington-wide losses are projected to be about 22% by 2090 as a worst case (ISAB 2007). Losses in the Oregon Columbia basin are more severe with a projected 40% decline. Bull trout may be disproportionately affected by these habitat changes because of their spawning requirements for very cold temperatures. These changes do not consider the associated impact of changing hydrology due to increased flood frequency and lower summer flows.

Box 3-26 Climate/Ocean Limiting Factors

- Susceptibility of weak populations to extirpation during periods of marine survival downturns,
- Management complacency when marine survival is good,
- Climate change reductions in habitat suitability and productivity for salmonids,
- Reducing flow, thus altering estuary habitat-forming processes,
- Reducing access to off-channel estuary habitat, and
- Reducing macro detrital inputs to the estuary food web.