3 Limiting Factors and Threats

The combination of habitat degradation, dam building and operation, fishing, hatchery operations, ecological changes, and natural environmental fluctuations, has resulted in reduced Columbia River salmonid populations. Other fish and wildlife species have also been affected – many have decreased in numbers but others have increased. Understanding the threats and limiting factors and how they function is essential to the development of recovery actions. Thorough overviews of the threats and limiting factors have been provided in Volume I, Chapter 3 of the Technical Foundation. Extensive details of the local threats and limiting factors in each subbasin are presented in Volume II of the Technical Foundation.

This chapter summarizes the limiting factors and ongoing threats to salmon, steelhead, and trout species. Limiting factors are described in relation to the biological needs of the species, and the threats are those activities that lead to the limiting factors. 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. Limiting factors and threats for salmon and steelhead are described under the broad categories of stream habitat, mainstem and estuary habitat, hydropower, harvest, and hatchery operations. Limiting factors and threats are also summarized for other fish and wildlife species.

3.1 Habitat –Streams

3.1.1 Background

Healthy stream habitat is critical for recovering and sustaining populations of salmon, steelhead and trout in the lower Columbia region. Many essential habitat features have been altered or degraded by human activities such as dams, logging, agriculture, urban development, road building, gravel mining, channelization, and water withdrawals.

Properly functioning conditions (PFC) represent favorable or optimum habitat for salmon as described by NOAA Fisheries in the “matrix of pathways and indicators” approach to assessing habitat (NMFS 1996). PFCs generally represent a reasonable upper bound of the potential for habitat improvement although, in some cases, the large-scale changes required would be difficult to implement (e.g., levee removal). The attainment of PFC stream conditions throughout an ESU’s historical habitat would increase the likelihood that an ESU would recover. However, PFC conditions may not be necessary for populations to reach recovery. Likewise, populations may fall short of recovery despite having PFC habitat conditions if distribution has been substantially reduced or out-of-subbasin mortality factors are severe.

Estimates of current stream capacity to produce salmon and steelhead generally ranges from 6 to 84% of PFC benchmark conditions as determined using EDT modeling (Table 1). Species averages range from a low of 23% for chum to a high of 74% for summer steelhead. These percentages describe the scope for potential improvement and the relative scale of habitat degradation for different species and subbasins.

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. Bull trout are affected by many of the same habitat changes that have affected other salmon and steelhead species. In the lower Columbia, bull trout movement within historical headwater areas has also been limited by tributary dams, particularly in the Lewis River and White Salmon River subbasins.

Table 1. Current habitat condition by species relative to historical conditions. The current condition of stream habitat is expressed as a percentage of historical condition using the Ecosystem Diagnosis and Treatment (EDT) model and PFC as defined by NOAA Fisheries (NMFS 1996).

	Chinook					Steelhead	
Subbasin	Spring	Fall (tule)	Fall (bright)	Chum	Coho	Winter	Summer
Grays/Chinook	--	69	--	28	33	64	--
Eloch/Skam	--	70	--	28	41	64	--
Mill/Ab/Ger	--	66	--	28	68	75	--
L. Cowlitz	--	43	--	14	26	15	--
U. Cowlitz	47	46	--	--	47	61	--
Cispus	40	--		--	70	62	--
Tilton	27	--	--	--	8	20	--
NF Toutle	0	48	--	--	na	21	--
SF Toutle	0	--	--	--	14	40	--
Coweeman	--	64	--	--	30	64	--
Kalama	55	67	--	27	47	72	83
NF Lewis	53	--	93	--	50	76	na
EF Lewis	--	56	--	30	32	57	55
Salmon	--	na	--	0	17	28	--
Washougal	--	58	--	18	25	55	73
L. Gorge	--	74	--	41	46	90	--
U. Gorge (Wind)	--	39	--	14	47	57	86
White Salmon	na	na	--	na	na	--	--
Average	***32***	***58***	***93***	***23***	***38***	***54***	***74***

Note: "—" indicates that an historical population for the species and subbasin did not exist. "na" indicates that an historical population for the species was present in the subbasin, but EDT habitat analyses are not available.

3.1.2 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 based on the assessments and data gathering presented in the Technical Foundation and 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.

Although dams are responsible for the greatest share of blocked habitat, inadequate culverts make up approximately 86% of all barriers (WDFW SSHIAP data). Estimates made from culvert surveys throughout the state indicate that approximately half of culvert problems are related to private and public logging roads (State of Washington 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.

In general, habitat connectivity, essential to these migratory species, is lost because of:

- Blockages to stream habitats because of structures,
- Blockages to stream habitats because of impaired water quality or channel morphology,
- Blockages to off-channel habitats,
- 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.

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 1.

- In the Lewis River basin alone, the 240-foot high Merwin Dam has blocked 80% of the available steelhead habitat since 1931 (WDF/WDW 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.

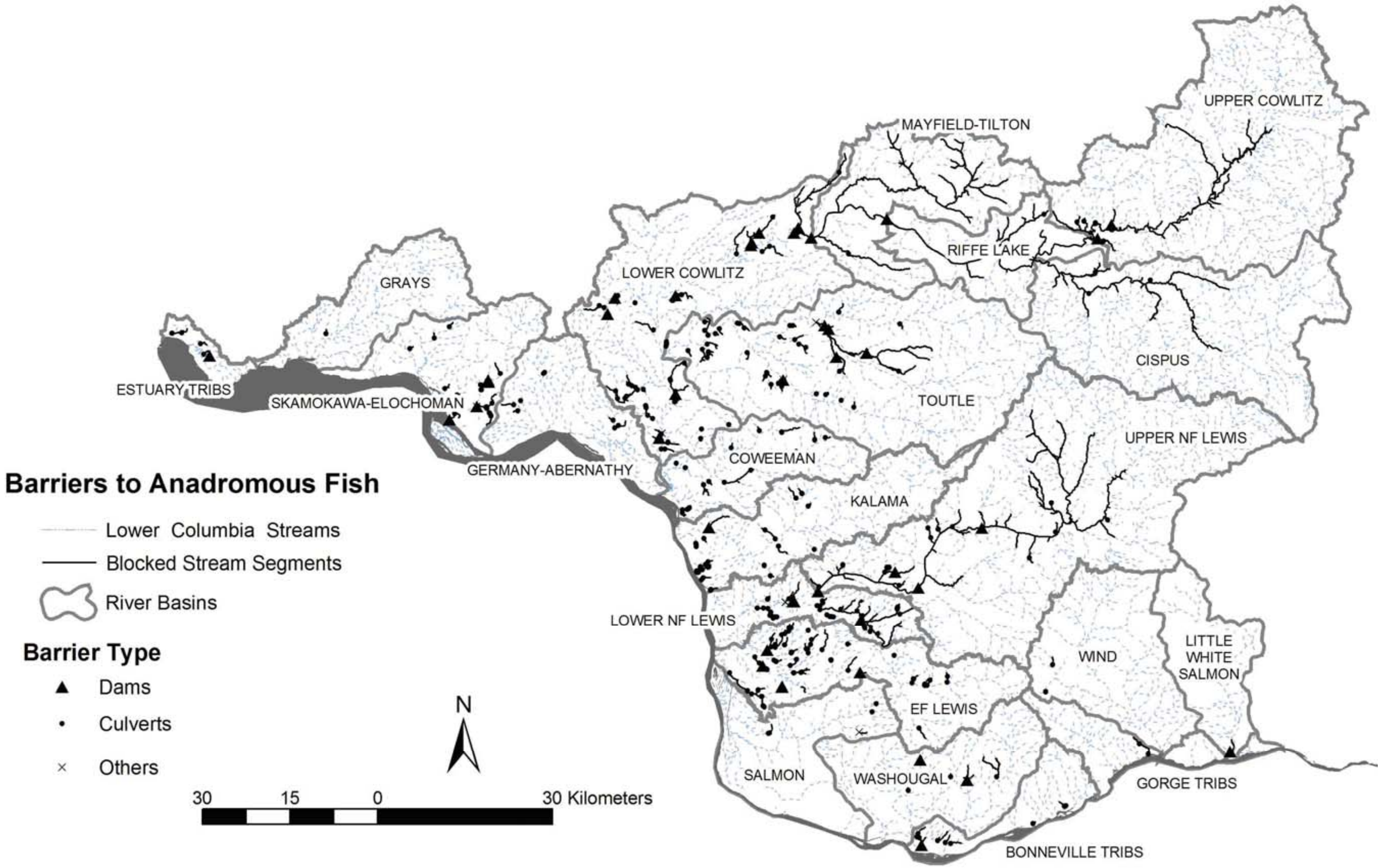

Figure 1. Regional map depicting blockages to anadromous fish and the extent of potentially accessible stream segments above blockages. Blockages and potential stream segments are included if passage for any anadromous species is obstructed. The primary source for these data is the Salmon and Steelhead 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.

Aquatic organisms have adapted to the range of habitat conditions that are created and maintained by natural streamflow regimes (Poff et al. 1997) and a range of streamflows are necessary for creating habitat diversity (Bisson et al. 1997). Streamflows in excess of natural conditions, however, can increase hillslope sediment delivery and alter channel morphology through bed and bank erosion, with subsequent impacts on aquatic habitats (Chamberlain et al. 1991). Alterations to winter and spring flows can affect incubation and emigration survival by increasing the likelihood of scouring eggs and alevins from the gravel or displacing juveniles from rearing habitats (e.g., Pearsons et al. 1992, Montgomery et al. 1996). Decreased summer low flow volumes can impact aquatic habitats through loss of available habitat area and increased risk of elevated stream temperatures. Alterations to summer and fall flows may impact spawner distributions and juvenile rearing success.

Characteristics of catchment land cover influence the rate, duration, and magnitude of water runoff in a basin. In the Pacific Northwest, alterations of land cover affect runoff by decreasing soil infiltration rates, interrupting subsurface flow, and increasing snow accumulation and melt rates.

Although western Washington is characterized as having abundant rainfall, a significant portion of annual precipitation 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 in the Pacific Northwest, 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. 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 stormflow 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 hillslopes 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 meltwater (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).

In summary, salmon, steelhead and trout life histories are constrained because of:

- 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).

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 2. 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 (WDOE 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.

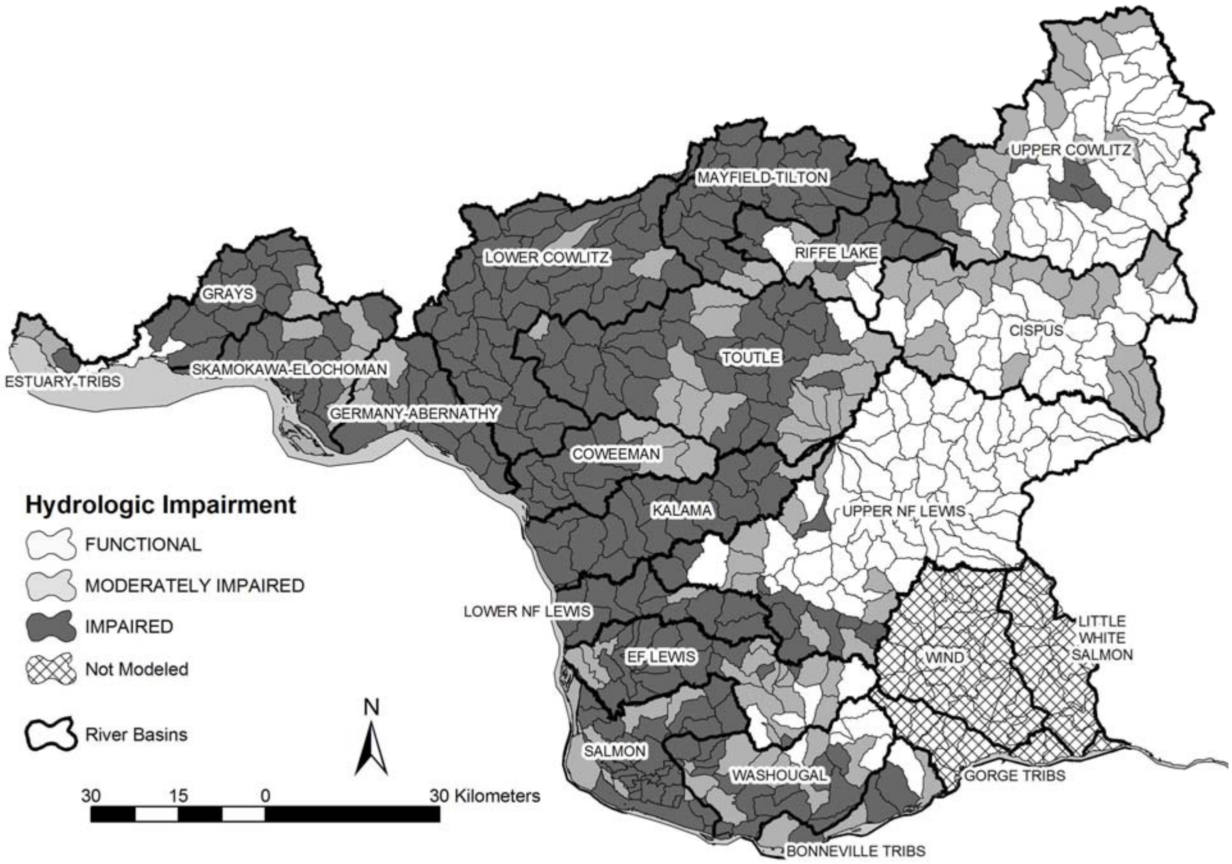

Figure 2. Map of hydrologic impairments across the lower Columbia region. Impairment categories were calculated as part of the Integrated Watershed Assessment (IWA). (see Vol. II for presentation of subbasin-level results). These impairment ratings represent local hydrology (runoff) conditions, not including upstream effects.

- 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.
- 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/sq mi. In many basins the forest road density exceeds 7 mi/sq mi.
- 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.

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 DOE 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.

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.

In summary, water quality characteristics that can limit salmonids include:

- Altered stream temperature regimes,
- Reduced dissolved oxygen concentrations,
- Excessive turbidity,
- Nutrient over-enrichment

[1] The Toe-Width is the distance from the toe of one streambank to the toe of the other streambank 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.

- Bacteria, and
- Chemical contaminants (from point and non-point sources).

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 the WDOE or documented impairments submitted to WDOE 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. 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 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.

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).

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.

Important habitats and habitat diversity can be reduced by:

- 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.

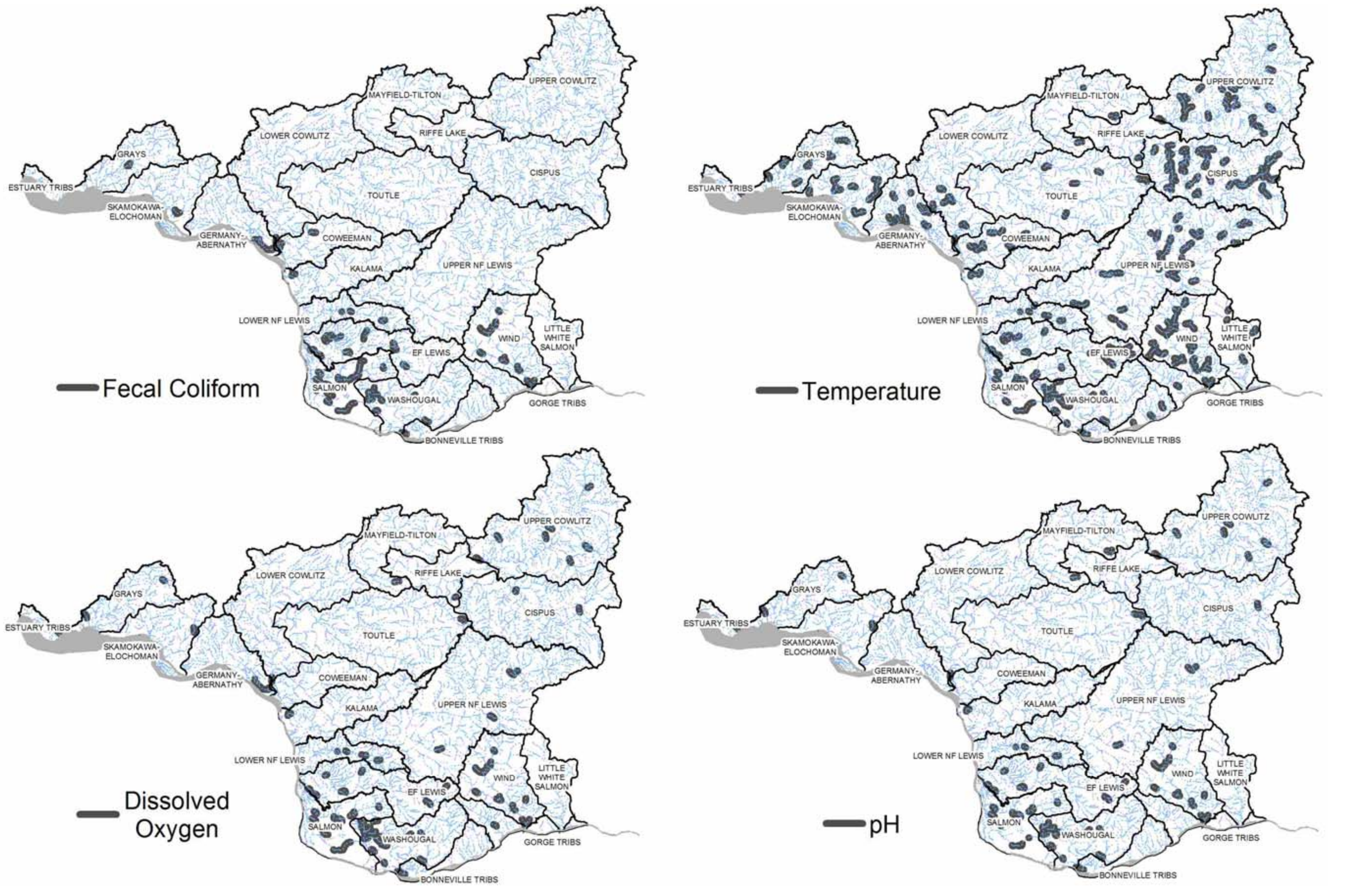

Figure 3. Map of stream segments on the 2002/2004 303(d) list for selected parameters. The selected parameters are the most widespread water quality impairments in the region.

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 macroinvertebrate production. Juvenile

[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).

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 macroinvertebrate 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.

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.

The ways in which substrate and sediment features can injure salmon include:

- 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.

***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 4 (see Vol. II for a presentation of subbasin-level results).

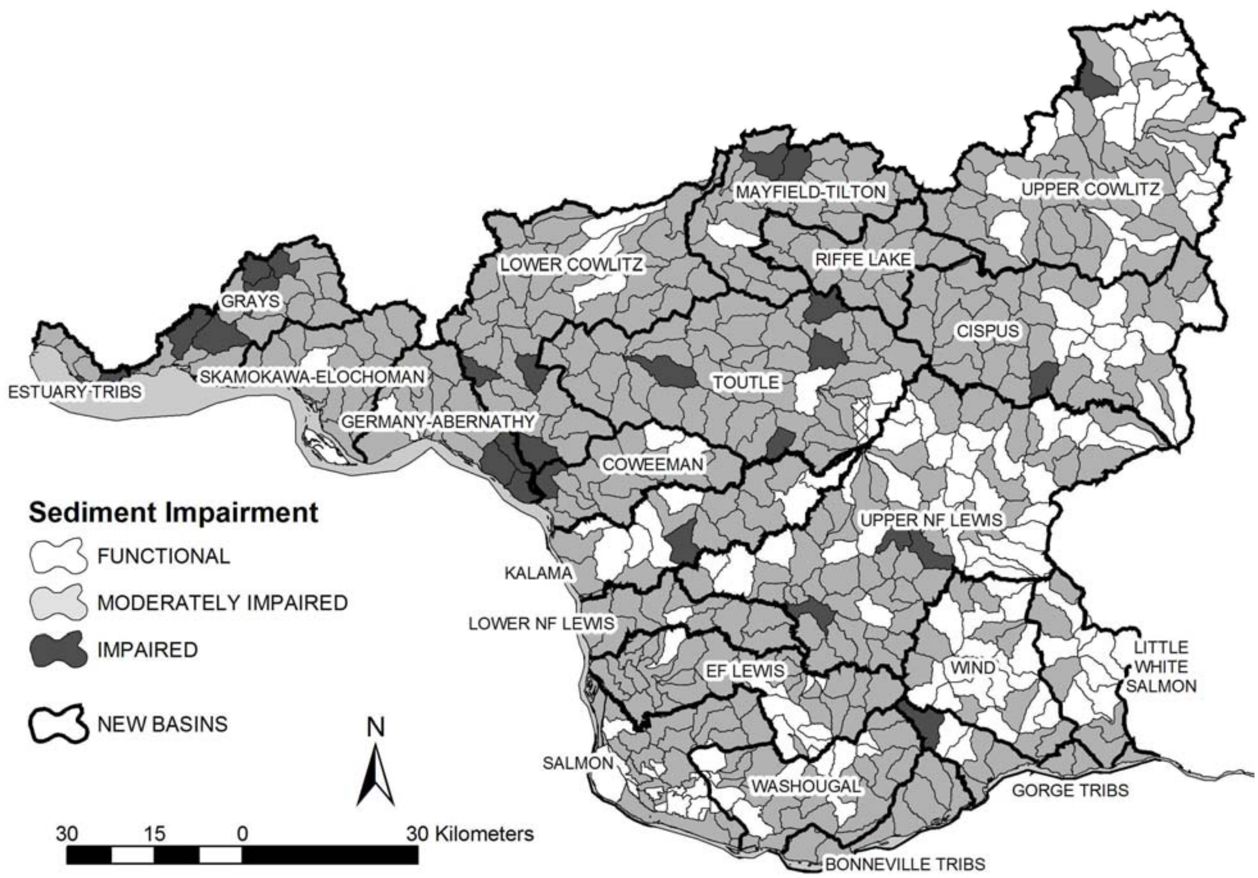

Figure 4. Map of sediment supply problems across the lower Columbia region. Impairment categories were calculated as part of the Integrated Watershed Assessment. (see Vol. II for presentation of subbasin-level results). These impairment ratings represent local sediment supply conditions, not including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

Woody Debris

Processes and Effects **—** 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 macroinvertebrate 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. 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).

The loss of woody debris from the stream habitats can result in negative effects on salmonids because of:

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

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 streambanks 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).

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 streamflows due to urbanization can alter channels dramatically through widening and incision (Booth 1990). Alternatively, streambank reinforcement for erosion control, such as riprap, reduces habitat complexity and can result in diminished salmonid abundance (Knudsen and Dilley 1987).

These impairments affect salmon through:

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

***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 streambanks. 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. litterfall) 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 macroinvertebrate distribution and abundance. Meehan (1996) found a significant difference in macroinvertebrate 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).

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.)

Riparian degradation is common throughout the lower Columbia region, especially in lower elevation river valleys that have experienced intensive land-use pressures, and includes:

- 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.

Current Conditions — Riparian conditions are generally considered poor across the lower Columbia region. The IWA riparian assessment (Figure 5), 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 streambanks 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.

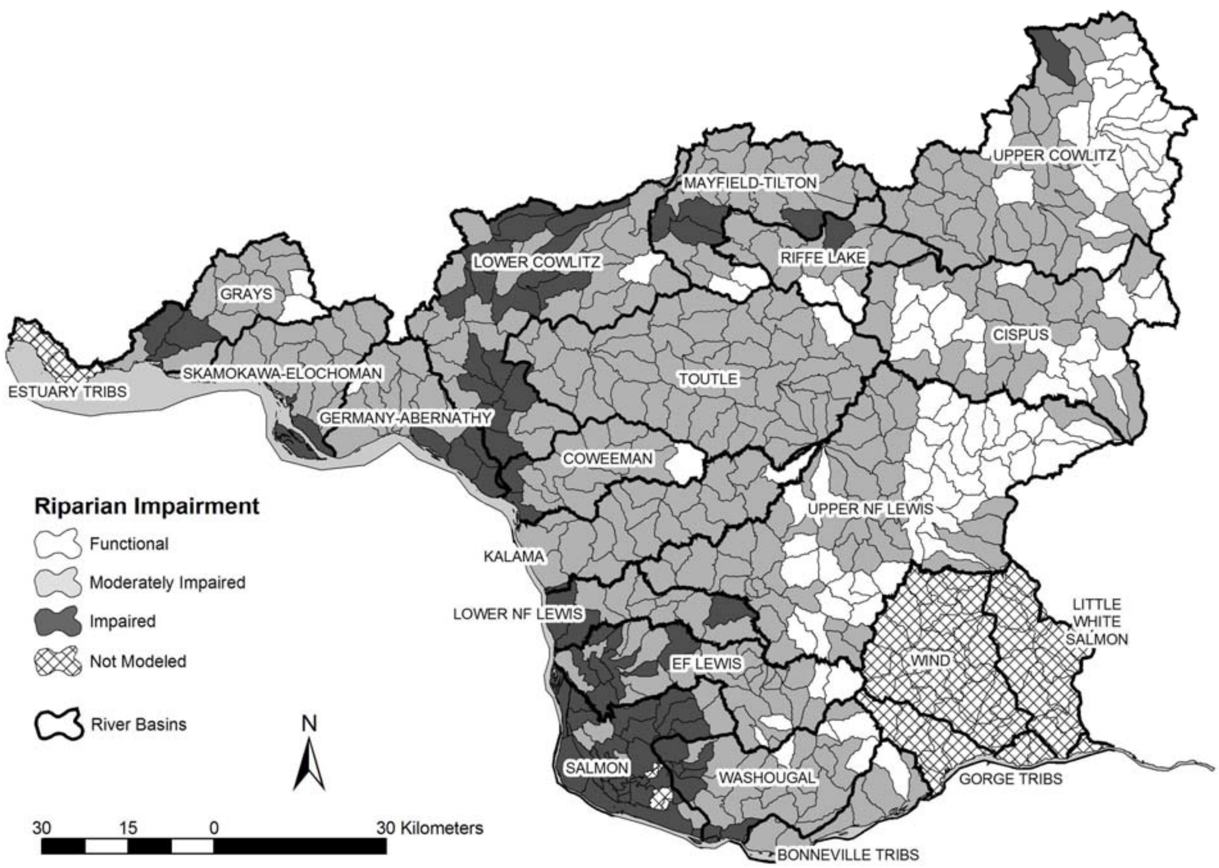

Figure 5. Map of riparian impairments across the lower Columbia region. Impairment categories were calculated as part of the Integrated Watershed Assessment. (see Vol. II for presentation of subbasin-level results).

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 erosivity. 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.

Impairment of floodplain function can alter in-stream, riparian, and off-channel habitats. Floodplain alterations that reduce salmon, steelhead and trout viability include:

- 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.

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.

3.1.3 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 practices. They include land and water uses with direct effects on stream channels, riparian areas, and floodplains, as well as effects on watershed process conditions that are believed to be impacting fish habitat. The sources of the threats (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 lower Columbia 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,
- The 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. 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, which lies primarily within the Lake River basin, makes up the largest urban area in the Washington lower Columbia region. There are also several other sizeable urban areas including Washougal/Camas, and Kelso/Longview. There is also considerable rural residential development throughout the region, much of it occurring within river valleys and often alongside streams. Rooftops, pavement, and landscaping increases impervious surfaces and decreases the ability of the soil to absorb rainwater, therefore increasing runoff volumes during storm events and decreasing groundwater recharge. The increase in the drainage network because of storm drains and road ditches further alters flow regimes by concentrating runoff. 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 and 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 Estuary and Lower Mainstem Habitat

3.2.1 Background

Juvenile and adult salmon may be found in the Columbia River estuary at all times of the year, as different species, life history strategies, and size classes continually move into tidal waters. The lower Columbia River mainstem and estuary subbasins are treated generally in Volume I, Chapter 3 and in detail in Volume II, Chapter 1 of the Technical Foundation. This section is intended to briefly and succinctly describe the limiting factors and threats in the estuary and lower mainstem as they relate to salmonid survival, production, and life history diversity.

Estuaries have important impacts on juvenile salmonid survival. Estuaries provide juvenile salmonids an opportunity to achieve the critical growth necessary to survive in the ocean (Neilson and Geen 1986, Wissmar and Simenstad 1988 as cited in Nez Perce et al. 1995, Aitkin 1998 as cited in USACE 2001, Miller and Sadro 2003). Juvenile chinook salmon growth in estuaries is often superior to river-based growth (Rich 1920a, Reimers 1971, Schluchter and Lichatowich 1977). Estuarine habitats provide young salmonids with a productive feeding area, free of marine pelagic predators, where smolts can undergo 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. (2001, as cited in Fresh et al. 2003); they demonstrated that improvement of juvenile salmon survival during the estuarine and early ocean stage would significantly improve salmon population growth rates.

Juxtaposition of high-energy areas with ample food availability and sufficient refuge habitat is a key habitat structure necessary for salmonid growth and survival in the estuary. In particular, tidal marsh habitats, tidal creeks, and associated complex dendritic channel networks may be especially important to subyearlings as areas of both high insect prey density, and as potential refuge from predators afforded by sinuous channels, overhanging vegetation, and undercut banks (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 (Simenstad et al. in press, as cited in Bottom et al. 2001). 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.

The importance of proximally available feeding and refuge areas may hold true even for species that move more quickly through the estuary. For example, Dawley (1989) found prey items in the majority of stomachs of salmon smolts known to migrate through the Columbia estuary quickly (i.e., days), indicating that these smolts are utilizing estuarine resources. Additionally, radio-tagged coho in Grays Harbor estuary moved alternatively from low velocity holding habitats to strong current passive downstream movement areas (Moser et al. 1991). Further, Fresh et al. (2003) reported that both small and large chinook salmon (i.e., ocean- and stream-type chinook from upper and lower basin populations) utilized peripheral marsh and forested wetland habitat in the Columbia River estuary. Consistent with these observations, 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 and these cues may depend on the environmental gradients experienced during migrations.

3.2.2 Limiting Factors

Human-induced changes have substantially influenced current habitat conditions in the lower Columbia River mainstem and estuary. Adult migration behavior, health, and survival are all affected by conditions at the freshwater:saltwater interface and in lower river mainstem. Changes in river flow, circulation, water quality, contaminants, channel alterations, and predation may all be having impacts on adults and juveniles. Because estuaries also provide juvenile salmonids an opportunity to achieve the critical growth necessary to survive in the ocean, proximity of high-energy areas with ample food availability and sufficient refuge habitat is a key habitat structure necessary for salmonid growth and survival in the estuary. Loss of connections among these habitats can determine whether juvenile salmonids are able to access the full spectrum of habitats they require.

Anthropogenic factors have substantially influenced current habitat conditions in the lower Columbia River mainstem and estuary. The primary anthropogenic factors that have determined estuary and lower mainstem habitat conditions include hydrosystem construction and operation (i.e., water regulation), channel confinement (primarily diking), channel manipulation (primarily dredging), and floodplain development and water withdrawal for urbanization and agriculture. Generally, these anthropogenic factors have influenced estuary and lower mainstem habitat conditions by altering hydrologic conditions, sediment transport mechanisms, and/or salinity and nutrient circulation processes. Often, there are no simple connections between a single factor and a single response, as many of the factors and responses are interrelated. Further, it is difficult to separate anthropogenic factors from concurrent natural variation when evaluating human impacts.

As one example on a broad scale, evaluations of anthropogenic factors are complicated by climatic effects. Variations in climate-driven Columbia River discharge occur in time scales from years to centuries (Chatters and Hoover 1986, 1992 as cited in Bottom et al. 2001). The Columbia Basin’s response to climatic cycles is governed by the basin’s latitudinal position; climate in the region displays a strong response to both the Pacific Decadal Oscillation (PDO) and El Niño Southern Oscillation Index (ENSO) cycles (Mantua et al. 1997 as cited in Bottom et al. 2001). The effects of poor estuary and mainstem habitats are exaggerated during periods of low ocean productivity. However, despite our ability to measure changes in climate, Bottom et al. (2001) discussed the difficulty in separating climate versus anthropogenic effects on river discharge and the habitat-forming processes it governs.

River Flow

Flow effects from upstream dam construction and operation, irrigation withdrawals, shoreline anchoring, channel dredging, and channelization have significantly modified estuarine habitats and have resulted in changes to estuarine circulation, deposition of sediments, and biological processes (ISAB 2000, Bottom et al. 2001, USACE 2001, Johnson et al. 2003b). Flow regulation in the Columbia River basin has been a major contributor to the changes that have occurred in the estuary from historic conditions. The predevelopment flow cycle of the Columbia River has been modified by hydropower water regulation and irrigation withdrawal (Thomas 1983, Sherwood et al. 1990 as cited in Nez Perce et al. 1995, Weitkamp 1994, NMFS 2000c, Williams et al. 2000, Bottom et al. 2001, USACE 2001).

Before the development of the hydrosystem, Columbia River flows were characterized by high spring runoff from snowmelt and regular winter and spring floods. Dam construction and operation have altered Columbia River flow patterns substantially throughout its basin. Historic flow records at The Dalles, Bonneville Dam, and Beaver, Oregon, demonstrate that spring freshet flows have been reduced by about 50%, as water is stored for power generation and irrigation, and winter flows have increased about 30% (Figure 6) Flood control operations have reduced flood volume and frequency. Hydrosystem operations change to accommodate daily fluctuations in power demand and can result in significant daily flow variation downstream from some hydropower facilities.

Most of the spring freshet flow reduction is attributed to dam filling, about 20% is a result of irrigation withdrawals, and only a small portion (5%) is connected to climatic change (Bottom et al. 2001).

Reduction of maximum flow levels, dredged material deposition, and diking have all but eliminated overbank flows in the Columbia River (Bottom et al. 2001), resulting in reduced large woody debris recruitment and riverine sediment transport to the estuary. Overbank flows were historically a vital source of new habitats. Moreover, historic springtime overbank flows greatly increased habitat opportunity into areas that at other times are forested swamps or other seasonal wetlands. Historic bankfull flow levels were common prior to 1975 but are rare today. Further, the season when overbank flow is most likely to occur today has shifted from spring to winter, as western subbasin winter floods (not interior subbasin spring freshets) are now the major source of peak flows (Bottom et al. 2001, Jay and Naik 2002).

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. Greater flows increase velocity, which increases juvenile and decreases adult travel rates. Extensive study has detailed the relationship between juvenile migration travel times and flow volume. The relationship is particularly strong at low to moderate flow volumes. Flow regulation and reservoir construction has increased smolt travel times through the Columbia and Snake mainstems many-fold, although the significance of this relationship to juvenile survival remains a subject of considerable controversy. The potential delay of emigrants reaching the estuary during a critical physiological window for smoltification or for ocean dispersion is a significant concern, especially for upriver salmon stocks, where delays are compounded across long migration distances. Moreover, increased travel times also increase exposure to Columbia River predation. For lower basin stocks, however, the mainstem journey is relatively short and only fish originating in the Wind, Big White Salmon, Little White Salmon, and Columbia Gorge tributaries are directly affected by passage through one mainstem dam (Bonneville).

Interactions of flow and dam passage can be particularly problematic for migrating salmon. General passage issues have been discussed in the subbasin habitat section of the Technical Foundation, but higher flows generally increase the survival of juveniles as they pass through the dams, because more fish can pass over the spillways, where mortality is low, than through the powerhouses, where turbine passage mortality can be significant. The increased spill typically associated with high flows also reduces travel time by avoiding fish delays in dam forebays. For this reason, many fish and hydrosystem managers implement a water budget of prescribed flows to facilitate fish migration rates and dam passage. 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 (Reischel and Bjornn 2003).

Flow also affects habitat availability for mainstem spawning and rearing stocks. Significant numbers of chum and fall chinook spawn and rear in the mainstem and side channels of the Columbia downstream from Bonneville Dam. Flow patterns determine the amount of habitat available and can also dewater redds or strand juveniles (NMFS 2000c).

In summary, river flow changes in the estuary and lower mainstem impair salmon through:

- Changes in timing and magnitude of natural seasonal flow patterns,
- Loss of migration-stimulating flows,
- Lack of access to floodplain habitats,
- Reduced or fluctuating availability of spawning habitats
- Reduced sediment transport,
- Lack of sediment deposition, and
- Reduced large woody debris delivery.

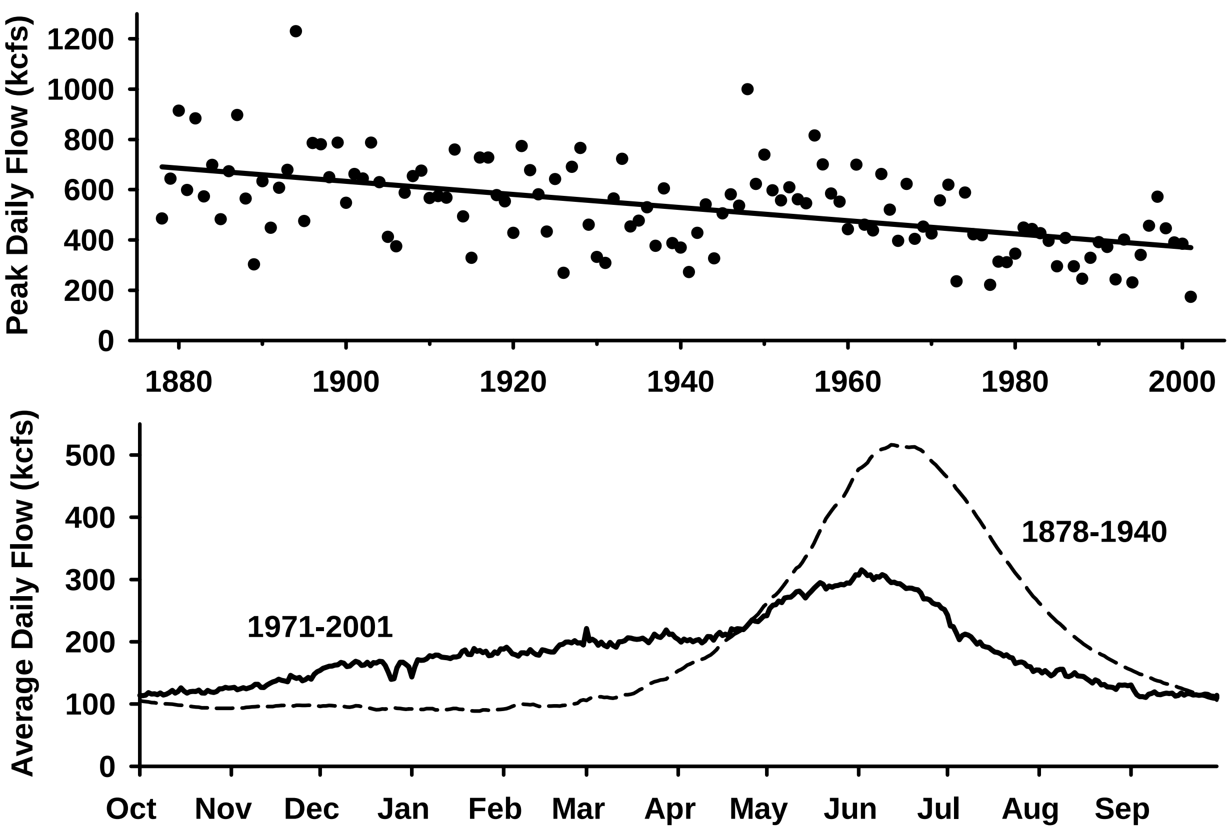

Figure 6. Historical changes in average daily flow patterns and flood frequency in the Columbia River at The Dalles.

Circulation

Small changes in salinity distribution may have significant effects on the ecology of fishes in the estuary, including salmonids. Salinity distribution is affected by tidal flow and river discharge, now both strongly influenced by upriver dam operation, the dredged shipping channel, and the jetties at the river mouth. Tidal energy and river discharge determines the location, size, shape, and salinity gradients of the estuary turbidity maximum zone, which affects seasonal species distributions and structure of entire fish, epibenthic, and benthic invertebrate prey species assemblages throughout the Columbia River estuary. Therefore, small changes in the distribution of salinity gradients may change the type of habitats available when juvenile salmon make the critical physiological transition from fresh to brackish water. These changes impact salmon through:

- Alterations of salinity patterns and food webs,
- Effects on physiology of smoltification, and
- Influences on predator and prey species distributions.

Water Temperature and Clarity

Flow regulation and reservoir construction have increased average water temperature in the Columbia River mainstem as illustrated in Figure 7. Summer water temperatures now regularly exceed optimums for salmon (NMFS 2000a). Water temperatures in fish ladders can be higher than ambient river temperatures, which compounds this problem.

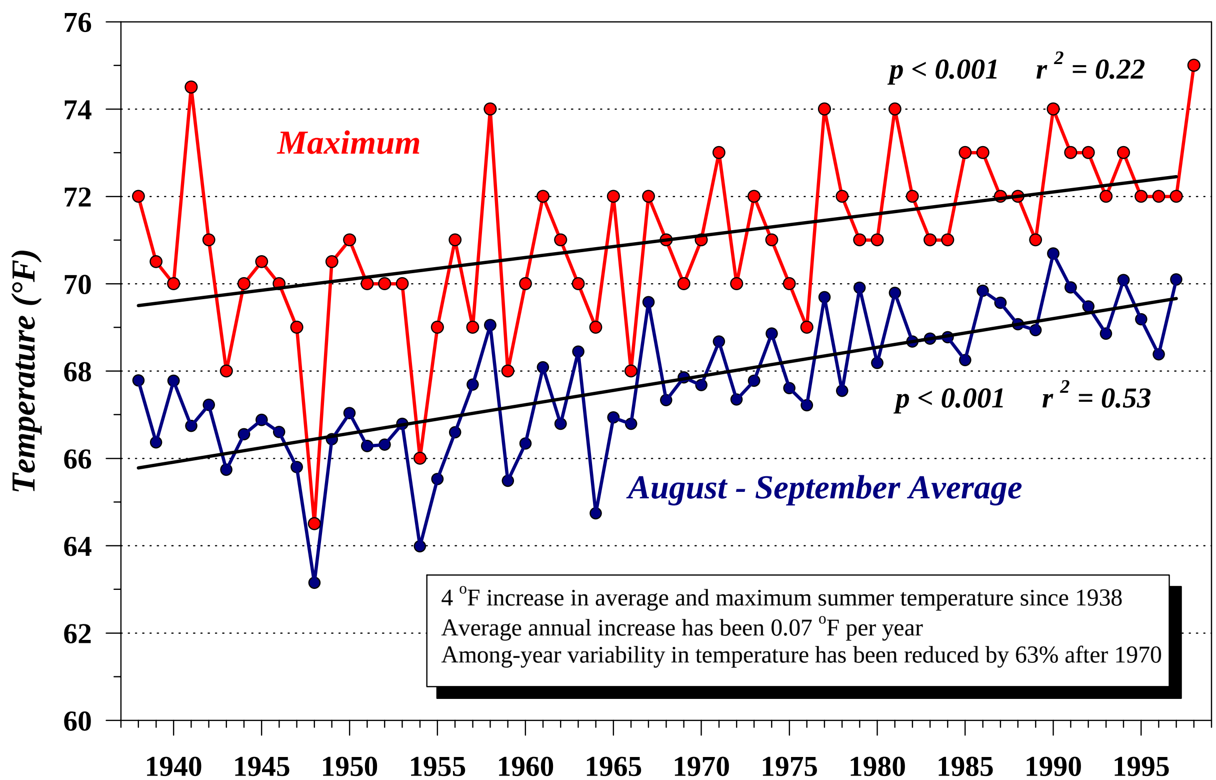

Figure 7. Historical changes in summer water temperatures at Bonneville Dam.

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). In the lower Columbia, many summer and fall migrating adults typically pull into the cooler Cowlitz, Lewis, and Wind River mouths before continuing up the Columbia. Warm temperatures can increase the fishes' susceptibility to disease, but the overall effects of delay in migration rate due to high water temperature are unknown. Since the early 1990s, some upper basin dams have been operated to provide cold water for downstream temperature control to benefit migrating juvenile and adult salmon.

Flow regulation and reservoir construction also have increased water clarity. Increased water clarity can affect salmon through food availability and susceptibility to predation.

In summary increased water temperatures and water clarity can impact salmon through:

- Exceedance of optimum temperatures,
- Altered migration patterns,
- Increased susceptibility to disease,
- Changes in food availability, and
- Increased susceptibility to predation.

Gas Supersaturation

There are important trade-offs between fish passage and gas saturation to be considered when formulating spillway operation policies at lower Columbia River dams. Supersaturating water with atmospheric gases, primarily nitrogen, can occur when water is spilled over high dams. 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).

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). Monitoring shows that salmonid mortality continues to be associated with exceptionally high river flows (NMFS 2000). For instance, Bonneville Dam turbines exceeded 130% capacity for 24 days in 1997. During that time, daily prevalence of gas bubble disease was high in sockeye (14-100% for 3 weeks) but lower for chinook (0-6.5% prevalence).

Gas supersaturation poses the greatest risk for Washington lower Columbia basin salmon stocks that must pass Bonneville Dam or are destined for areas downstream. Gas levels equilibrate slowly; thus, gas levels at Bonneville Dam that are high enough to have impacts on fish may extend for long distances downstream. Dissolved gas saturation below lethal levels may still have chronic effects, such as increased susceptibility to disease or predation; these effects are poorly understood. 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). In summary, gas supersaturation affects salmon through:

- Direct mortality, or
- Chronic effects increasing susceptibility to disease or predation.

Contaminants

Environmental contaminants have been detected in lower Columbia River water, sediments, and biota at concentrations above available reference levels. Significant levels of dioxins/furans, DDT, and metals have been identified in lower Columbia River fish and sediment samples. In general, contaminant concentrations are often highest in industrial or urban areas, but may be found throughout the lower Columbia River mainstem and estuary as a result of transport and deposition mechanisms. Salmonids may uptake contaminants through direct contact or biomagnification through the food chain. Contaminants affect salmon through:

- Predisposition to disease,
- Increased stress, and
- Interrupted physiological processes.

Channel Alterations and Habitat Disconnection

Thomas (1983) suggested that channel confinement (i.e. diking) is particularly detrimental to estuary habitat capacity because it entirely removes habitat from the estuarine system, while other anthropogenic factors change estuary habitats from one type to another. The lower mainstem and estuary habitat in the Columbia River has, for the most part, been reduced to a single channel where floodplains have been reduced in size, off-channel habitat has been lost or disconnected from the main channel, and the amount of large woody debris has been reduced (NMFS 2000c). Dikes prevent overbank flow and affect the connectivity of the river and floodplain (Tetra Tech 1996); thus, the diked floodplain is higher than the historic floodplain and inundation of floodplain habitats only occurs during times of extremely high river discharge (Kukulka and Jay 2003). It is estimated that the historical estuary had 75 percent more tidal swamps than the current estuary partially because tidal and flood waters could reach floodplain areas that are now diked or otherwise disconnected from the main channel (USACE 2001, Johnson et al. 2003b).

Thomas (1983) documented substantial changes to estuary habitats from historic to current conditions in the area of RM 0-46.5. Estuary-wide tidal marsh and tidal swamp acreage has decreased 43% and 77%, respectively, from 1870 to 1983, primarily as a result of dikes and levees that have disconnected the main channel from these floodplain habitats and also from water regulation that has decreased historic peak flows that previously provided water to these habitats. Losses of tidal marsh habitat have been most extensive in Youngs Bay, where a loss of over 6,000 acres was documented. Extensive tidal swamp habitat has been lost in all estuary areas where this habitat was historically present. Losses of medium- and deep-water habitat acreage have been less severe (25% and 7%, respectively). Acreage of medium-depth water habitat was lost in all areas of the estuary except the upper estuary, where a slight increase in acreage was observed; acreage loss was greatest in the entrance, Cathlamet Bay, and Baker Bay areas of the estuary. Similarly, deep-water habitat acreage was lost in most areas of the estuary; losses were highest in the Baker Bay and upper estuary areas. Only shallows/flats estuary habitat realized a net increase 10% in acreage from 1870 to 1983. This increase in acreage was primarily a result of water regulation that has decreased historic peak erosive flows and decreased erosion following construction of the jetties at the river mouth. In total, 36,970 acres (23.7%) of the estuarine habitat acreage has been lost from 1870 to 1983. During this period, lost estuarine habitats were converted to the following non-estuarine habitats: developed floodplain (23,950 acres), natural and filled uplands (5,660 acres), non-estuarine swamp (3,320 acres), non-estuarine marsh (3,130 acres), and non-estuarine water (910 acres).

Development and maintenance of the shipping channel has greatly affected the morphology of the estuary. The extensive use of jetties and pile dikes to maintain the shipping channel has impacted natural flow patterns and large volumes of sediments are dredged annually. Dredged materials are disposed of in the ocean, in the flow adjacent to the shipping channel, along shorelines, or on upland sites. Annual maintenance dredging since 1976 has averaged 3.5 million cubic yards per year in the estuary. By concentrating flow in one deeper main channel, the development of the navigation channel has reduced flow to side channels and peripheral bays.

Juvenile salmonids in the estuary must continually adjust their habitat distribution in relation to twice-daily tidal fluctuations and seasonal and anthropogenic variations in river flow. Juveniles move from low-tide refuge areas in deeper channels to salt marsh habitats at high tide and back again. Therefore, 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. Dike construction for agricultural or urban development has isolated the main channel from its historical floodplain in many places and prevented normal flows that previously provided water to these habitats. Poor and/or malfunctioning tide gates further reduce flow exchange and prevent juvenile passage among habitats.

Losses to lower mainstem and estuary salmonid habitat due to diking and dredging reduce salmon productivity through:

- Loss of natural habitats
- Reduced woody debris deliveries to rearing habitats
- Reduced water flow to side channel habitats
- Lack of access to productive rearing areas,
- Decreased macrodetritus inputs and foodweb productivity,
- Stranding of juveniles behind poor tide gates, and
- Reduced refuge from predators.

Sediment Transport

Sediments in the estuary may be marine- or freshwater-derived and are transported via suspension in the water column or bed load movement. Riverine sediments available for transport have decreased as a result of dam construction; reservoirs restrict bedload movement and trap upstream supply of sediments. Sand sediments are vital to natural habitat formation and maintenance in the estuary; dredging and disposal of sand and gravel have been among the major causes of estuarine habitat loss over the last century (Bottom et al. 2001).

Sediment transport is non-linearly related to flow; thus, it is difficult to accurately apportion causes of sediment transport reductions to climate change, water withdrawal, or flow regulation (Jay and Naik 2002). However, the largest single factor in reduced sediment transport appears to be the reduction of spring freshet flow as a result of water regulation and irrigation withdrawal. Recent analyses indicate a two-thirds reduction in sediment-transport capacity of the Columbia River relative to the pre-dam period (Sherwood et al. 1990, Gelfenbaum et al. 1999). Therefore, flow reductions affect estuary habitat formation and maintenance by reducing sediment transport (Bottom et al. 2001, USACE 2001). The reduction in sand and gravel transport has been higher (>70% reduction compared to predevelopment flow) than for silt and clay transport (Bottom et al. 2001), which has important implications for habitat formation and food web dynamics.

Construction of the north and south jetties at the Columbia River mouth significantly increased sediment accretion in nearby marine littoral areas. Ocean currents that formerly transported sediments alongshore were disrupted and accretion, particularly in areas adjacent to the river mouth (i.e. Long Beach, Clatsop Spit), increased significantly in the late 1800s and early 1900s. Sediment accumulation rates have slowed since 1950, potentially as a result of reduced sediment supply from adjacent deltas or the Columbia River (Kaminsky et al. 1999). Because of the decreased sediment supply from the Columbia River and ebb-tidal deltas, recent modeling results indicate that the shorelines immediately north of the historic sediment source areas at the entrance to the Columbia River are susceptible to erosion in the future (Kaminsky et al. 2000).

Changes in lower mainstem and estuarine sediment budgets have impacted salmon by way of:

- Reduced estuarine habitat formation,
- Loss of habitat diversity, and
- Decreased predator avoidance capabilities.

Predation

Significant numbers of salmon are eaten by fish, bird, and marine mammal predators during migration through the mainstem Columbia River. Predation likely has always been a significant source of mortality but has been exacerbated by 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). While some predation occurs at dam tailraces and juvenile bypass outfalls, by far the greatest numbers of juveniles are consumed as they migrate through the Columbia River estuary, as discussed in section 2162688.1.1228652. Native fishes, particularly northern pikeminnow, prey on juvenile salmonids. Marine mammals prey on adult salmon, but the significance is unclear.

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, as outlined in Table 2.

Table 2. Projected abundance of northern pikeminnow, salmonid consumption rates, and estimated losses of juvenile salmonids to predation*

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

* From NMFS (2000b).

Pikeminnow numbers likely have increased as favorable slack-water habitats have been created by impoundment and flow regulation. In unaltered systems, pikeminnow predation is limited by smolt migratory behavior; the 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 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 since the 1970s gradually have spread downstream throughout the lower mainstem. 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.

Piscivorous birds congregate near dams and in the estuary around man-made islands where they consume large numbers of outmigrating juvenile salmon and steelhead (Roby et al. 1998). Caspian terns, cormorants, and gull species are the major avian predators (NMFS 2000a). While some predation occurs at dam tailraces and juvenile bypass outfalls, by far the greatest numbers of juveniles are consumed as they migrate through the Columbia River estuary. Ruggerone (1986) estimated that gulls consumed 2% of the juvenile salmon and steelhead passing Wanapum Dam but comparable estimates have not been made for Bonneville Dam. Roby et al. (1998) estimated that avian predators consumed 10-30% of the total estuarine salmonid smolt population in 1997. (Additional discussion of bird predation in the estuary is included in section 45044960.1311136.0.)

Marine mammals prey on adult salmon, but the significance is unclear. Seals and sea lions are common in and immediately upstream of the Columbia River estuary and are regularly observed up to Bonneville Dam. 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, it is difficult to interpret the significance of this mortality factor for salmon, considering that large pinniped populations have always been present in the Columbia

River. However, current marine mammal predation may be proportionally more significant, since all sources of mortality on depressed stocks become more important. Their numbers were reduced by hunting (including bounty hunters) and harassment from the late 1800s until the Federal Marine Mammal Protection Act (FMMPA) was adopted in 1972. Their numbers have significantly increased since the adoption of FMMPA. Fishers historically viewed seals and sea lions as competitors and the old Fish Commission of Oregon funded a control program. These mammals can be troublesome to sport and commercial fishers by taking hooked or net-caught fish before they can be landed.

In summary, predation has been increased on salmonids by human-caused alterations including:

- Dams and impoundments,
- Decreased water flows,
- Predator habitat creation at artificial islands, and
- Introduced sport fishes.

3.2.3 Threats

The primary anthropogenic factors that have determined estuary and lower mainstem habitat conditions include hydrosystem construction and operation (water regulation), channel confinement (primarily diking), channel manipulation (primarily dredging), and floodplain development and water withdrawal for urbanization and agriculture. Generally, these anthropogenic factors have influenced estuary and lower mainstem habitat conditions by altering hydrologic conditions, sediment transport mechanisms, and/or salinity and nutrient circulation processes. Often, there are no simple connections between a single factor and a single response, as many of the factors and responses are interrelated.

Hydrosystem Alterations of Flow Patterns

Continued operation of upstream dams and irrigation withdrawals will affect estuarine circulation, deposition of sediments, and biological processes. Reduction of maximum flow levels, dredged material deposition, and diking have all but eliminated overbank flows in the Columbia River resulting in reduced large woody debris recruitment and riverine sediment transport to the estuary. Water level fluctuations associated with hydropower peak operations may reduce habitat availability and strand juveniles during the downstream migration. Threats to salmon from altered flows include:

- Lack of sediments delivered to estuary,
- Disruption of natural flow patterns (that affect migration and predation)
- Altered estuarine salinity patterns and estuary turbidity maximum function,
- Loss of water-driven access to river edge and off-channel habitat,
- Decreased recruitment of macrodetritus (decreased foodweb productivity),
- Altered juvenile migrations and stranding, and
- Disrupted turbidity patterns (decreased predator avoidance).

Channel Alterations and Diking

Channel confinement (diking) is particularly detrimental to lower river and estuary habitat capacity because it entirely removes habitat from the estuarine system. The lower Columbia River mainstem has, for the most part, been reduced to a single channel where floodplains have been reduced in size, off-channel habitat has been lost or disconnected from the main channel, and the amount of large woody debris has been reduced. Dikes prevent over-bank flow and affect the connectivity of the river and floodplain.

Development and maintenance of the shipping channel has greatly affected the bathymetry of the estuary, which affects tidal flow, salinity gradients, and the estuary turbidity maximum. The shipping channel has been maintained through the extensive use of jetties, pile dikes, and maintenance dredging, all of which has impacted natural flow patterns. Dredged materials are disposed of in the ocean, in the flow adjacent to the shipping channel, along shorelines, or on upland sites. By concentrating flow in one deeper main channel, the development of the navigation channel has reduced flow to side channels and peripheral bays. Continuing threats to salmon from channel alterations include:

- Conversion of wetlands and estuaries to other uses,
- Existing dikes that eliminate habitat availability or connectivity,
- Altered habitats behind dikes and levees,
- Poor or malfunctioning tide gates that strand juveniles,
- Continued dredging of the shipping channel, and
- Dredge material-created habitat for predators.

Contaminants

Environmental contaminants enter the lower Columbia River ecosystem through a variety of point and non-point sources, as well as from upstream. Point sources include outfalls at the numerous industrial facilities from Longview to Vancouver; non-point sources include agricultural and residential application of pesticides, insecticides, and herbicides and overland flow from impervious surfaces in developed areas. Salmonids may uptake contaminants through direct contact or biomagnification through the food chain. Continuing threats to salmon from contaminants include:

- Agricultural pesticides an fertilizers,
- Industrial discharges,
- Non-point urban and residential run-off of pollutants

3.3 Habitat – Ocean

3.3.1 Background

Just 7 years after record low returns that many feared were the last gasps of endangered salmon and steelhead populations, record high numbers of salmon and steelhead were counted at Bonneville Dam.3 Although dominated by hatchery fish, the 868,000 chinook, 260,000 coho, 115,000 sockeye, and 630,000 steelhead counted at Bonneville Dam in 2001 represent 5- to 25-fold increases from recent low counts of 189,000 chinook, 10,000 coho, 9,000 sockeye, and 162,000 steelhead.

Have fears of salmon extinction been overblown? Are the increases in response to two decades of costly protection and restoration? Have salmon recovered and is ESA listing no longer warranted? At least partial answers to these questions can be found by examining ocean productivity patterns and their effects on salmon survival.

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).

3.3.2 Limiting Factors

Ocean Climate Patterns

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 patterns 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. 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).

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, as illustrated by Figure 8. In contrast, the 1960s and early 1970s were dominated by a

[3] 403,000 in 1994 and 411,000 in 1995; 1.9 million in 2001 and 1.4 million in 2002.

cool, wet regime. A close examination of 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.

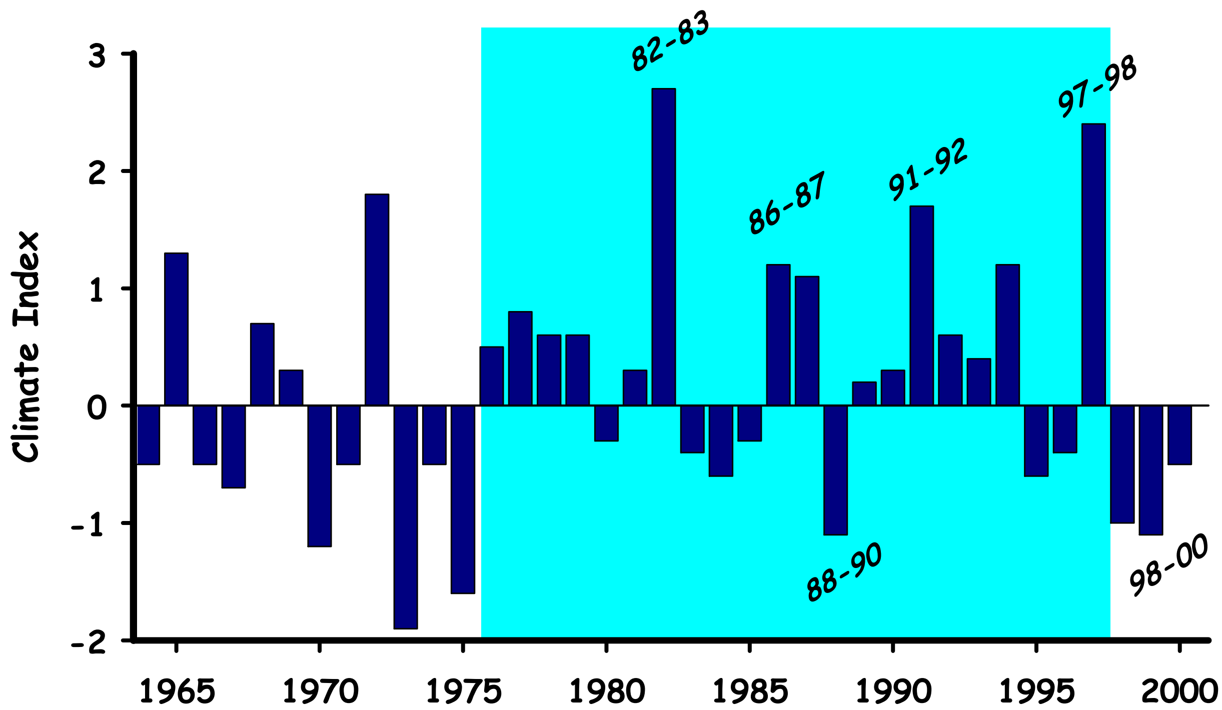

Figure 8. Annual variation in the multivariate El Niño southern oscillation (ENSO) index for December. Recent strong El Niño (positive values) and La Niña (negative values) years are labeled.

Climate and Ocean Productivity

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 9). 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, Pearcy 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.

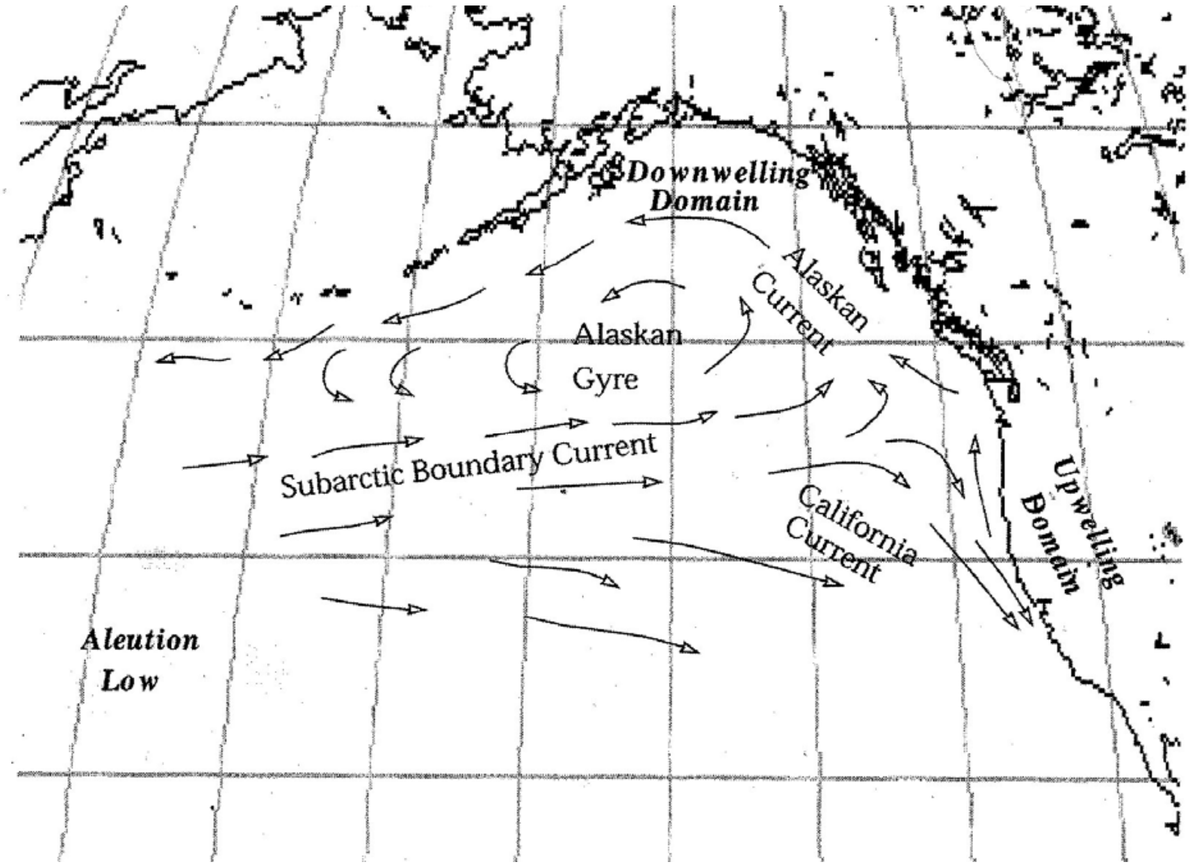

Figure 9. North Pacific currents and production domains. Years with an intense winter Aleutian low shift (warm dry in the Pacific Northwest) the subarctic current northward, strengthen the Alaskan current and increase the downwelling domain production. Years with a weak Aleutian low (cool wet in the Pacific Northwest) shift the subarctic current southward and strengthen the California current and the upwelling domain production (Anderson 2000).

Climate effects on ocean productivity can be compounded by parallel effects in freshwater. In the Pacific Northwest, cool, wet patterns that improve ocean survival and growth also increase precipitation, increase streamflow, and reduce temperature. Increased stream flow and cooler temperatures increase stream habitat quantity and quality for rearing salmonids. These changes also improve migration survival conditions for both juveniles and adults. Conversely, salmon productivity is reduced by low flows and warm temperatures during drought years that are often associated with El Niño. El Niños thus produce compound impacts by reducing both freshwater and saltwater survival conditions.

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. While ocean conditions are affected by the PDO, the phenomenon also influences freshwater environments as well, as precipitation and temperature patterns on land are also affected by the PDO. The PDO regimes have been related to abundance patterns in zooplankton, and subsequent production of Alaskan pink and sockeye salmon (Hare and Francis 1977). 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.

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).

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, 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 CWT 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 10). 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 10).

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).

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.

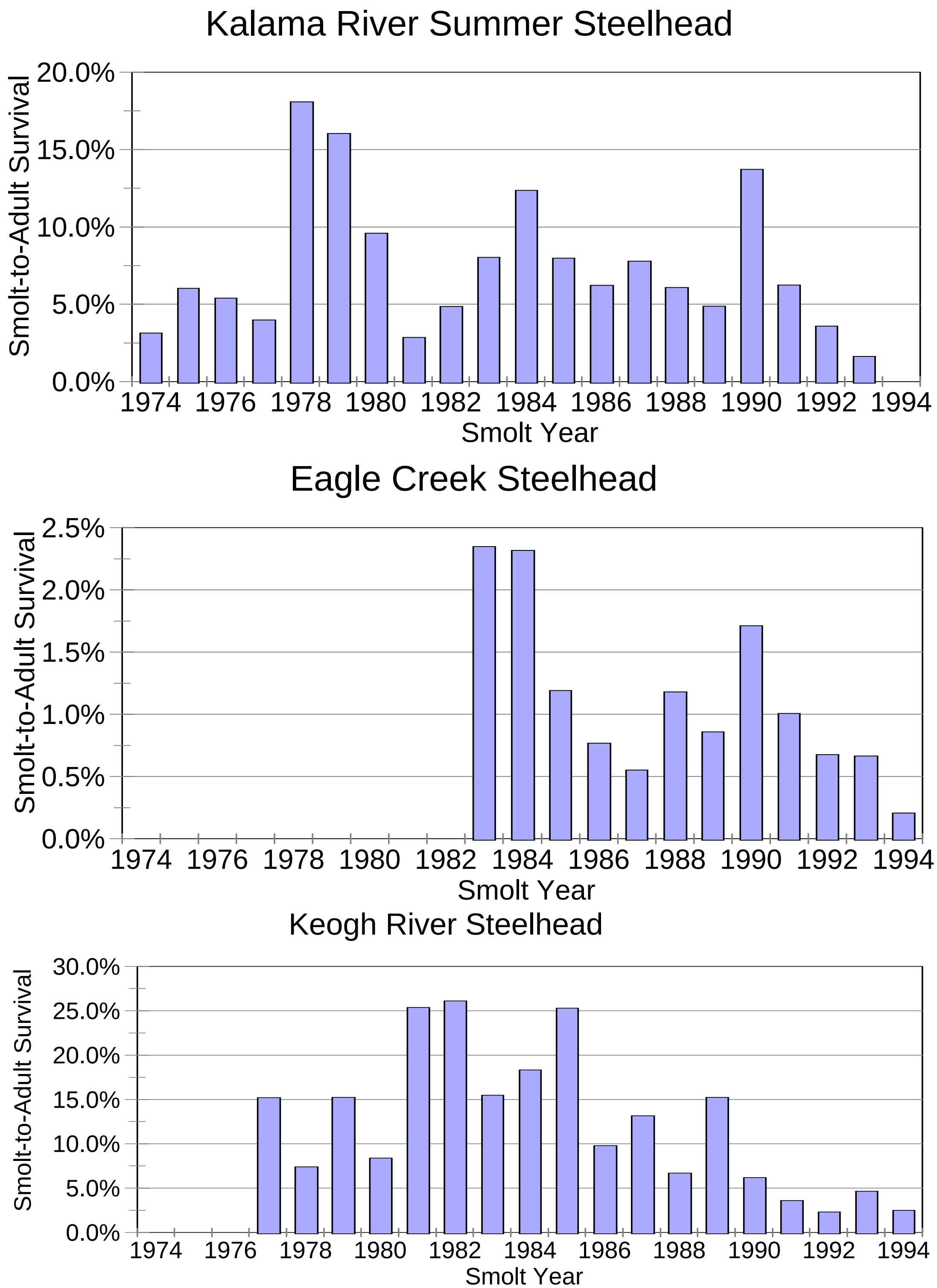

Figure 10. Annual means of smolt-to-adult survival rate of winter and summer steelhead from Kalama River Hatchery, winter steelhead from Eagle Creek National Fish Hatchery, and wild winter steelhead from the Keogh River, British Columbia.

3.3.3 Threats

There are very few management actions that can be taken relative to the effects of ocean conditions on salmon survival and productivity. The most notable aspect that humans can control to at least some extent is the number of smolts that leave freshwater each year. This can be accomplished through managing spawner escapements, hatchery releases, and habitat conditions. It is therefore essential that managers have a thorough understanding of the ways in which oceanic variations influence the production of returning adult salmon and of the importance of maintaining abundant smolt production.

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. This phenomenon is further described in section 4.6.2.4. 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.

In summary, the ocean-related threats to salmon viability and productivity include:

- Susceptibility of weak populations to extirpation during periods of marine survival downturns,
- Management complacency when marine survival is good,
- Inability to produce sufficient smolts that maximize adult returns, and
- Marine competition from hatchery stocks.

3.4 Hydropower

3.4.1 Background

Hydropower development in the lower Columbia Basin has created additional limiting factors for salmon such as restricted migrations, altered habitats, and increased predation and competition in the altered habitats. The ongoing operation of hydropower facilities will continue to pose threats to existing salmon populations and will present limitations to rebuilding populations. The only mainstem hydropower facility in the lower Columbia region is the Bonneville Dam, but operations of numerous dams upstream of Bonneville strongly influence water and flow levels which affect salmon in the lower Columbia. Significant tributary hydropower dams in the lower Columbia region are on the Cowlitz and Lewis rivers.

3.4.2 Limiting Factors

Flow Alterations

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 juvenile and decreases adult travel rates. Higher flows generally increase the survival of juveniles as they pass through the dams, because more fish can pass over the spillways, where mortality is low, 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. Hydropower flow alterations impact salmon by:

- Delayed migrations,
- Reducing survival through hydropower facilities,
- Disrupting spawning activities, and
- Stranding juveniles.

Water Quality

Flow regulation and reservoir construction have increased average water temperatures beyond optimums for salmon in the Columbia River mainstem. High water temperatures can cause migrating adult salmon to stop or delay their migrations. Warm temperatures can also increase the fishes' susceptibility to disease. Flow regulation and reservoir construction also have increased water clarity. Increased water clarity can affect salmon through 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. 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. Significant levels of dioxins/furans, DDT, and metals have been identified in lower Columbia River fish, sediment, and water samples. Water quality issues associated with hydropower operations limit salmon by:

- Temperatures elevated beyond tolerance limits,

- Delayed upstream migration,
- Increased susceptibility to disease,
- Gas bubble disease (supersaturated water), and
- Increased exposure to contaminants.

Altered Ecosystems

Modifications of riverine habitat to impoundments result in changes in habitat availability, migration patterns, feeding ecology, predation, and competition. For example, the Bonneville Dam impoundment has inundated limited spawning habitat in the lower reaches of upper Gorge tributaries. 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. Similar losses occur at Cowlitz and Lewis river hydropower dams. Together, these factors result in significant limitations of salmon by:

- Loss of spawning and rearing habitats,
- Migration and emigration delays,
- Increased predation on juveniles,
- Increased juvenile competition, and
- Changes in food availability.

Migration Barriers

***Blocked 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, and the majority of fall Chinook habitat since 1931. In the Cowlitz basin, the three mainstem dams inundated a total of 48 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.

***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 (Reichel and Bjornn 2003). These problems can result in significant upstream passage losses at dams. Average per dam survival rates in the lower Columbia River mainstem have been estimated at approximately 89% for spring chinook, 94% for fall chinook, and 95% for steelhead based on fish counts at successive dams, fallbacks after dam passage, harvest, and tributary escapements (*US v. Oregon* Technical Advisory Committee, unpublished data).

Fallback of adult salmon and steelhead after dam passage can be substantial; high levels of fallback are typically associated with 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). Adult salmonids that fall back over dams do not translate into a total loss as some fish may re-enter the fish ladder, successfully pass the dam, and continue 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 (Table 3). 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, ACOE, 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).

Table 3. Median entry times in days into Bonneville Dam fish bypass system by upstream chinook and steelhead migrants, 1996–97.

Species	1996	1997
Chinook	2.0	2.2
Steelhead	1.9	0.3

From NMFS (2000a)

Passage delays at dams are at least partially offset by more rapid movement of fish through slackwater reservoirs, so the net effect of dam and reservoir construction on upstream travel time for adults is unclear. 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 were 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.

***Juvenile Dam Passage* —** 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. Delay results as juveniles stack up in dam forebays during daylight, when they are reluctant to sound to enter turbine or spillway intakes. Juveniles may experience substantially different mortality rates depending on whether passage occurs via turbines, spill, or a fish bypass system. Fish passage at Bonneville Dam is particularly complex, with two passage routes at each of the two powerhouses, plus an unattached spillway.

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 90% per dam. Balloon tag tests conducted by Normandeau Associates Inc. indicated survival rates in the mid-90% range (Normandeau Associates Inc. et al. 1995, 1996, 1999).

Spillways 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. Improvements to spillway and tailrace configurations have been implemented since Holmes' study, and more recent research at other Columbia and Snake River projects have estimated typical spill survival to be around 98-100% (NMFS 2000). Historical operations attempted to minimize spill in order to maximize power generation. Current practices provide dedicated spill 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 gatewell. 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). Typical values for Bonneville Dam range from 16 to 48% (Table 4). Bypass mortality rates are typically quite low (<1%). The Bonneville second powerhouse bypass has been a conspicuous exception; past survival problems have recently been ameliorated by modifying the collection channel to improve hydraulic conditions and a new conveyance pipe and outfall have been installed to reduce predation problems (Gilbreath and Prentice 1999).

Table 4. Average juvenile fish guidance efficiencies (NMFS 2000) and 1988–97 bypass mortality rates (Martinson et al. 1998) at Bonneville Dam.

	Fish Guidance Efficiency (%)		Bypass Mortality	
Species	**Powerhouse 1**	**Powerhouse 2**	**Powerhouse 1**	**Powerhouse 2**
Yearling Chinook	38	44	0.1%	1.5%
Subyearling Chinook	16	18	0.4%	1.4%
Steelhead	41	48	0.1%	1.1%
Coho	—	—	0.1%	0.9%
Sockeye	—	—	0.4%	7.9%

In summary, Lower Columbia salmon are limited by hydropower migration barriers including:

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

3.4.3 Threats

Hydropower operations 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 Bonneville Dam and all upstream hydropower, flood control, and irrigation operations has 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 redds. Threats to salmon from hydropower water management include:

- Alteration of the natural diurnal and seasonal flow pattern (including abrogation of the prescribed water budget),
- Gas supersaturation during high flows,
- Stranding of juveniles,
- Disrupted spawners, and
- Dewatered 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 are encountering numerous obstacles to both upstream and downstream migrant survival. At Bonneville Dam on the mainstem, fish ladders provide for upstream dam passage of adult salmon but are not 100% effective. For example, approximately 10% of adults fall back over the dam and either die or reenter the fish ladders. Likewise, approximately 10% of downstream-migrating juveniles die as they pass Bonneville Dam. Certain species, such as chum salmon, do not negotiate fish ladders very well; access to historical habitats in the mainstem have been blocked by Bonneville Dam. Ongoing threats to salmon from hydropower obstructions and delays 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 lower Columbia 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 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.

3.5 Harvest

3.5.1 Background

This section provides an overview of fisheries and fishery regulatory processes that would be considered when analyzing potential fishery impacts to focal fish species of the lower Columbia River. It is intended to illustrate the complexities in fishery management involving salmon and steelhead which travel through various freshwater and ocean jurisdictions during their life cycle and are subject to numerous catch allocation agreements, conservation requirements, and legal mandates. The section explains the different types of fishery impacts, the types of fisheries and areas in which fisheries occur, and the multitude of jurisdictions and processes these fish are subjected to. This section also provides perspective on historic and current harvest impacts for each species, including an estimate of change in hatchery and wild harvest rates from the 1930s to date, and an illustration of current harvest distribution (who is catching the fish) between ocean and freshwater fisheries. The section also displays several examples of management criteria, including ESA mandates, which drive the harvest of individual species in the various fisheries to which they contribute. Catch and effort numbers illustrate the magnitude of targeted or incidental catches as the majority of present-day effort is focused on harvestable hatchery fish and healthy wild fish.

In the early part of the 20th century, nearly all commercial fisheries in this region operated in freshwater, where they harvested only mature salmon. Ocean fisheries became more important in the late 1950s as more restrictions were imposed on freshwater and coastal estuary fisheries. Ocean harvest of salmon peaked in the 1970s and 1980s. In recent years, ocean commercial and recreational harvest of salmon has generally been reduced as a result of international treaties, fisheries conservation acts, regional conservation goals, the Endangered Species Act, and state and tribal management agreements.

Analysis of fisheries questions may consider a variety of direct and indirect effects. 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. The emphasis of weak stock management has changed over the last 25 years, as ocean and freshwater fisheries have been widely reduced and refocused on hatchery-origin or healthy wild fish using a combination of time, area, and mark-selective regulations: Although direct harvest of weak stocks or populations, including many of those of Washington's lower Columbia River, has never been a desirable management practice, incidental fishery impacts have now become much more important in managing weak stocks than directed harvest. On the other hand, limits intended to protect weak stocks in mixed stock fisheries reduce access to healthy wild or hatchery runs. Relatively small numbers or proportions of a protected stock may be impacted in a mixed stock fishery, but the regulatory consequences of those small impact allowances can result in significant reduction in harvest opportunity in mixed stock fisheries.

Fishery impact analyses may be conducted at population or fishery-specific levels. Population-specific analyses would treat impacts by all fisheries in aggregate. Fishery-specific analyses would consider fine-scale impacts. By nature of their wide ranging travels, anadromous salmonids can be exposed to a wide variety of fisheries from their lower Columbia watershed of origin all the way to Canada and Alaska (Figure 11). This broad distribution can substantially complicate analysis and attempts to limit impacts on specific stocks.

Analysis of fishing and harvest is also complicated by the need to consider fisheries impacts at both the species impact and population goal levels. Fishing mortality can be considered an impact that interacts with other factors to affect salmon productivity and viability and thus needs to be addressed as part of recovery planning and actions. However, directed harvest or increased accessibility to other populations in mixed stock fisheries are also key elements of broad recovery goals, because recovery objectives include sustaining healthy, harvestable populations.

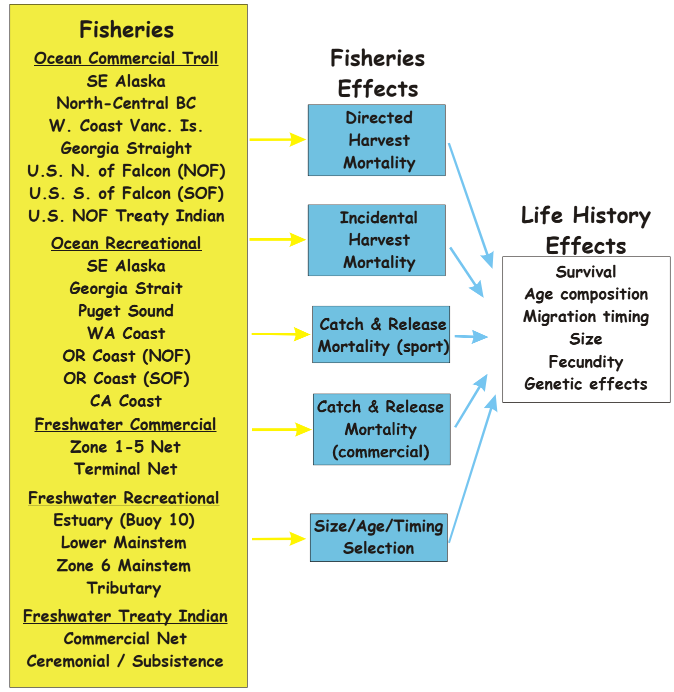

Figure 11. Fisheries, fisheries effects, and life history effects.

Fisheries Types and Areas

By nature of their wide-ranging migrations, anadromous salmonids can be exposed to a variety of fisheries from their basin of origin all the way to Canada and Alaska. Lower Columbia River salmonids are harvested in commercial, sport, and tribal fisheries throughout the West Coast of the United States and Canada. The following sections are a brief description of different regional fisheries.

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. US/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 PST limitations.

In June 1999, under the PST, Canada and the US 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 US 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 US 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.

***United States West Coast Ocean* —** Ocean fisheries along the U.S. West Coast are separated into four major management areas (Figure 12):

1. US/Canada border to Cape Falcon, Oregon
2. Cape Falcon, Oregon to Humbug Mountain, Oregon
3. Humbug Mountain, Oregon, to Horse Mountain, California
4. Horse Mountain, California to the US/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 13 and Figure 14).

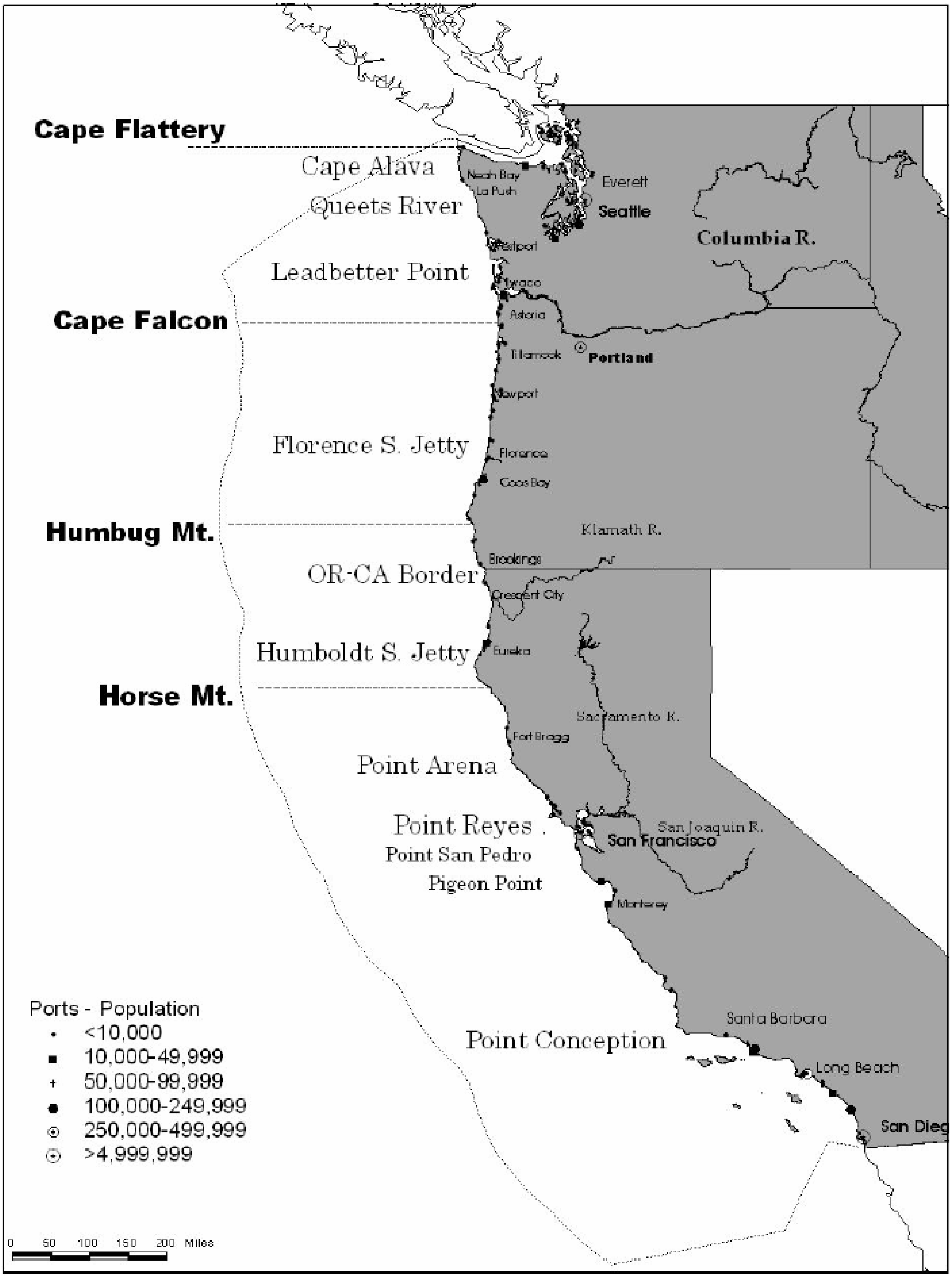

Figure 12. Major management areas in US West Coast ocean fisheries.

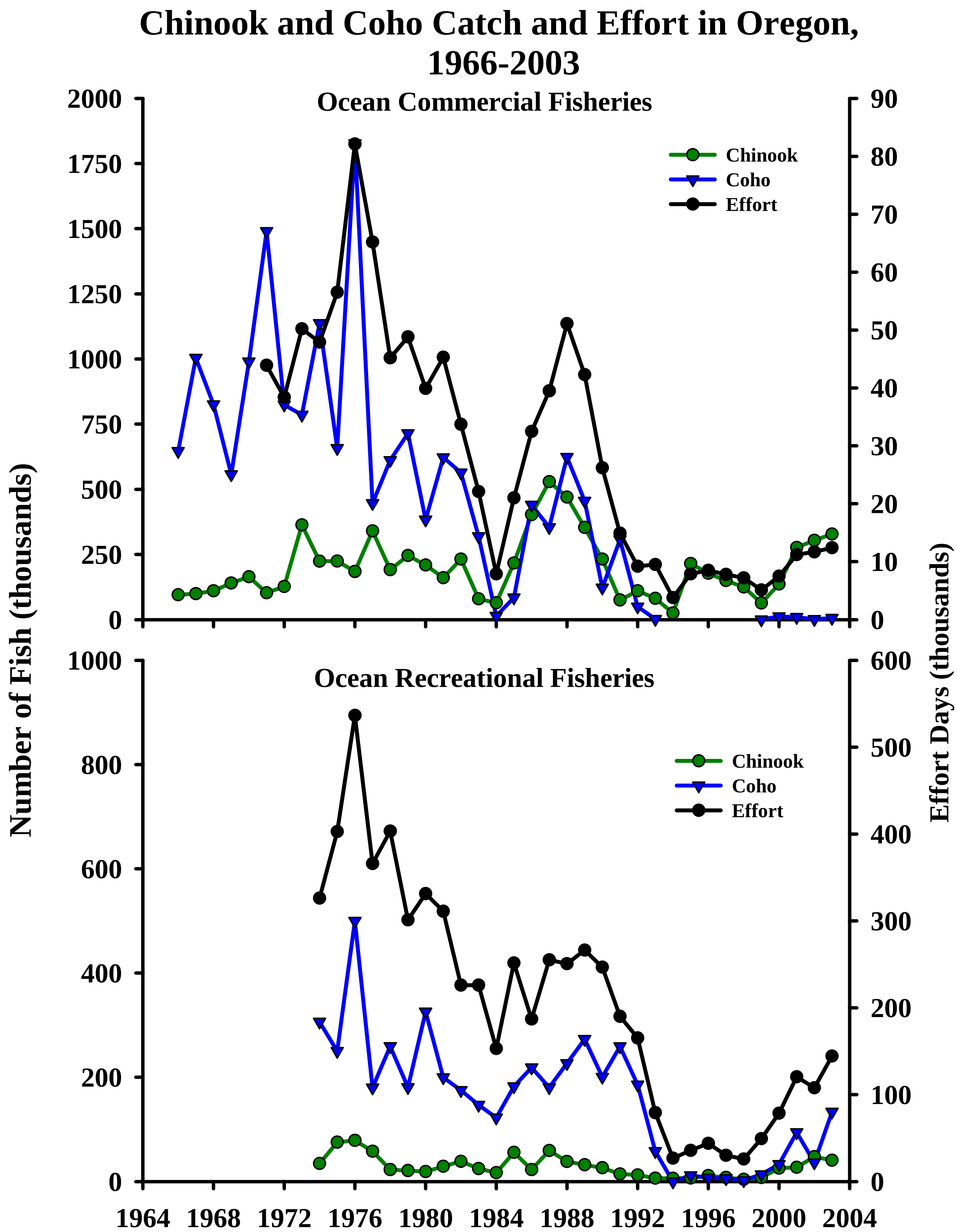

Figure 13. Commercial and recreational ocean catch and effort for chinook and coho in Oregon, 1966–2003.

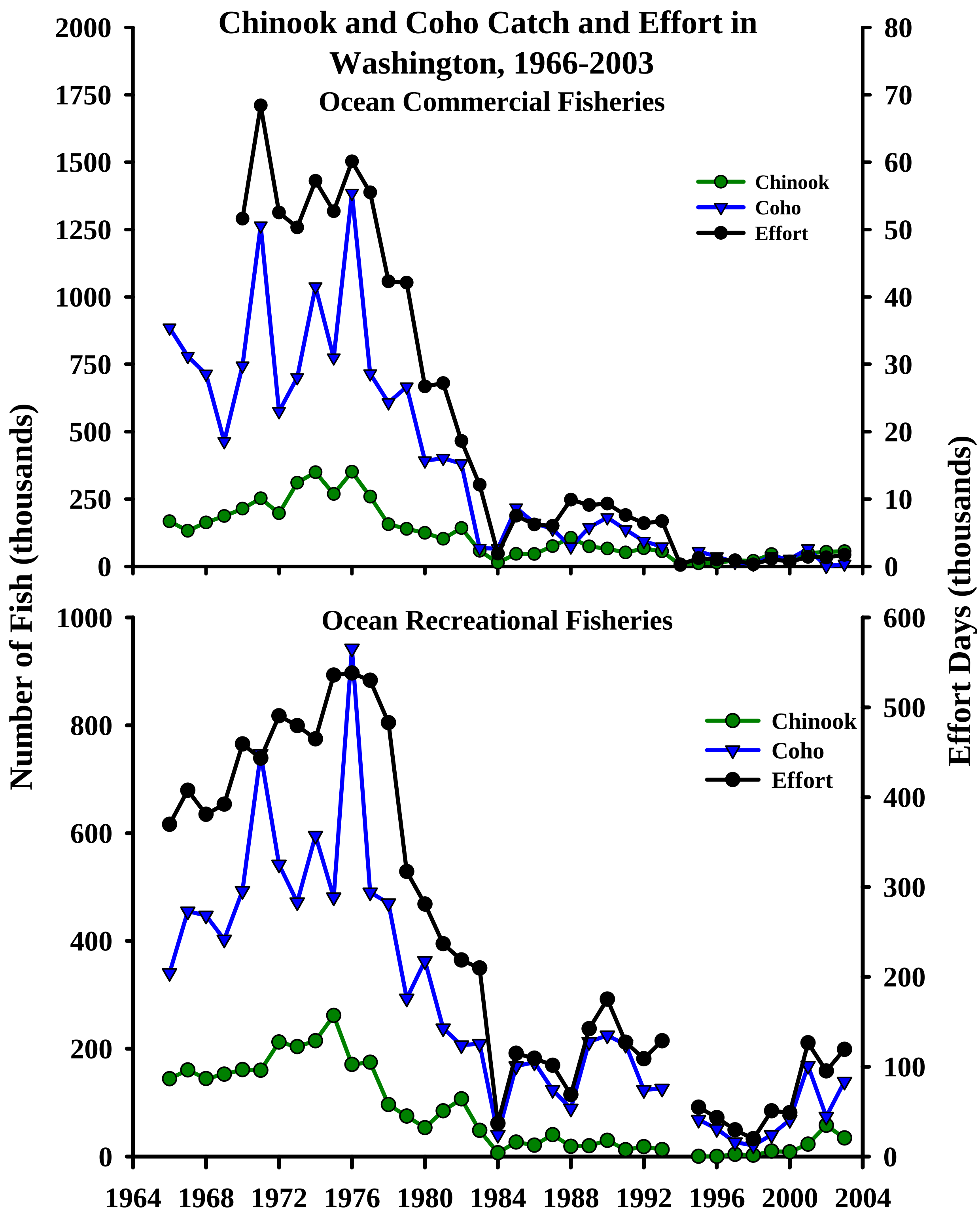

Figure 14. Commercial and recreational ocean catch and effort of chinook and coho in Washington, 1966–2003.

Lower Columbia River Commercial **—** Europeans began using Pacific salmon about 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 15). 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).

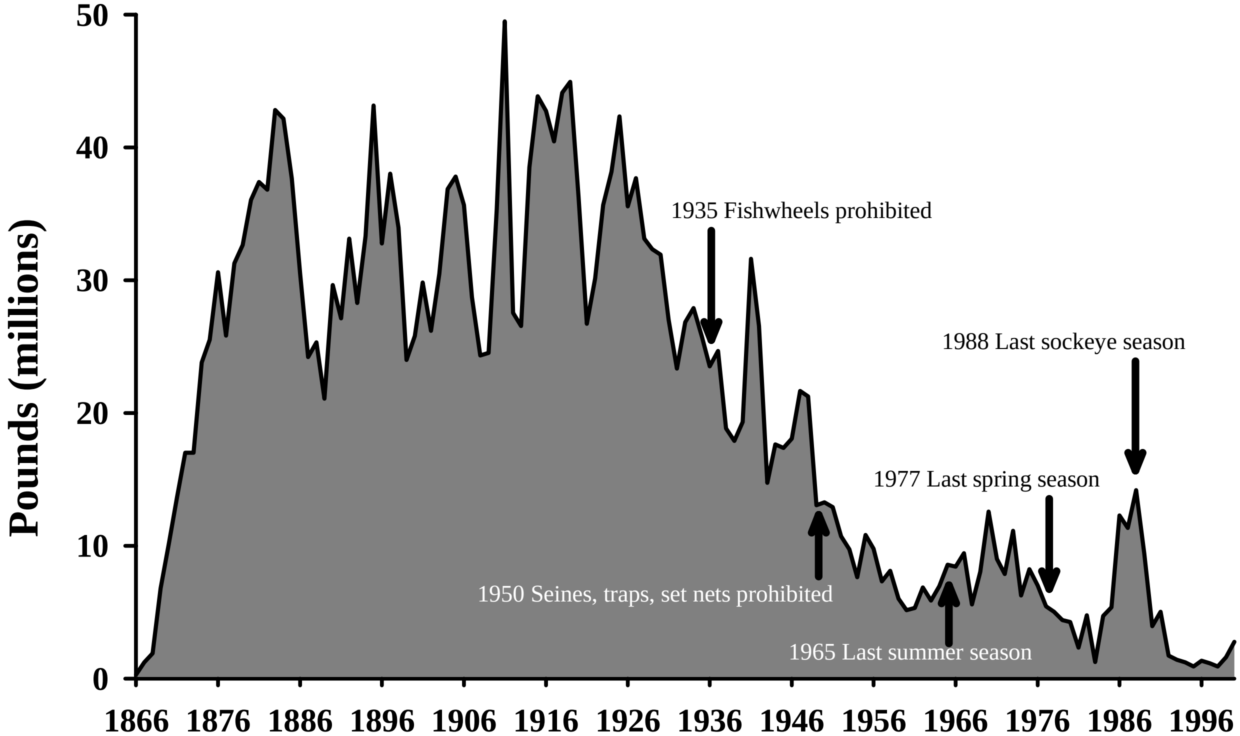

Figure 15. Commercial landings of salmon and steelhead from the Columbia River in pounds, 1866–1999 (ODFW and WDFW 2000).

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 16). 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 17). 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 17).

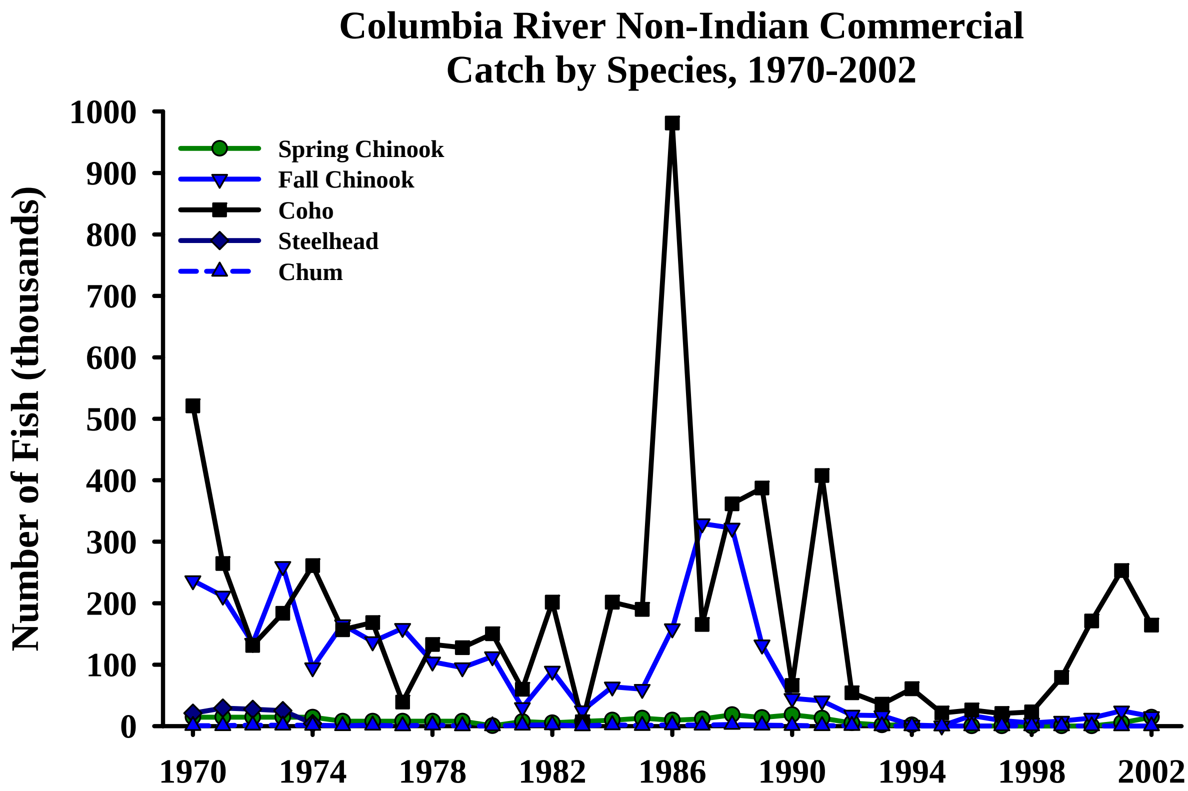

Figure 16. Non-Indian commercial fishery catch in the Columbia River, 1970–2002.

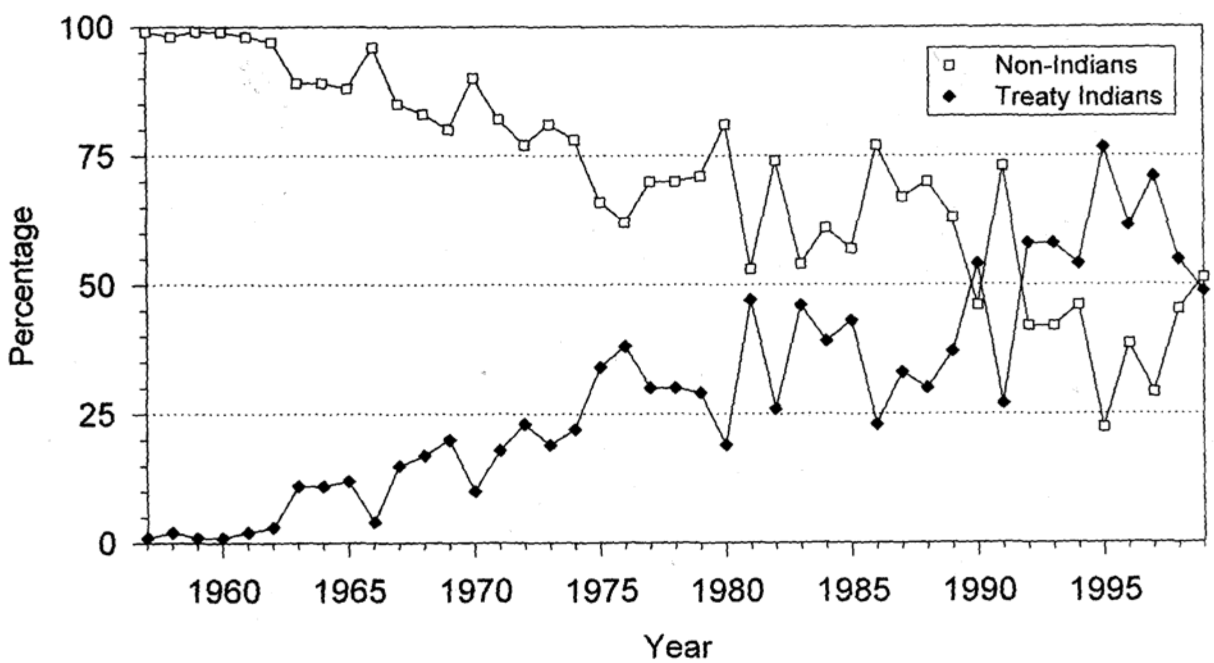

Figure 17. Percentage of Columbia River commercial landings of salmon and steelhead in pounds made by non-Indians and treaty Indians, 1957–02 (ODFW and WDFW 2004).

Lower Columbia River non-Indian commercial fisheries occur below Bonneville Dam in the mainstem (statistical Zones 1-5) 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).

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 no spring season 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* —** Before 1975, lower Columbia River recreational fisheries primarily targeted salmon and steelhead. Season closures for spring and summer chinook and declines of other salmonids transitioned much of the effort to sturgeon (Figure 18). Recent-year improvements in salmonid returns and selective fishery opportunities in the recreational fishery have resulted in a rebound in salmonid angler effort, and catch of certain salmonids has also increased in the mainstem Columbia (Figure 19).

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. 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 recreation 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. Since 1986, lower Columbia sturgeon angler effort has ranged from approximately 140,000 to 200,000 trips per year.

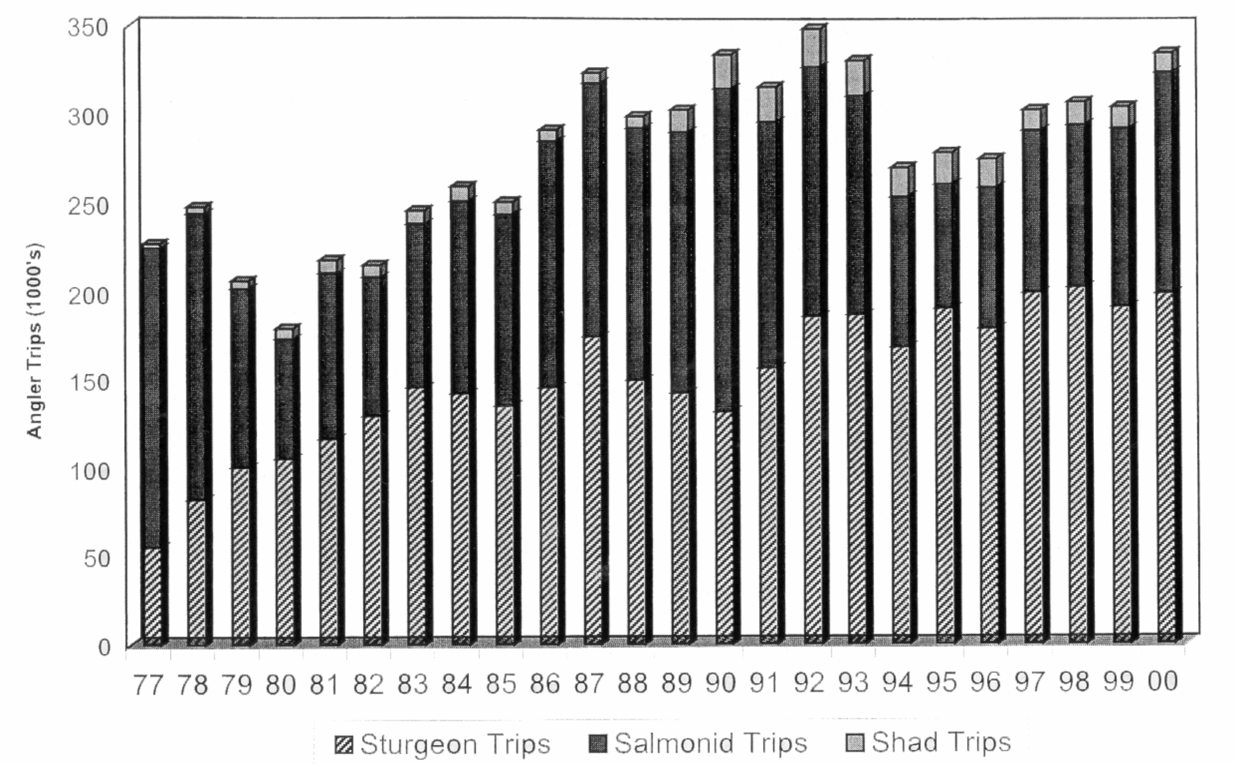

Figure 18. Angler effort by species on the lower Columbia River, 1977–2000.

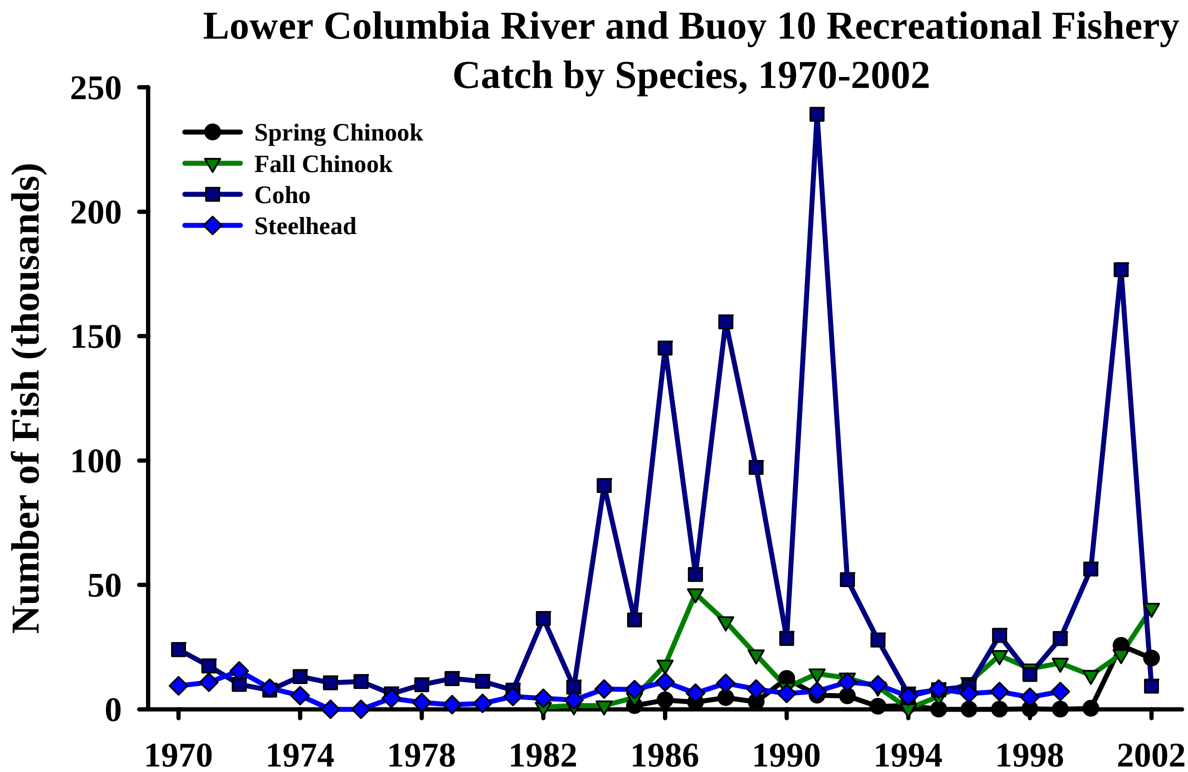

Figure 19. Recreational fishery catch in the lower Columbia River, 1970–2002.

Lower Columbia Tributary Recreational — Salmon and steelhead sport fishing occurs in most Washington lower Columbia River tributaries. Tributary harvest is managed consistent with objectives of the WDFW wild salmonid policy. They are principally managed to meet wild salmon and steelhead escapement objectives and to meet the objectives of the artificial propagation programs (WDFW FMEP, 2003). 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. Hatchery-produced fall chinook are not all marked, so fall chinook fisheries retain both wild and hatchery fish. 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 Lewis bright peak in mid September-mid October. Coho fisheries occur during August-January with two peaks; early coho catch peaks in September and late coho in October. 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 (WDFW, 2003).

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 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, joint action by Oregon and Washington 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 20). 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 20).

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 20), and a Columbia River management agreement which establishes ESA fishery impact limits based on and abundance-based management strategy.

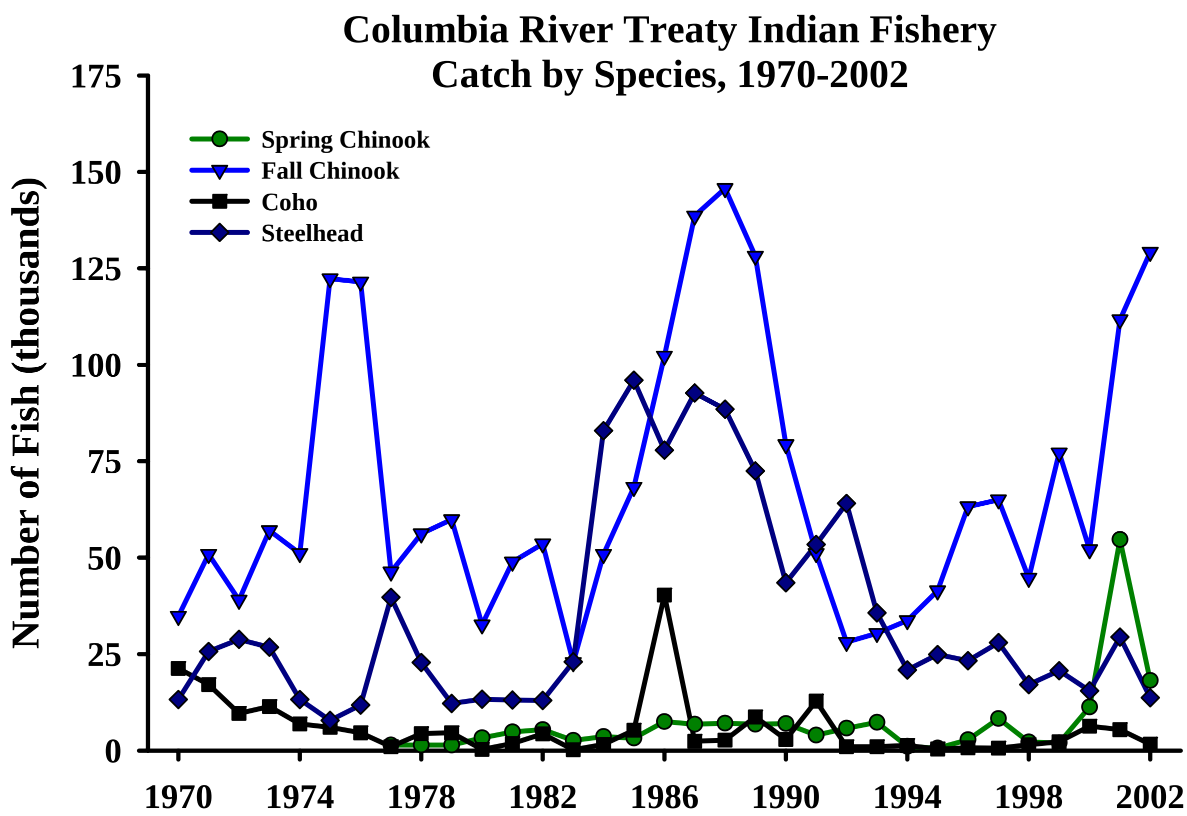

Figure 20. Treaty Indian fishery catch, 1970–2002.

Fisheries Management Structure

Because of their exposure to fisheries across large geographic regions of the West Coast, Pacific salmon and steelhead 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), the Endangered Species Act (ESA) administered by NOAA Fisheries, The Pacific Fishery Management Council (PFMC), the states of Oregon and Washington, the Columbia River Compact, and management agreements negotiated between the parties to *US v. Oregon*.

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, Transboundary, 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 US 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, groundfish, 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 12). 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 NOAA Fisheries 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 PFMC evaluates ESA consultation standards each year and provides guidance for the upcoming ocean fishing season. The standards for 2003 are presented for those ESUs with potential connections to lower Columbia River salmonids (Table 5). Further ESA restrictions apply to specific inside Columbia River fisheries and are discussed in the species-specific sections to follow.

***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.

***US v. Oregon* —** In 1968, the US 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 *US v. Oregon*. After 20 years of legal tests and negotiations, the 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 *US v. Oregon* negotiated three-year (1996–98) management agreements: one each for upper Columbia fall chinook and uppe 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. 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. The CRFMP is currently being negotiated for a longer-term agreement for all species to be in place by 2004.

Table 5. List of species managed by the PFMC with potential impacts on lower Columbia River salmonids.

ESU	Stock Representation in Salmon FMP	ESA Consultation Standard	Council Guidance for 2003
Lower Columbia River chinook—threatened	Sandy, Cowlitz, Kalama, Lewis spring	No specific requirements	Meet hatchery escapement goals
	Sandy, Cowlitz, Kalama fall	Brood year adult equivalent exploitation rate on Coweeman tule fall chinook ≤ 49%	Same as consultation standard
	North Fork Lewis fall	5,700 MSY level adult spawning escapement	Same as consultation standard
Upper Willamette chinook— threatened	Upper Willamette River spring	No specific requirements; rare occurrence in Council fisheries	Same as consultation standard
Upper Columbia River spring chinook—endangered	Upper Columbia River spring	No specific requirements; rare occurrence in Council fisheries	No additional constraints; Ocean fishery impacts minor
Snake River fall chinook— threatened	Snake River fall	30% reduction from the 1988–93 average adult (age 3 & 4) exploitation rate for all ocean fisheries	Same as consultation standard
Snake River spring/summer chinook— threatened	Snake River spring/ summer	No specific requirements; rare occurrence in Council fisheries	Same as consultation standard
Oregon Coast coho—threatened	S. central OR coast N. central OR coast N. OR coast	15% (in 2003) combined marine/ freshwater exploitation rate	Same as consultation standard
Lower Columbia River/Southwest Washington coho—candidate	Sandy and Clackamas River	No specific requirements	≤ 20% ocean exploitation rate

Columbia River Compact — In 1918, the US 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 21).

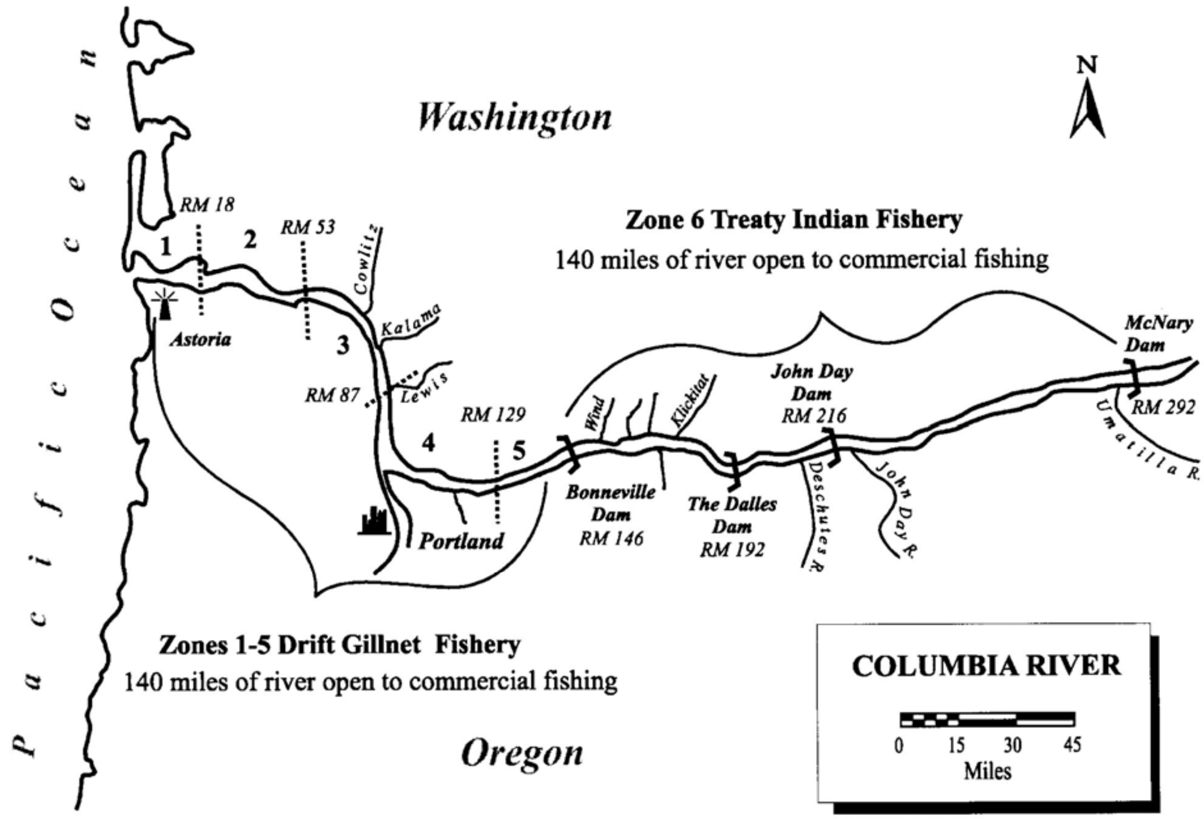

Figure 21. Columbia River commercial fishing zones.

Endangered Species Act (ESA) — Throughout the 1990s, 12 Columbia River basin Evolutionarily Significant Units (ESUs) were listed as threatened (T) or endangered (E):

- Snake River fall chinook (T—April 1992)
- Snake River spring/summer chinook (T—April 1992)
- lower Columbia River chinook (T—March 1999)
- upper Willamette River chinook (T—March 1999)
- upper Columbia River spring chinook (T—March 1999)
- Columbia River chum (T—March 1999)
- Snake River sockeye (E—November 1991)
- upper Columbia River steelhead (E—August 1997)
- Snake River steelhead (T—August 1997)
- lower Columbia River steelhead (T—March 1998)
- upper Willamette River steelhead (T—March 1999)
- middle Columbia River steelhead (T—March 1999)

An additional ESU (lower Columbia/SW Washington coho) was designated as a candidate species in July 1995. NOAA Fisheries also reviewed the status of this ESU and its boundary designations in 2001-2003, but has not published findings on the review. In addition, numerous other listed or candidate ESUs along the California, Oregon, and Washington coasts affect ocean fisheries targeted on harvesting Columbia River salmonids. Because of the ESA status of many Columbia River salmonids, harvest managers must consult annually with NOAA Fisheries to assure fishers are regulated to meet no-jeopardy standards established for ESA-listed species. NOAA Fisheries issues incidental take permits to regulatory agencies and Tribes for fisheries that have satisfied ESA regulatory requirements.

3.5.2 Limiting Factors

Overall Fishing Impacts

Currently, harvest occurs in the Canada/Alaska ocean, U.S. West Coast ocean, lower Columbia River commercial and recreational, tributary recreational, and in-river treaty Indian (including commercial, ceremonial, and subsistence) fisheries, as described above. Total exploitation rates have decreased for lower Columbia salmon and steelhead, especially since the 1970s.

An approximation of current fishing impact rates on lower Columbia River naturally spawning salmon populations ranges from 2.5% for chum salmon to 45% for tule fall Chinook (Table 6). Fishery impact rates for hatchery produced spring Chinook, coho, and steelhead are higher than for naturally-spawning fish of the same species because of selective fishing regulations. These rates, for naturally-spawning and hatchery fish, include estimates of direct harvest mortality as well as estimates of incidental mortality in catch and release fisheries. These rates generally reflect recent year (2001-2003) fishery regulations and quotas controlled by weak stock impact limits and annual abundance of healthy targeted fish. Actual harvest rates will vary for each year dependent on annual stock status of multiple west coast salmon populations, however, these rates generally reflect expected impacts of harvest on lower Columbia naturally-spawning and hatchery salmon and steelhead under current harvest management plans.

Table 6. Approximate annual exploitation rates (% harvested) for naturally-spawning lower Columbia salmon and steelhead under current management controls (represents 2001-2003 fishing period).

	AK./Can. Ocean	West Coast Ocean	Col. R. Comm.	Col. R. Sport	Trib. Sport	Wild Total	Hatchery Total	Historic Highs
Spring Chinook	13	5	1	1	2	22	53	65
Fall Chinook (Tule)	15	15	5	5	5	45	45	80
Fall Chinook (Bright)	19	3	6	2	10	40	na	65
Chum	0	0	1.5	0	1	2.5	2.5	60
Coho	<1	9	6	2	1	18	51	85
Steelhead	0	<1	3	0.5	5	8.5	70	75

Rates are very low for chum salmon, which are not encountered by ocean fisheries and return to freshwater in late fall when significant Columbia River commercial fisheries no longer occur. Chum are no longer targeted in Columbia commercial seasons and prohibited from retention in sport fisheries. Columbia River fall Chinook are subject to freshwater and ocean fisheries from Alaska to their rivers of origin in fisheries targeting abundant Chinook stocks originating from Alaska, Canada, Washington, Oregon, and California. Columbia tule fall Chinook harvest is also constrained by a Recovery Exploitation Rate (RER) developed by NOAA Fisheries for management of Coweeman naturally pawning fall Chinook. Harvest of lower Columbia bright fall Chinook is managed to achieve an escapement goal of 5,700 natural spawners in the North Fork Lewis. Steelhead, like chum, are not encountered by ocean fisheries and non-Indian commercial steelhead fisheries are prohibited in the Columbia River. 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 are not marked for selective fisheries, but likely will be in the future because of recent legislation enacted by Congress.

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 7). In the 1980s coordinated ocean and freshwater weak stock management commenced. More fishery restrictions followed ESA listings in the 1990s.

Table 7. 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

Access to harvestable surpluses of strong stocks in the Columbia River and ocean is regulated by impact limits on weak populations mixed with the strong. 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 8). 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.

Table 8. Current 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 (15% limit)	Columbia River
	Upriver ESA (2% limit)	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 (49% limit)	West Coast Ocean, Columbia River
	Coweeman, EF Lewis closures	Tributary sport
	Snake Fall Chinook ESA (8.25% non-Indian limit)	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 (8.25% non-Indian limit)	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 (2-5% limit)	Columbia River
Coho	Hatchery escapement goals	All U.S. fisheries
	OCN Coho ESA (abundance limit, typical 8-15%)	West Coast Ocean
	Oregon state coho ESA (typical 13% limit)	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 (Indian-15%,NI-2%)	Columbia River, Tributary sport
	FMEP	

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.

Sources of Fishing Effects

***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 a specific stock in the mix can be achieved 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). Stock identification techniques are constantly being improved to assist managers in making informed and timely fishery decisions. For example, 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. Regulations prohibiting harvest of wild fish (i.e. nonadipose fin-clipped fish) have been relatively successful. However, the occurrence of delayed mortality as a result of releasing wild fish captured in commercial fisheries is presently unmeasured.

***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, 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.

Effects of Fisheries on Population Biology and Structure

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.

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 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 spring need to decide chinook, coho, and steelhead.

In summary, salmon and steelhead production is impacted by fishing activities that:

- Depress the number of successful spawners,
- 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 any of the spawners' genetic characteristics, and/or
- Alters the population structure or diversity.

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, and
- Complexity of management institutions causing an inability to get agreement.

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 (about 18% of the total runs) occurs in the ocean incidental to target fisheries for Alaskan, Canadian, Columbia River hatchery, and California hatchery Chinook stocks. Current fishing impact rates on wild spring Chinook in Columbia basin fisheries account for an additional average of 4%. 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, and
- Poaching.

Fall Chinook Fishery

The majority of lower Columbia fall Chinook populations are considered to be depressed (not meeting escapement expectations). Recent fishing rates on lower Columbia fall Chinook have averaged 40-45%, approximately half of the 70-80% rate until the 1990s. Columbia River tule fall Chinook are harvested in ocean commercial and recreational fisheries from Oregon to Alaska (about 30% of the total run size), as well as the Columbia River commercial gill net and sport fisheries (about 15% more). 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. Unlike spring Chinook, hatchery fall Chinook are not fin-marked, so harvest rates are the same for hatchery and wild fish. Columbia River and tributary fisheries quotas are set for tules according to a limit of 49% for Coweeman fall Chinook and for lower river brights by an escapement target of 5,700 to the North Fork Lewis River. Fishing-related threats to wild fall Chinook include:

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

Coho Fishery

Wild coho stocks in Lower Columbia River tributaries in Washington are considered depressed, primarily because of chronically low escapement and production and much of the small natural production is thought to be from hatchery strays. 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 exploitation rate of wild coho is about 15% to 20%, while the exploitation of hatchery coho has remained similar to the 1990s rate of approximately 50%. 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-finclipped) 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
- Poaching.

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. NOAA Fisheries' 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. Even though no fisheries target chum salmon, fishing activities result in the following threats:

- Incidental catch in sport and commercial fisheries, and
- Poaching.

Steelhead Fishery

Historical abundance of steelhead is undocumented. However, no existing summer or winter steelhead runs are meeting escapement goals and, of the six historical summer steelhead populations and the 17 winter steelhead populations in the Lower Columbia ESU. 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. Interception of steelhead in ocean salmon fisheries is rare. Currently, the primary fisheries targeting steelhead occur in the Columbia River mainstem and tributaries; these fisheries harvest primarily hatchery fish and wild fish 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
- Poaching.

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,
- Poaching.

3.6 Hatchery

3.6.1 Background

Salmon and steelhead production in the lower Columbia region is currently dominated by hatchery fish, as was expected when the hatchery mitigation programs were developed. There are 20 salmon and steelhead production hatcheries in the lower Columbia Basin as well as a number of associated rearing facilities and acclimation sites. Lower Columbia hatcheries are used for producing fish for sport and commercial harvest, augmenting and/or supplementing natural production, and as conservation banks for severely depleted populations. These hatcheries have played a major role in producing salmon for harvest. They have also impacted wild populations. Fisheries managers and the public are struggling to find the 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. Although strides are being made in reducing the impacts of hatcheries, wild salmon and steelhead are still being limited and threatened by hatchery practices.

Hatcheries currently release over 50 million salmon and steelhead per year in Washington lower Columbia River subbasins (Table 9). Two-thirds (34 million) are tule fall Chinook, 9.6 million are coho, spring Chinook total 5.4 million, steelhead 2.5 million, and chum 0.5 million. Fall Chinook and chum are released as subyearlings; other species are 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.

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. After artificial production practices were first perfected in the early 1900s, hatcheries were seen as an inexhaustible source of fish for harvest. Many hatcheries were initially built as mitigation to offset the detrimental effects of development on salmon habitat and access. For instance, 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. However, the significance of local adaptation to population health was poorly understood and hatcheries regularly mixed stocks from different basins which further exacerbated the effects of hatchery selection practices and domestication. Further, widespread hatchery releases masked the declines of naturally spawning fish as the habitat declined. The 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.

Attitudes changed with recognition of the potential risks of hatcheries and hatchery fish to the diversity and productivity of the remaining naturally spawning populations and our ability to accurately assess naturally spawning population status. Prevailing opinion shifted to the perspective that hatcheries did more harm than good. Widespread hatchery closures were advocated to protect the remaining naturally spawning fish. Controversy and confusion resulted as many people had difficulty reconciling the need for more fish to prevent extinction with the idea that hatcheries produced more fish but these fish were somehow undesirable.

Table 9. 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***

We now know that each extreme view contains elements of the truth. Hatcheries are not a panacea for salmon enhancement or recovery. Nor are they the root cause of salmon decline. Hatcheries, like any good tool, can generate valuable benefits but can also cause significant adverse impacts if not prudently and properly employed.

There are 20 salmon and steelhead production hatcheries in the lower Columbia basin (Figure 22) as well as a number of associated rearing facilities and acclimation sites. These hatcheries have played a major role in producing salmon for harvest. Fisheries managers and the public are attempting to find the balance between hatchery facilities that can; 1) produce excess 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. 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 some key natural production, especially tule fall chinook and coho, now largely supported by hatchery augmentation. Rather, modifying hatchery programs so they support an integrated, comprehensive approach to rehabilitating depleted populations, and providing fish for harvest while minimizing impacts to wild fish, should be the goal for hatcheries into the future (NRC 1996).

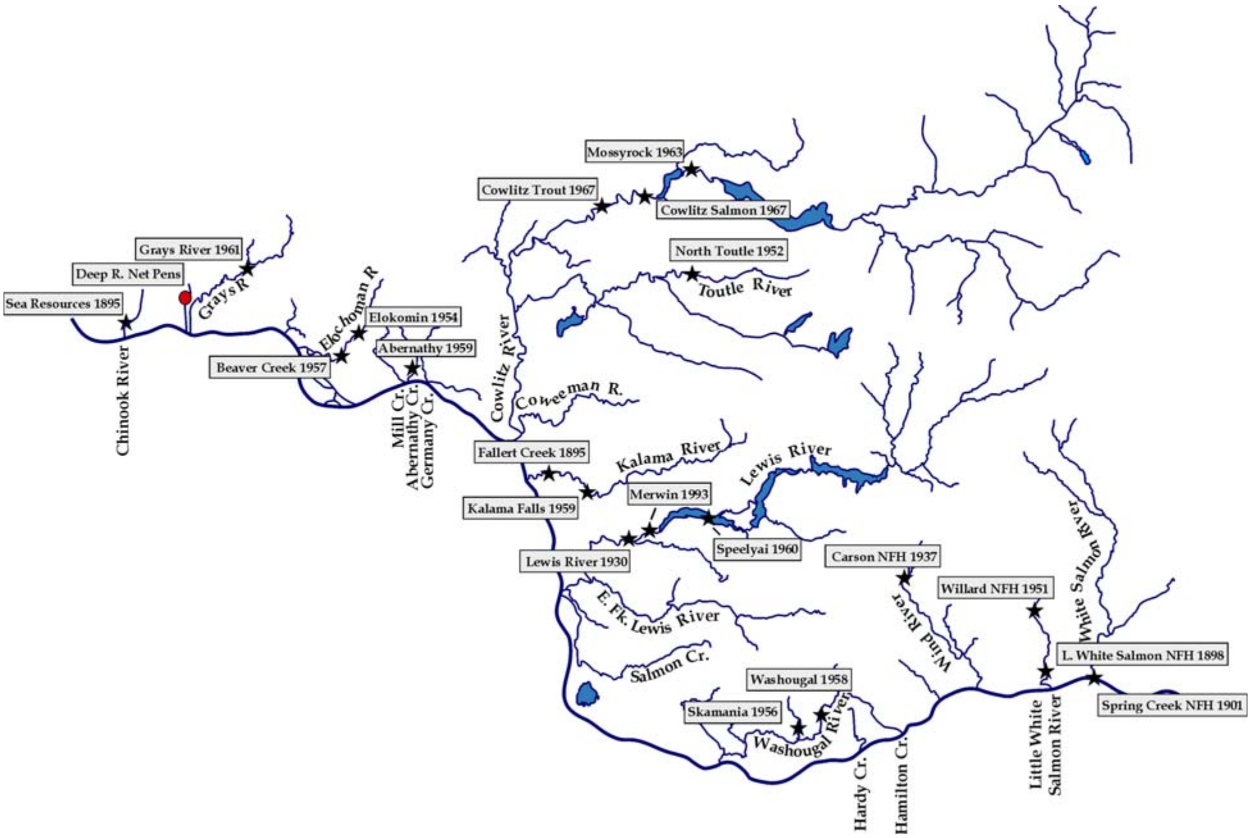

Figure 22. Lower Columbia production fish hatcheries and beginning dates of operation.

Types of Hatcheries

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 1997). 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. 1991). There are currently no true conservation hatchery programs in the lower Columbia planning area.

This hatchery section describes detrimental effects that hatchery programs can potentially have on natural fish populations. This section is intended to illustrate the types of potential risks associated with hatchery operations in general and describe the specific lower Columbia basin hatchery programs in the context of those risk factors, including magnitude and time of hatchery fish released by species, adult returns of hatchery and natural fish, genetics, hatchery/wild interaction potential, the effects of water quality and diseases, passage problems, mixed harvest potential, and programs to supplement wild fish. The section is not intended, however, to quantify the risks to natural fish populations nor reach conclusions concerning presence or absence of risk factors in particular hatchery programs in the lower Columbia basin. Rather, it provides perspective on the overall importance of hatcheries in the lower Columbia as well as specific details on individual programs that can be used, during development of the Management Plan, in formulating risk assessments for impacted natural fish populations and the risks to fisheries and fisheries agreements as a result of potential adjustments to present hatchery programs.

Lower Columbia Basin Hatchery Operations

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 will continue to be evaluated for compatibility with natural populations (ISAB 2003). As wild population rebuilding unfolds, however, the objective to maintain adequate salmon and steelhead hatchery production to support fisheries in the lower Columbia should not be dismissed.

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 (CBFWA 1990, cited in 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.

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 (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, and 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.

NOAA Fisheries is in the process of preparing an Environmental Impact Statement (EIS) for the funding and operation of Columbia River hatcheries authorized under the Mitchell Act (Public Law 75-502). The EIS will evaluate the environmental impacts of a full range of alternatives for funding and operation of Columbia River Hatchery programs consistent with the Mitchell Act, Endangered Species Act (ESA), Tribal trust responsibilities, and broader NOAA Fisheries objectives for sustainable fisheries under the Magnuson-Stevens Fisheries Conservation and Management Act. Currently, funds are provided to the Washington Department of Fish and Wildlife (WDFW), 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 potentially address the following issues: 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 impact 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 rights affected by hatchery production; and 5) Will hatchery operations have disproportional impacts on lower income groups? NOAA Fisheries expects to complete a final EIS and make ESA determinations on hatchery programs supported through the Mitchell Act by the fall of 2006.

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).

In 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.

3.6.2 Limiting Factors

Hatchery programs provide one of the few alternatives for mitigating the large losses of salmon populations, for example, in instances where dams completely block access to salmon spawning areas. However, poorly designed hatchery programs often are detrimental to wild salmon production (Cone and Ridlington 1996, Walters et al. 1988, NRC 1996, Lichatowich 1999). Comprehensive analyses of the impacts of hatcheries on wild salmon involve investigating a variety of effects, many poorly understood.

Hatchery effects on wild fish can be positive and/or negative. Hatchery managers have numerous operational choices (left panel, Figure 23) that affect the biology and productivity (center panel, Figure 23), and thereby influence the life cycle, of both the hatchery fish and the wild fish with which they interact (right panel, Figure 23). Direct and indirect effects and hatchery releases can impact natural stocks in a number of possible ways. The following sections present more detailed information on how hatchery practices can result in life cycle effects on wild populations; the magnitude and actual occurrence of these effects vary among hatcheries and depend on specific operational procedures at individual facilities.

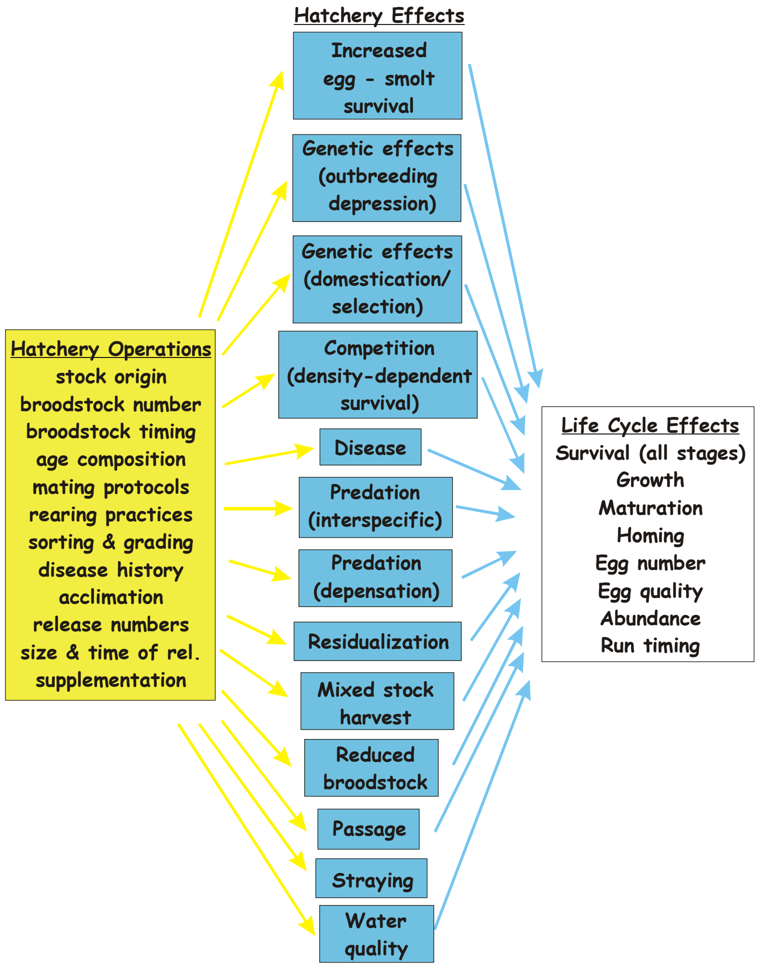

Figure 23. Potential links between hatchery operating procedures and effects on salmonids.

Increased Egg to Smolt Survival

Hatcheries substantially increase net productivity by increasing egg-to-smolt survival; because hatcheries are able to control the incubation and rearing environment, they usually can achieve higher egg-to-smolt survival than is 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).

On the other hand, because of their ability to produce many offspring from relatively few adults, hatchery programs have been widely considered for supplementation of weak natural runs (Cuenco et al. 1993), although this approach remains controversial (NRC 1996). Conservation hatchery programs are a key component in ongoing attempts to preserve and rebuild several listed Columbia basin salmon stocks (Waples and Do 1994).

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 (Resisenbichler 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.

Genetic differences in hatchery fish

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) (Reisenbichler 1997).

Loss of genetic variation within a population generally occurs through either genetic drift or selection as listed above. *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), rather than the simple number of fish in the population. The artificial reduction in effective population size may be caused by the use of males to fertilize multiple females. Simon et al. (1986) found that survival from smolt to age 2+ was significantly and positively correlated ($P<0.01$) to effective population size. 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. 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). New guidelines for hatchery practices issued by state and federal agencies on the West Coast have been designed to eliminate artificial reductions in effective population size.

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 we cannot predict 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 1970, 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 (Resienbichler 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 with every salmonid species that survival to adulthood increases as smolt size at a given time increases. Thus, when a hatchery eliminates the environmental perils of early spawning, a new selective advantage is provided to early spawning fish. Hatchery practices can minimize this selectivity scenario by taking eggs throughout the spawning period and may also control growth by regulating water temperature.

Genetic influence of hatchery fish on natural spawners — 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).

In summary, genetic limitations to wild salmon and steelhead productivity result from hatchery operations through:

- 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.

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 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.

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.*"

Developing and improving supplementation, as well as standard, hatchery programs will continue to be a key component in ongoing attempts to preserve and rebuild listed Columbia basin salmon stocks.

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.

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. Evidence indicates that straying is more likely among some races of salmon than others. Chapman et al (1991) reviewed the evidence on straying of spring and summer chinook throughout the Columbia basin and found high homing fidelity to nearly every hatchery. However, straying of spring chinook from Lookingglass Hatchery in the Grand Ronde basin into other tributaries of the Grand Ronde River was significant in the 1980s. Quinn and Fresh (1984) documented evidence from Cowlitz River spring chinook that social interaction aids in homing; straying rates increase as spawner abundance declines. To reduce the potential for straying, hatchery programs routinely release hatchery salmon from acclimation ponds to improve homing fidelity. Research by ODFW (2002) on coastal steelhead populations showed that direct stream releases did not increase the potential straying relative to acclimation.

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.

In summary, mixing populations between hatcheries and between hatchery and wild fish may impact Lower Columbia salmon by:

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

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. When hatchery fish are released into streams where wild fish are present, there can be competition for food and space (McMichael et al. 2000). Competition between wild and hatchery individuals 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). When hatchery fish are released into streams where there are wild fish, 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 — Salmonid smolts actively feed during normal downstream migration (Becker 1973, Muir and Emmelt 1988, Sagar and Glova 1988). 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. From 1987 to 1991, empty stomachs were observed in 26% to 38% of the yearling chinook salmon smolts sampled at Lower Granite Dam and in 1991, compared to less than 55 empty stomachs at McNary and Bonneville dams

(Muir and Coley 1994). This data suggests that, in some reservoir areas or portions of reservoir areas, food availability is limited and that increased hatchery production could compound the problem. The areas where food is limited and the effect of reduced feeding success on smolt performance and survival are unknown (Muir and Coley 1994). 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.

***Estuarine Conditions* —** The estuary is clearly an important rearing area for juvenile anadromous salmonids of all species and sizes as they move toward the ocean (Healey 1991). 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. 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 and Wissmar (1984) cautioned that estuary conditions may limit rearing production of juvenile chinook, and many other studies have demonstrated the importance of the estuary to survival and population fitness (Miller et al. 2003).

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). Chapman et al. (1994) concluded that the survival of juveniles transported to below Bonneville Dam at a size too small to ensure high initial marine survival may depend upon growth in the estuary for successful ocean entry. 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. Fish that arrive in the estuary later in the season may benefit from increased food supplies. Chapman et al. (1994) notes that subyearling chinook released later in the summer returned at significantly higher rates than subyearlings released early in the summer.

Ocean Conditions — There has been a general consensus that most density-dependent mechanisms at sea, if they occur, take place very early; probably 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.

In summary, hatchery fish may compete for food and/or space with Lower Columbia wild fish throughout their shared life history, resulting in:

- 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.

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 by IHOT and the Pacific Northwest Fish Health Protection Committee have reduced the abundance and virulence of pathogens in hatchery populations.

Hatchery programs therefore affect disease processes in salmon and steelhead through:

- 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). However, most residual steelhead observed are in poor condition and likely do not survive long enough to become piscivorous (Petit, Idaho Department of Fish and Game, personal communication). This hypothesis is consistent with findings by Mauser (1991, unpublished), Partridge (1986), and Schuck (1991, unpublished) as described by Cannamela (1992). Recent hatchery management practices to address residualism concerns include targeting the size at release for steelhead to a range of 185-220 mm. Constructing 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.

In summary, hatchery fish can result in increased predation on wild salmon through:

- 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. Hatchery-origin fall chinook are not currently adipose fin-clipped for selective harvest and selective regulations are not in place for fall chinook fisheries. Wild fish harvest rates are also controlled by 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).

Hatchery fish produced for harvest can impact wild populations through:

- 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. Weirs often cannot be operated as desired or according to protocol because of 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).

Impacts to wild fish from blocked migratory access at hatcheries, and impacts to wild fish from hatchery fish access, include:

- 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 WDOE. 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). 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 effect 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).

Thus, hatchery operations can influence water quality and quantity to the detriment of wild fish through:

- 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, and
- Blocked habitat at hatchery facilities.

3.7 Ecological Interactions

3.7.1 Background

Ecological relationships describe species-species relationships and species-environment relationships; paramount to these relationships are the effects to the specific life stage of focal species, if known. Two general categories of interspecies relationships exist: native-native interactions and native-exotic interactions. Each of these categories are further segregated into predation or competition aspects of species interactions. Additionally, some exotic species interactions address full scale ecosystem alterations.

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 make quantification difficult. 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. This section includes consideration of ecological influences of other species and habitat changes on salmonids. The status of other related species, and the ecological interactions that influence them, is addressed in Section 4.8, below.

3.7.2 Limiting Factors

Ecological Interactions

Predation — Significant numbers of salmon are lost to fish, bird, and marine mammal predators during migration through the mainstem Columbia 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). While some predation occurs at dam tailraces and juvenile bypass outfalls, by far the greatest numbers of juveniles are consumed as they migrate through the Columbia River estuary. Marine mammals prey on adult salmon, but the significance is unclear. Approximate predation rates can be estimated although interpretation can be complicated. In the lower Columbia River, northern pikeminnow, Caspian tern, and marine mammal predation on salmon has been estimated at approximately 5%, 10-30%, and 3-12%, respectively of total salmon numbers.

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. 2001). 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. 2003). 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. 2003).

Northern pikeminnow are also a significant predator on salmonid smolts in the lower Columbia River as discussed above in section 4.2.2.8. Pikeminnow predation is greatest downstream of mainstem dams. Pikeminnow abundance in the estuary is likely low because of salinity; thus, pikeminnow predation is not likely to be an important limiting factor on juvenile salmonids in the estuary.

***Competition* –** Competition among salmonids and between salmonids and other fish may occur in the subbasins, mainstem, or estuary. At present levels of natural production, density-dependent competition is not likely a limiting factor in the subbasins, although these relationships have not been clearly established. Large hatchery releases within each subbasin may trigger density-dependent competition, but the potential for this is minimized by releasing hatchery fish that are ready to emigrate.

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 macrodetritus to microdetritus base (i.e. increased importation of plankton from upstream reservoirs) has benefited zooplanktivores, including American shad (Sherwood et al. 1990). 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. In press). 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 (up to RKm 62) 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). Another study examined shad abundance as prey contributing to faster growth rates of northern pikeminnow, which in turn are significant predators of juvenile salmonids (Petersen et al. In press). 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 (WDFW and ODFW 2002).

The intensity and magnitude of competition in estuaries depends in part on the duration of residence of hatchery and natural juvenile salmonids. Estuaries may be "overgrazed" when large numbers of ocean-type juveniles enter the estuary *en masse* (Reimers 1973, Healey 1991). Food availability may be negatively affected by the temporal and spatial overlap of juvenile salmonids from different locations; competition for prey may also develop when large releases of hatchery salmonids enter the estuary (Bisbal and McConnaha 1998), although this issue remains unresolved (Lichatowich 1993 as cited in Williams et al. 2000). Reimer (1971) suggested that density-dependence affects growth rate and hypothesized that fall chinook growth in the Sixes River was poor from June to August because of greater juvenile densities in the estuary but that increased growth rate in the fall resulted from smaller population size and a better utilization of the whole estuary. 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.

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). However, Witty et al. (1995) could not find any papers or studies that evaluated specific competition factors between hatchery and wild fish in the Columbia River estuary. Simenstad and Wissmar (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. 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).

The ecological interactions of predation and competition limit salmon by:

- 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.

Effects of Ecosystem Changes on Salmonids

Natural and anthropogenic factors have negatively altered habitat-forming processes, available habitat types, and the estuarine food web, resulting in decreased salmonid survival and production. The most significant habitat effects have resulted from modified river flow and channel manipulations. River flow changes have occurred as a result of hydrosystem operations, water withdrawals for agriculture and urban development, and decreased precipitation from climate changes. Channel manipulations encompass a suite of factors, but primarily refer to dikes that disconnect the river and floodplain or dredging that alters the river's bathymetry. Subsequently, estuary and lower mainstem habitat changes have facilitated the increase of important juvenile salmonid predators (specifically, Caspian terns and northern pikeminnow), thereby decreasing juvenile salmonid survival and abundance through the lower mainstem and estuary.

In a recent analysis of limiting factors, Fresh et al. (2003) evaluated the effects of river flow, habitat quality/availability, contaminant toxicity, and Caspian tern predation on juvenile salmonid abundance, life history diversity, and viable salmon population criteria. They concluded that the most important limiting factors are flow and habitat changes and the primary effects are on shallow water habitats and the salmonid life history strategies that depend on these habitats. Thus, habitat losses that have occurred in the estuary and lower mainstem (namely shallow water, peripheral habitats such as wetlands and side channels) are more limiting on subyearling life history strategies (commonly ocean-type life history) than yearling life history strategies (stream-type salmonids) that are not critically associated with these habitat types (Fresh et al. 2003). They further evaluated the effects of each limiting factor on viable salmon population criteria (abundance, population growth rate, spatial structure, and diversity; McElhany et al. 2000) and concluded that flow and habitat substantially limit all viability criteria for ocean-type salmonids.

Decreased Habitat Diversity and Productivity – Historically, floodwaters of the Columbia River inundated the margins and floodplains along the estuary, allowing juvenile salmon access to a wide expanse of low-velocity marshland and tidal channel habitats (Bottom et al. 2001). Flooding occurred frequently and was important to habitat diversity and complexity. Historical flooding also allowed more flow to off-channel habitats (i.e. side channels and bays) and deposited more large woody debris into the ecosystem. Historically, seasonal flooding increased the potential for salmonid feeding and resting areas in the estuary during the spring/summer freshet season by creating significant tidal marsh vegetation and wetland areas throughout the floodplain (Bottom et al. 2001). These conditions rarely exist today because of hydropower system water regulation.

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. 2001, 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 microdetritus 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. 2001, USACE 2001). The historic macrodetritus-based food web was distributed throughout the lower river and estuary, but the modern microdetritus-based food web is focused on the spatially confined ETM region of the estuary (Bottom et al. 2001). 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. 2001, USACE 2001).

Columbia River mainstem reservoirs trap sediments and nutrients, as well as reduce sediment bedload 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. 2001). 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. 2001).

Additionally, the decreased habitat diversity and 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 time of capture 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.

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.

Altered Migration Patterns — Hydrologic effects of the Columbia River dams include water level fluctuations, altered seasonal and daily flow regimes, reduced water velocities, and reduced discharge volume. Altered flow regimes can affect the migratory behavior of juvenile and adult salmonids. For example, water level fluctuations associated with hydropower peak operations may reduce habitat availability, inhibit the establishment of aquatic macrophytes that provide cover for fish, and strand juveniles during the downstream migration. Reservoir drawdowns reduce available habitat which concentrates organisms, potentially increasing predation and disease transmission (Spence et al. 1996 as cited in NMFS 2000c).

Water regulation, as part of hydropower system operations, has drastically reduced historic spring freshet flows and altered juvenile salmon emigration behavior. Often, historic lower Columbia River spring freshet flows were approximately four times the winter low flow levels. Today, spring freshet flows are only about twice the winter low flow level, which is now generally increased during reservoir drawdown in winter. Spring freshets are very important to the emigration of juvenile salmonids; freshet flows stimulate salmon downstream migration and provide a mechanism for rapid migrations.

In summary, the effects of altered ecosystems on salmonid ecology include:

- Creation of habitat or structures that favor salmonid predators,
- Altered stream flow regimes,
- Loss of stream, off-channel, and estuarine rearing habitats,
- Change from macro- to micro-detritus base of the food web,
- Loss of juvenile life-history types, and
- Reduction of marine-derived nutrients delivered to freshwater ecosystems via salmon carcasses.

Non-native Species

The nature of exotic 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.

The transition of the estuarine food web from a macrodetritus to microdetritus base (increased importation of plankton from upstream reservoirs) has benefited zooplanktivores, including American shad. Because of their abundance and consumption rates, American shad may have modified the estuarine food web. Also, shad and subyearling salmonid diets may overlap, suggesting potential competition effects.

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. These ecological interactions limit salmon by:

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

3.7.3 Threats

Predation

Human-induced habitat change has promoted the increase in native predator populations. For example, the Caspian tern breeding population in the estuary has expanded as a result of dredge material islands while northern pikeminnow abundance has increase because of favorable slackwater habitats created from the hydrosystem. At present, we lack the ability to determine how current levels of predation on salmonids compare to historical levels. Continued threats that affect predation on salmonids include:

- Operation of mainstem dams and other structures that encourage congregation of predators as a result of regulated water flow, and
- Creation of dredge material islands that increase habitat capacity for avian predators, such as Caspian tern.

Competition

Competition within and among species has been altered and exaggerated by ecological interactions, such as modified habitats and introduced species. Changes in food-webs that have resulted from the mainstem impoundments, or from introduced species, are also contributing to increased competition for food and space. Large hatchery releases may trigger density-dependent competition in streams, the mainstem, and/or the estuary.

Continued threats to salmonids from altered competition patterns include:

- Excessive hatchery releases,
- Altered streamflows that affect habitat,
- Mainstem impoundments that benefit competitive species,
- Increasing non-native fish populations
- Reduced juvenile salmonid food base,
- Limitations on freshwater productivity,

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 are not clear. Continuing threats from these ecosystem relationships include:

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

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 other 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 gamefish 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.

3.8 Other Fish and Wildlife Species

The other fish and wildlife species addressed in this Management Plan are affected by many of the same limiting factors and threats that affect salmonids. Regardless of their current abundance trend, implementation of an ecosystem-based approach to recovery of ESA-listed species indicates that an evaluation of effects of each recovery action on other species is warranted. Given the diversity of species comprising these other fish and wildlife species, population trends in response to current habitat conditions throughout the lower Columbia River ecosystem are quite variable. Some species are thriving in the altered lower Columbia River ecosystem, others have experienced precipitous declines, others appear unaffected by habitat changes that have occurred from historical to present times, while status of other species is unknown because data to assess population response to present habitat conditions are limited. The status and abundance trends of the non-salmonid focal species in the Columbia River estuary and lower mainstem are summarized below.

Four fish species are relatively abundant throughout the lower Columbia: cutthroat trout, white sturgeon, northern pikeminnow, and American shad. Two anadromous fish species (Pacific lamprey and eulachon) have experienced declining or variable trends in recent years; both are an integral part of the lower Columbia River ecosystem and are considered an important food source for sturgeon and pinnipeds. Other fish and wildlife species populations appear to be stable, but have low abundance compared to elsewhere in their range; species that fall into this category include green sturgeon, smallmouth bass, walleye, channel catfish, river otter, seals, and sea lions. The Columbia River seal and sea lion population appears stable or increasing. Aspian terns, native to the region but historically were not present in the lower Columbia River ecosystem, are now consistently found in the area because of human-induced habitat change. The sandhill crane and dusky Canada goose are other avian species that were not historically present in the lower Columbia River ecosystem. Agricultural lands in the lower Columbia floodplain have attracted cranes and geese to the region. Two avian species (bald eagle and osprey) have relatively stable populations trends but appear to be experiencing low reproductive success as a result of contaminant exposure. Two vastly different species (Columbian white-tailed deer and western pond turtle) have extremely low abundance levels in the lower Columbia River ecosystem. Data are sparse for a number of species, specifically yellow warbler and red-eyed vireo. Evidence suggest that abundance of both of these species is generally low in the lower Columbia River ecosystem; only possible breeding evidence exists for the area. Further details on all of these species are presented below.

3.8.1 Other Sensitive Species

Bald Eagle

Because of their presence in the mainstem and estuary, bald eagles may be limited by many of the same factors identified for salmonids in the estuary and mainstem habitat section. In particular, floodplain development and presence of contaminants negatively affect bald eagles (Table 10). Bald eagles are strongly associated with large trees during nesting, perching, and roosting; thus, the loss of mature forest habitats in the Columbia River estuary and lower mainstem has likely decreased potential eagle territories. The lower Columbia River bald eagle population is one of only two regional populations in Washington that has exhibited low reproductive success representative of a decreasing population (the other regional population was in Hood Canal). Bald eagle populations in the estuary and lower mainstem have suffered from low reproductive success because of contaminants in the ecosystem that caused eggshell thinning. The populations have remained stable because of adult influx from nearby populations.

The Washington and Oregon bald eagle populations were listed as endangered under the ESA in 1978. In 1995, the USFWS reclassified the listing to threatened. In 1999, the USFWS proposed to delist the bald eagle throughout its range, however, this delisting has not been finalized.

Table 10. Suspected bald eagle limiting factors.

Life Stage	Limiting Factors
Reproductive Success	**BE.LF.1** Contaminant exposure. Contaminants have been documented throughout the lower mainstem and estuary. Uptake may be via prey consumption or direct contact. Contaminants are known to decrease eggshell thickness, which affects survival.
	BE.LF.2 Availability of nesting habitat. Eagles prefer mature forest habitats with adequate nest and roost trees in close proximity to abundant fish resources.

Sandhill Crane

The lower Columbia River mainstem and estuary is not a historic breeding or overwintering area for sandhill cranes. Sandhill cranes currently do not breed in the area, but agricultural development throughout the lower Columbia River floodplain has attracted overwintering sandhill cranes. Up to 1,000 sandhill cranes are estimated to winter in the lower Columbia River floodplain and an additional 2,000 to 3,000 sandhill cranes are estimated to use the lower Columbia River floodplain as a migratory stopover. All cranes observed wintering at Ridgefield NWR and Sauvie Island Wildlife Area, Oregon, in late November 2001 and February 2002 were Canadian sandhills, and based on observations of marked birds, wintering cranes regularly move back and forth between these areas (Ivey et al. in prep.). Because of their presence in the mainstem and estuary, sandhill cranes may be limited by many of the same factors identified for salmonids in the estuary and mainstem habitat section. In particular, floodplain development and loss of riparian habitat in the lower mainstem and estuary limit the capacity for sandhill crane overwintering and use during migration (Table 11). Crane habitat on the lower Columbia bottomlands between Vancouver and Woodland is threatened with industrial development, conversion of agricultural lands to cottonwood plantations, tree nurseries, or other incompatible uses, and crane use is disturbed by hunters and other recreational users.Reclamation of agricultural land for habitat restoration projects may discourage overwintering by sandhill cranes, although future development of herbaceous wetlands may provide adequate winter habitat for sandhill cranes currently using the region.

Table 11. Sandhill crane and dusky Canada goose limiting factors.

Life Stage	Limiting Factors
Winter Population	**SC/DCG.LF.1** Availability of overwintering habitat. Urbanization and conversion of agricultural crops to non-preferred forage crops is reducing the acreage of goose and crane overwintering habitat. Continued habitat loss will decrease the number of overwintering birds the subbasins can support. Wildlife refuges within the subbasins provide a vital baseline of winter habitat.

Dusky Canada Goose

Approximately 16,000 dusky Canada geese currently winter in the Willamette Valley and SW Washington. The dusky Canada goose has been intensively managed since the 1950s with habitat preservation in the form of federal refuge creation and harvest regulations that reduced the harvest of dusky Canada geese. Beginning in the early 1970s and increasing to the present, tens of thousands of several Canada geese races began wintering in the same areas as the duskys. Harvest management that focuses on subspecies other than duskys became more complex and challenging in the face of this massive build-up of other races of geese, particularly given the duskys' declining productivity and relatively high vulnerability to hunting. Because of their presence in the mainstem and estuary, the dusky Canada goose may be limited by many of the same factors identified for salmonids in the estuary and mainstem habitat section. In particular, floodplain development and loss of riparian habitat in the lower mainstem and estuary limit the capacity for dusky Canada goose overwintering (Table 11).

Columbian White-Tailed Deer

The conversion of much of its habitat to agricultural lands and unrestricted hunting reduced Columbian white-tailed deer numbers to a just a few hundred in the early 20th century. Columbian white-tailed deer are present in low-lying mainland areas and islands in the Columbia River upper estuary and along the river corridor in the vicinity of Cathlamet, WA, and Westport, OR. They are most closely associated with Westside oak/dry Douglas fir forest within 200m of a stream or river; acreage of this habitat type has decreased substantially from historic to current conditions. Habitat conversion, losses, and isolation, coupled with low population productivity, are currently the most important threats to Columbian white-tailed deer population viability. The lower Columbia population, which has experienced a long-term decline, was significantly affected by flooding conditions in 1996.

Columbian white-tailed deer are a federal endangered species. In 1999, the USFWS proposed to delist the Columbian white-tailed deer throughout the entire range, but public concern over delisting motivated USFWS to withdraw the delisting proposal. Columbian white-tailed deer limiting factors are addressed more fully in the USFWS recovery plan. Restoration of contiguous preferred habitat is vital to population recovery.

Seals and Sea Lions

There are no large-scale limiting factors or threats to harbor seals, Steller sea lions, and California sea lions in the lower Columbia River estuary and mainstem. However, they are considered a threat to migrating adult salmonids, as was described in the Ecological Interactions section of this Management Plan.

The Columbia River seal and sea lion population appears stable or increasing. Harbor seals are the only pinniped considered a year-round resident in the Columbia River mainstem and estuary. Abundance is highest in winter and lowest in summer as a result of migratory behavior and the timing of the breeding season. Sea lions (both Steller and California) are considered seasonal residents of the Columbia River mainstem and estuary. Counts of Steller sea lions at the south jetty of the Columbia River typically peak during the winter months. Peak counts of 50-60 animals were reported in 1985. Recent surveys by WDFW and ODFW show an increase in Steller sea lions abundance at the south jetty with peak counts of 300-700 animals recorded.

Western Pond Turtle

The western pond turtle is a Washington state endangered species; they are limited to localized areas within Skamania and Klickitat counties. Their presence in Skamania and Klickitat counties suggests that they are affected by subbasin habitat limiting factors identified for those areas. Western pond turtles are limited by loss of riparian and wetland habitats, as well as predation by introduced bullfrogs and non-native fish. Wetland draining, filling, and development eliminated considerable habitat during the past century. Bullfrogs and warmwater fish are significant predators on hatchling and small juvenile western pond turtles. Raccoons are major predators on turtles and turtle eggs. Limiting factors are addressed more fully in the WDFW Western Pond Turtle Recovery Plan.

3.8.2 Species of Ecological Significance

Cutthroat Trout

Resident or fluvial cutthroat are regulated by local habitat conditions; sea-run populations encounter additional mainstem Columbia River and estuary effects. Because of their similar habitat requirements, cutthroat trout in the lower Columbia region are limited by the same subbasin and estuary/mainstem habitat limiting factors and threats identified above for other salmonids.

The USFWS found that cutthroat trout populations in the Washington part of the distinct population segment were widely distributed and remained at levels comparable to healthy-sized populations. Cutthroat trout are thought to be distributed throughout most areas where they were historically present.

White Sturgeon

The lower Columbia white sturgeon population is among the largest and most productive in the world. The deep water habitats in which sturgeon are commonly associated remain available throughout the lower mainstem and estuary. However, because of their mainstem and estuary residency, white sturgeon are limited by many of the same factors identified for salmonids in the estuary and mainstem habitat and the ecological interactions sections. Mainstem dams block movements, fragment the habitat, and reduce anadromous prey in reservoirs upstream from Bonneville Dam. Sturgeon rarely use fish ladders which were engineered to pass the more surface-oriented salmon. On the other hand, hydrosystem development and operation has artificially created what functionally amounts to white sturgeon spawning channels downstream from Bonneville Dam, resulting in reliable annual recruitment (L. Beckman USGS (retired), G. McCabe Jr. NMFS (retired), M. Parsley, USGS, Cook Washington, personal communication). White sturgeon eggs and juveniles may be susceptible to direct mortality during Columbia River dredging operations (Table 12). Additionally, sturgeon are susceptible to fishery exploitation, but, current harvest levels and regulations appear to be maintaining sturgeon adult abundance in the lower Columbia river (Table 12). Columbia River white sturgeon were severely over-fished during the late 1800s prior to the adoption of significant fishery restrictions; recovery to present abundance levels required decades.

Green Sturgeon

Little is known about green sturgeon and considerable research effort is needed to establish green sturgeon habitat usage and preferences in the lower Columbia River ecosystem. Because of their presence in the mainstem and estuary, green sturgeon may be limited by many of the same factors identified for salmonids in the estuary and mainstem habitat and the ecological interactions sections; green sturgeon are believed to be limited by the same factors identified for adult white sturgeon (Table 12).

NOAA Fisheries completed a status review for green sturgeon in 2003 and determined that listing under the Endangered Species Act was not warranted but are a candiate species. Green sturgeon spend most of their life in nearshore marine and estuarine waters from Mexico to southeast Alaska (Houston 1988; Moyle et al. 1995). While green sturgeon do not spawn in the Columbia Basin, significant populations of subadults and adults are present in the estuary during summer and early fall. Green sturgeon are occasionally observed as far upriver as Bonneville Dam. These fish may be seeking warmer, summer river waters in the northern part of their range.

Table 12. Sturgeon limiting factors by life stage.

Life Stage	Limiting Factors
Egg Incubation	**WhS.LF.1** Sedimentation of spawning substrates. Deposition of fine sediments in the preferred spawning habitats (deepwater, rocky substrates) results in egg suffocation. Fine sediment sources include adjacent tributary subbasins as well as migration of sediments from mainstem deposits.
	WhS.LF.2 Egg hypoxia. Hypoxia may have disproportionate negative effects on sturgeon compared to other fish because of their limited capacity to osmoregulate at low dissolved oxygen concentrations. Dissolved oxygen levels may be low for any number of reasons. Delivery of oxygenated water is decreased through sedimentation.
	WhS.LF.3 Predation mortality. Demersal white sturgeon embryos are vulnerable to predation. Research on the upper Columbia indicated that 12% of naturally-spawned white sturgeon eggs were subject to predation, although the research suggests that predation was likely underestimated. If predation mortality is substantial, recruitment failure can result.
	WhS.LF.4 Direct dredging mortality. Although, white sturgeon prefer to spawn in rocky substrates with sufficient interstitial spaces, spawning has been observed in sands and fine sediments. Additionally, eggs broadcast among rocky substrates may disperse downstream and settle among sands or fine sediments. Dredging activities in areas where embryos are present results in direct mortality.
	WhS.LF.5 Contaminant/parasite exposure. Contaminants have been documented throughout the lower mainstem and estuary. Contaminants are known to have detrimental effects on development and physiological processes.
Juvenile Rearing	**WhS.LF.6** Predation mortality. Juvenile white sturgeon losses to predation are probably low because of the protective scutes, benthic habitats, and fast growth.
	WhS.LF.7 Direct dredging mortality. White sturgeon association with benthic habitats make them susceptible to suction dredging mortality. There is speculation that dredging operations may attract white sturgeon, compounding potential losses.
	WhS.LF.8 Contaminant/parasite exposure. Contaminants have been documented throughout the lower mainstem and estuary. Contaminants are known to have detrimental effects on growth and physiological processes.
	WhS.LF.9 Interaction with introduced species. Hundreds of species introductions, both intentional and unintentional, have occurred in the lower Columbia mainstem and estuary. Effects on white sturgeon are unknown and may be offsetting. For example, shad have become an important food source for adult sturgeon while shad and gamefish may compete for food sources with juvenile sturgeon.
Adult Abundance	**WhS.LF.10** Fishing mortality. At present, size restrictions in the fishery are allowing for sturgeon survival to older ages, thus maintaining adequate abundance of spawning adults. Fishery regulations, fishing effort, harvest levels, and population response needs to be monitored closely to ensure adult spawning abundance is maintained.
	WhS.LF.11 Interaction with introduced species. Hundreds of species introductions, both intentional and unintentional, have occurred in the lower Columbia mainstem and estuary. Effects on white sturgeon are unknown and may be offsetting. For example, shad have become an important food source for adult sturgeon while shad and gamefish may compete for food sources with juvenile sturgeon.
	WhS.LF.12 Incidental mortality. Operations at Bonneville Dam, specifically dewatering of turbines, can strand white sturgeon and result in mortality. Significance of this mortality factor needs to be evaluated.

Eulachon (Smelt)

Because of their anadromous life history, eulachon are limited by many of the same factors and threats identified above for salmonids, particularly subbasin habitat, mainstem and estuary habitat, and ecological interactions limiting factors (Table 13). Eulachon (smelt) numbers and run patterns can be quite variable; low runs during the 1990s raised considerable concern by fishery agencies. Current patterns show a substantial increase in run size compared to the 1990s. The low returns in the 1990s are suspected to be primarily a result of low ocean productivity. Eulachon support a popular sport and commercial dip net fishery in the tributaries, as well as a commercial gill-net and small trawl fishery in the Columbia. They are used for food and are also favored as sturgeon bait. Nevertheless, hydropower development on the Columbia River has decreased the available spawning habitat for eulachon. Prior to the completion of Bonneville Dam, eulachon were reported as far upstream as Hood River, Oregon (Smith and Saalfeld 1955). Additionally, dredging has the potential to impact adult and juvenile eulachon (Larson and Moehl 1990); dredging operations in the lower Columbia River have made local substrate unstable for the incubation of eulachon eggs. Thus, future dredging operations should be scheduled to avoid eulachon spawning areas during peak spawning times (Romano et al. 2002).

Table 13. Eulachon limiting factors by life stage.

Life Stage	Limiting Factors
Egg Incubation	**Eu.LF.1** Sedimentation of spawning substrates. Deposition of fine sediments in the preferred spawning habitats (coarse sands) can result in egg suffocation. Fine sediment sources include adjacent tributary subbasins as well as migration of sediments from mainstem deposits.
	Eu.LF.2 Egg hypoxia. Dissolved oxygen levels may be low for any number of reasons. Delivery of oxygenated water is decreased through sedimentation.
	Eu.LF.3 Predation mortality. Eulachon eggs may be vulnerable to predation. Eggs have been documented as an important food item of juvenile sturgeon in the lower mainstem. Eulachon eggs comprised up to 25% of stomach contents for sturgeon $\leq$350mm; the percentage increased to 51% for sturgeon 351-724mm.
	Eu.LF.4 Direct dredging mortality. Dredging activities in areas where eggs or developing larvae are present results in direct mortality. Also, evidence suggests that dredging activity in the vicinity of spawning areas makes the substrate too unstable for egg incubation.
	Eu.LF.5 Contaminant exposure. Contaminants have been documented throughout the lower mainstem and estuary. Contaminants are known to have detrimental effects on development and physiological processes.
Juvenile Migration	**Eu.LF.6** Predation mortality. Juvenile eulachon losses to predation are unknown and need to be evaluated. Predation could be substantial because juvenile eulachon have poor swimming ability and emigrate at the mercy of river currents.
	Eu.LF.7 Near ocean survival. Mortality upon ocean entry is unknown, but may be substantial.
Adult Abundance	**Eu.LF.8** Fishing mortality. At present, fishery regulations, fishing effort, and harvest levels appear to be at sustainable levels; population response needs to be monitored closely to ensure population viability.
	Eu.LF.9 Predation mortality. Eulachon are an important food item for many estuary and lower mainstem species. Large congregations of avian predators accompany eulachon runs into spawning areas. Pinnepeds prey on eulachon as they migrate through the estuary; pinnepeds may also follow eulachon runs to spawning areas.
	Eu.LF.10 Migration barriers. Eulachon do not navigate fish passage structures well, thus Bonneville Dam restricts access to historical spawning areas. Optimal water temperature for upstream migration is about 40 °F; below this temperature, migration will be delayed.
	Eu.LF.11 Interaction with introduced species. Hundreds of species introductions, both intentional and unintentional, have occurred in the lower Columbia mainstem and estuary. Effects on eulachon are unknown.

Pacific Lamprey

One non-salmonid focal species population currently experiencing a decreasing trend is Pacific lamprey. There are two available indicators of Columbia River Pacific lamprey population abundance; neither are robust. Fishery harvest levels have been low in recent years, although harvest levels are a function of regulatory limits and fishing effort, which have both been restricted in recent years because of a perceived decline in lamprey abundance. Recent (1997-2001) passage counts at Bonneville Dam were low compared to historical passage, but the 2002 passage count approached the historical average. Bonneville Dam passage counts are missing from 1970 to 1996, so it is difficult to determine if the low abundance during the late 1990s is part of a long-term trend or a short-term function of low ocean productivity during that period.

Because of their anadromous life history, lamprey are limited by many of the same factors and threats identified above for salmonids, particularly subbasin habitat, mainstem and estuary habitat, and ecological interactions limiting factors. More specifically, lamprey are negatively affected by increased flood frequency in the subbasins (premature dispersal of ammocoetes), decreased river flow in the mainstem resulting from hydropower water regulation (altered juvenile dispersal mechanisms), and mainstem dam passage (limited access to spawning areas and decreased juvenile survival) (Table 14). Other tributary habitat problems include low flow, degraded riparian conditions, and high water temperature (Close 2000). Although adult lamprey can negotiate waterfalls, evidence suggests that adult lamprey experience considerable difficulty migrating through mainstem dam fish passage structures, which has severely limited lamprey access to historical spawning tributaries thereby affecting population viability. Additionally, juvenile lamprey have difficulty in downstream dam passage and do not appear to benefit from juvenile salmonid passage systems; as a result, juvenile lamprey mortality is thought to be high.

Table 14. Pacific lamprey limiting factors by life stage.

Life Stage	Limiting Factors
Juvenile Rearing and Migration	**PL.LF.1** Flow alteration. Juvenile Pacific lamprey are poor swimmers and rely on flow to carry them toward the ocean. Flow alterations in the Columbia River basin (hydrosystem operations, water withdrawal) have decreased peak flows in the lower Columbia River mainstem, as well as created inundated habitats throughout the basin. Flow reductions may delay downstream migration, disrupting the synchrony of physiological development and downstream migration timing.
	PL.LF.2 Direct dredging mortality. Juvenile Pacific lamprey are closely associated with fine sediments where they burrow and filter feed. Dredging activities in areas where juveniles are present results in direct mortality; an estimated 3-26% of juvenile lamprey passed through a dredge survived.
	PL.LF.3 Contaminant exposure. Contaminants have been documented throughout the lower mainstem and estuary. Contaminants are known to have detrimental effects on aquatic organisms. Juvenile Pacific lamprey are closely associated with fine sediments where contaminants commonly accumulate.
	PL.LF.4 Interaction with introduced species. Hundreds of species introductions, both intentional and unintentional, have occurred in the lower Columbia mainstem and estuary. Effects on Pacific lamprey are unknown.
	PL.LF.5 Predation mortality. Juvenile Pacific lamprey losses to predation are unknown and need to be evaluated.
Adult Migration	**PL.LF.6** Dam passage. Pacific lamprey are often unable or unwilling to migrate through fish ladders. Thus, Bonneville Dam, as well as many tributary or other mainstem dams, has limited upstream migration of Pacific lamprey to historical upriver spawning areas.

	PL.LF.7 Predation losses. Because of their high caloric value, Pacific lamprey are an important food source for marine mammals (pinnepeds) and sturgeon (and potentially others) in the lower Columbia River. The significance of predation on Pacific lamprey needs to be quantified.
	PL.LF.8 Harvest mortality. Historically, tribes harvested lamprey throughout the Columbia basin for food, ceremonial, medicinal, and trade purposes. Today, harvest is limited primarily to Willamette Falls and Sherars Falls (Deschutes River). Because of limitations on lamprey harvest (fishing effort, legal gear types, area closures, seasonal restrictions, diel restrictions), harvest may not be a major mortality factor.
	PL.LF.9 Interaction with introduced species. Hundreds of species introductions, both intentional and unintentional, have occurred in the lower Columbia mainstem and estuary. Effects on Pacific lamprey are unknown.

Northern Pikeminnow

The northern pikeminnow, a large (10-20 inches), long-lived (10-15 years), opportunisticly predaceous minnow has flourished with habitat changes in the mainstem Columbia River and its tributaries. Their abundance in the Columbia basin is highest from the estuary to The Dalles Dam. In the Lower Columbia, pikeminnow are concentrated around hydroprojects, particularly Bonneville Dam and multiple dams within the Cowlitz and Lewis subbasins.Larger individuals are considered a predation threat to migrating juvenile salmonids. As such, pikeminnow are thoroughly addressed in the Ecological Interactions sections of this Management Plan.

American Shad

The introduced American shad are also experiencing high productivity and abundance. Shad have recently increased to record abundance levels in the Columbia River; reasons for present abundance levels are thought to be mainstem dam passage improvements targeted toward salmon that have provided shad access to considerable amounts of spawning habitat, as well as abundant food sources for juvenile shad during their emigration. Also, hydrologic changes resulting from hydrosystem development appear to benefit American shad. There are no known threats to American shad in the lower Columbia River estuary and mainstem. However, shad are considered a threat to salmonids based on potential competition and food web effects as discussed in the Ecological Interactions sections of this Management Plan. Divergent trends in shad and salmon numbers occur primarily because the same habitat changes that favor shad are detrimental for salmon; interactions among these species are poorly understood.

Caspian Tern

Caspian terns are of conservation concern because of the concentration of breeding terns at relatively few sites. Currently two-thirds of the Pacific Coast and one-quarter of the North American population nests in the Columbia River estuary. In 1984, approximately 1,000 pairs of terns were observed breeding in the lower Columbia River; the breeding colony has since expanded to 10,000 pairs and represents the largest breeding colony in North America. Caspian terns nest on bare open ground of islands or beaches. They prefer newly formed, flat, sandy, unvegetated, mid-channel habitat. Dredging the navigational channel created several islands in the estuary that have been colonized. The U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, and NOAA Fisheries are preparing an Environmental Impact Statement (EIS) for Caspian Tern management in the Columbia River estuary. The purpose of the EIS is to explore options to reduce the level of tern predation on Columbia River salmonids while insuring the protection and conservation of Caspian terns in the Pacific Coast/Western region (California, Oregon, Washington, Idaho, and Nevada). Threats to and from Caspian terns are expected to be part of the EIS, which is scheduled for release in the near future. Federal and State agencies and non-governmental organizations have agreed to explore options for restoring, creating, and enhancing nesting habitat for Caspian terns throughout portions of the Pacific Coast/Western region. The potential benefits of this proposed action would reduce the level of tern predation on migrating juvenile salmonids in the Columbia River, and lower the vulnerability of a significant portion of breeding Caspian terns in the Pacific Coast/Western region to catastrophic events.

Osprey

The osprey population along the lower Columbia River mainstem has increased slightly in recent years. Although forest habitats used for nesting have likely decreased, osprey have adapted to nesting on man-made structures. Osprey appear less selective of breeding sites than bald eagles, as they are often observed nesting on man-made structures such as channel markers or power poles. Because of their presence in the mainstem and estuary, osprey may be limited by many of the same factors identified for salmonids in the estuary and mainstem habitat section. In particular, floodplain development and presence of contaminants negatively affect osprey (Table 15). Contaminant levels in osprey tissue are high enough to result in decreased egg thickness, but the increasing population in recent years suggests that young production is not a limiting factor.

Table 15. Suspected osprey limiting factors.

Life Stage	Limiting Factors
Reproductive Success	**Os.LF.1** Contaminant exposure. Contaminants have been documented throughout the lower mainstem and estuary. Contaminants are known to decrease eggshell thickness, which affects survival. Uptake may be via prey consumption or direct contact. Columbia River osprey eggs contained the highest concentration of DDE reported in North America in the late 1980s and 1990s.
	Os.LF.2 Availability of nesting habitat. Osprey prefer mature forest habitats with adequate nest and roost trees in close proximity to abundant fish resources. Osprey appear to be adaptable and have been observed nesting on artificial structures such as channel markers or power poles.

Yellow Warbler

Within Washington, yellow warblers are apparently secure and are not of conservation concern. Yellow warblers are an indicator of riparian shrub habitat characterized by a dense deciduous shrub layer 1.5-4 m, with edge and with small patch size (heterogeneity). Habitat suitability for warblers is correlated with the percent of deciduous shrub canopy comprised of hydrophytic shrubs; warbler abundance is positively associated with deciduous tree basal area and negatively associated with closed canopy and cottonwood proximity.

Thus, loss of this specific habitat type limits yellow warblers in the lower Columbia River and estuary, although the extent of habitat loss is not clear. Yellow warblers are negatively affected by floodplain development and loss of riparian and wetland habitat.

Red-Eyed Vireo

the red-eyed vireo is common, more widespread in northeastern and southeastern Washington, and not a conservation concern. The red-eyed vireo is an indicator of forested riparian habitat characterized by tall, closed canopy forests of deciduous trees (cottonwood, maple, or alder and ash), with a deciduous understory, forest stand sizes larger than 50 acres, and riparian corridor widths greater than 50 m. Thus, loss of this specific habitat type limits red-eyed vireos in the lower Columbia River and estuary, although the extent of habitat loss is not clear. Red-eyed vireos are negatively affected by floodplain development and loss of riparian and wetland habitat. Habitat alterations along the lower Columbia River corridor have likely been more damaging to the possible presence of red-eyed vireos as opposed to yellow warblers because dense riparian forests along the lower Columbia River are likely less abundant than shrub-dominated wetland habitat. However, there are no data to compared historic and current breeding populations in the Columbia River estuary and lower mainstem.

River Otter

The river otter is a year-round resident of the lower Columbia River mainstem and estuary. Field observations and trapper data indicate the river otter population abundance in the lower Columbia River mainstem and estuary was relatively low in the early 1980s (Howerton et al. 1984); low abundance may be the normal equilibrium level for river otters in this region. River otters are understudied and considerable research is needed to identify limiting factors or threats to the lower Columbia River mainstem and estuary population. However, because of their association with estuary riparian and floodplain habitat, river otters are assumed to be limited by many of the same factors identified for salmonids in the estuary and mainstem habitat section. In particular, floodplain development and loss of riparian habitat in the lower mainstem and estuary likely limit the capacity for river otter. River otters are concentrated in shallow water tidal sloughs and creeks associated with willow-dogwood and Sitka spruce habitats located primarily in the Cathlamet Bay area. Although dikes throughout the estuary have disconnected substantial amounts of side channel and floodplain habitats from the mainstem, the Cathlamet Bay area remains as one of the most intact and productive tidal marsh and swamp habitat throughout the entire estuary. Further, because river otters are capable of traveling over land, it is not understood how the loss of habitat connectivity of side channel and floodplain habitat has affected species' behaviors such as foraging, resting, mating, and rearing. Contaminants in river otter tissue may have adverse physiological effects, however, data suggests that the effects may be temporary (Tetra Tech 1996).

3.8.3 Species of Recreational Significance

For other species in this group (smallmouth bass, walleye, and channel catfish), abundance in the lower Columbia River is low compared to elsewhere in the Columbia River basin, Smallmouth bass, walleye, and channel catfish are all introduced species in the Columbia River basin and there is currently no basis for attempting to increase their productivity or abundance in the lower Columbia River ecosystem, particularly because of potential negative consequences on salmonid recovery.

Walleye

Walleye have benefited from hydrosystem development and they have successfully colonized reservoir habitats throughout the basin. Abundance in the free-flowing portion of the Columbia River below Bonneville Dam is generally recognized to be lower than elsewhere in the Columbia River basin primarily because these fish are adapted to lakes and impoundments. Walleye numbers appear to be regulated by variable year class strength which is affected by fluctuating environmental conditions. Walleye are considered predators of migrating juvenile salmonids, as described in the Ecological Interactions section of this Management Plan.

Smallmouth Bass

Smallmouth bass have benefited from hydrosystem development, successfully colonizing reservoir habitats throughout the basin. Abundance in the free-flowing portion of the Columbia River below Bonneville Dam is generally recognized to be lower than elsewhere in the Columbia

River basin. Smallmouth bass are considered predators of migrating juvenile salmonids; as as addressed in the Ecological Interactions section of this Management Plan.

Channel Catfish

Channel catfish have benefited from hydrosystem development; they are found in reservoir habitats throughout the basin. Small numbers of channel catfish can be found in some areas of the lower Columbia. Dams may provide increased suitable spawning habitat as well as more favorable water temperatures. There are no known threats to channel catfish in the lower Columbia River.