TURNING THE DIALS

INTEGRATED ANALYSIS OF LIMITING FACTORS AND OPPORTUNITIES FOR IMPROVEMENT OF CHEHALIS SALMON AND STEELHEAD

REVIEW DRAFT

Report to:

Chehalis Basin Board

Washington Department of Ecology Office of the Chehalis Basin

by

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SUMMARY

This report describes an integrated analysis of limiting factors and opportunities for improvement of Chehalis Salmon and Steelhead based on a comprehensive review of the large volume of technical information available for Chehalis salmon and steelhead. The analysis includes: 1) an assessment of current fish status, 2) estimates of the impacts of human-related or potentially manageable limiting factors; and 3) a coarse scale evaluation of high-level strategies for salmon restoration. Analysis was facilitated by the interactive "Salmon Slider Tool" which uses a simple salmon life cycle computer model to relate fish numbers to changes in impacts of potentially manageable limiting factors to explore broad hypotheses and strategies as a tool for interactive learning.

Salmon and steelhead status in Grays Harbor systems was assessed based on recent average numbers of natural-origin spawners reported from State and Tribal stock assessment programs. A total of 28 salmon and steelhead populations have previously been identified in this region. Coho and Chum are relatively abundant followed by Fall Chinook and Winter Steelhead. Spring and Summer Chinook populations are small and very small, respectively. No information is available on a remnant run of natural-origin Summer Steelhead.

A limiting factors analysis quantified the impacts of human-related or potentially manageable limiting factors, including freshwater habitat, estuary habitat, major dams, selected predators, fisheries, and hatcheries. Factor-specific estimates were subject to different levels of uncertainty due to the variable quality of information available for each. Impacts are defined in a common currency as a percentage reduction in abundance associated with each limiting factor. Freshwater habitat impacts are substantial for all species. Impacts of other factors are generally less than freshwater habitat impacts but are generally comparable when considered in aggregate.

Life cycle analyses examine the effects of changes in limiting factors on adult abundance. Sensitivity analyses were used to explore system dynamics and the potential range of response to various changes in quantitative impacts to one or more limiting factors. Incremental improvements associated with freshwater habitat improvement scenarios and climate change assumptions identified in the Aquatic Species Restoration Plan were also included in this analysis as a point of reference. Scenario analyses generally examined the effects of combinations of changes in factors.

This analysis demonstrated that the relative magnitude of factor-specific impacts can generally be identified with varying levels of uncertainty. Freshwater habitat impacts are very large across all species and stocks. Impacts of other individual factors are lower but appear comparable to habitat impacts when considered in aggregate. Significant improvements in the status of Chehalis salmon and steelhead will require substantial improvements in freshwater habitat conditions. However, the greatest potential for improvement is produced by broad-based restoration strategies which provide compounding benefits from improvements in multiple factors. Substantial improvements will also be required to offset potential losses due to climate impacts. This high-level analysis does not identify the feasibility or specific actions necessary to reduce factor impacts – those details will require more detailed assessments associated with factor-level restoration plans.

The integrated analysis provided a systematic approach for considering all factors based on best information available in a synthesis of the many assessments, research results and modeling evaluations available for Chehalis salmon and steelhead. The analysis qualified related uncertainties and highlighted where information is limited. This analysis is most robust as a hypothesis-testing and learning exercise to examine the likely response of fish numbers to alternative restoration strategies. Where concerns or

disagreements on assumptions exist, the modeling framework encourages articulation of alternative assumptions, and allows for exploration of related implications in a systematic fashion. Ultimately, effective long-term salmon and steelhead restoration will test the response to substantive actions on the ground and adapt strategies accordingly.

INTRODUCTION

Chehalis Basin salmon and steelhead are limited by the impacts of a complex of habitat and non-habitat factors. The Chehalis Basin Board expressed interest in developing an integrated fisheries plan for the Chehalis Basin to assist the board in understanding and supporting actions that may affect the success of aquatic species habitat restoration actions. In response to this interest, the Washington Department of Fish and Wildlife initiated an integrated assessment of factors currently limiting Chehalis Basin salmon and steelhead and contracted with Fish Science Solutions, Inc. to conduct this analysis. A comprehensive understanding of the magnitude and interactions of all factors is essential to implementation of effective restoration strategies. This work is intended to inform the understanding, development, and communication of coordinated management efforts for conservation and restoration of Chehalis salmon and steelhead. This report is the product of that effort.

Where past planning efforts have often focused on individual factors, an integrated analysis considers the individual and combined effects of all factors. Related questions include:

- What is the relative significance of habitat and non-habitat factors in the decline of Chehalis salmon and steelhead?
- Are restoration actions fully integrated across all factors?
- Are the benefits of habitat restoration being canceled by other factors?
- How can concerted efforts work together to produce success?
- Is the recovery burden being shared “equitably” among all contributing parties?

This report describes an integrated analysis of limiting factors and opportunities for improvement of Chehalis Salmon and Steelhead. Project objectives include:

1. Identify the relative significance of all human-related and/or potentially-manageable factors which limit natural-production of Chehalis salmon and steelhead.
2. Evaluate limitations and potential for increasing fish numbers based on scenarios targeting key factors.

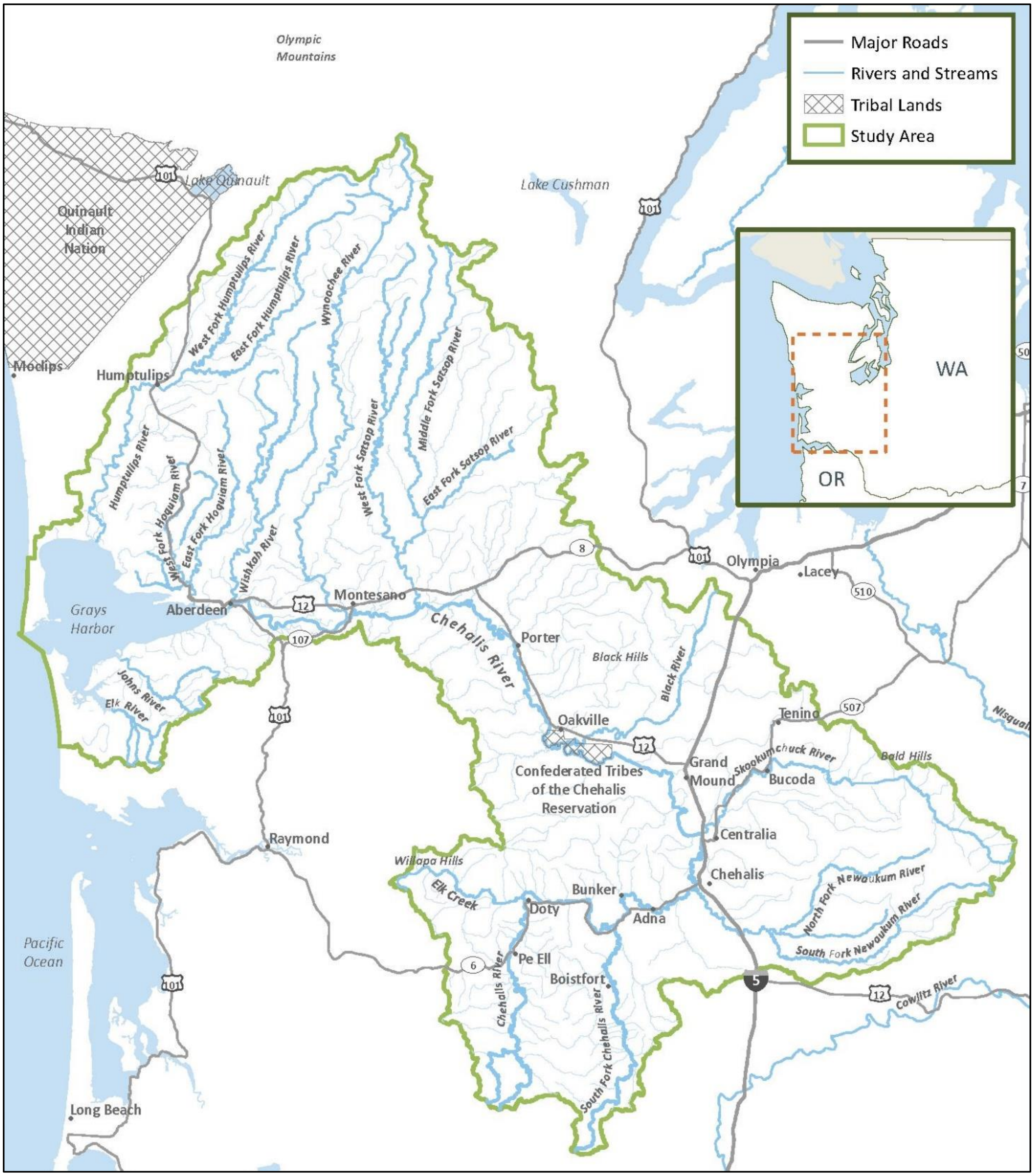

Figure 1. Chehalis Basin (source: ASRPSC 2019).

APPROACH

This project provides a comprehensive summary and high-level analysis of the available information on factors limiting salmon and steelhead produced by Grays Harbor systems. A large volume of technical information is available on specific factors. For instance, extensive assessments have been completed on freshwater habitat conditions and restoration (GHLE 2011; ASEPTC 2014; ASRPSC 2019) and potential effects of proposed flood control developments (WDE 2020). Table 1 identifies examples of key assessments which contributed to our integrated analysis.

Table 1. Timeline of key assessments of status and limiting factors of Chehalis salmon and steelhead.

1992	Washington State Salmon and Steelhead Stock Inventory	*Washington Department of Fish and Wildlife and Western Washington Treaty Indian Tribes (also updated in 2002)*
1993	Chehalis River Basin Fishery Resources: Status, Trends and Restoration	*U.S. Fish and Wildlife Service (Hiss and Knudsen 1993)*
2001	Salmon and steelhead habitat limiting factors: Chehalis Basin and nearby drainages water resource inventory areas 22 and 23	*Washington State Conservation Commission Report (Smith & Wegner 2001)*
2003	Assessment of salmon and steelhead performance in the Chehalis River basin in relation to habitat conditions and strategic priorities for conservation and recovery actions	*Report to Chehalis Basin Fisheries Task Force and Washington Department of Fish and Wildlife by Mobrand Biometrics*
2004	Puget Sound and Coastal Washington Hatchery Reform Project	*Hatchery Scientific Review Group*
2011	The Chehalis Basin Salmon Habitat Restoration and Preservation Strategy for WRIA 22 and 23	*Grays Harbor County Lead Entity*
2013	Washington Coast Sustainable Salmon Plan	*Washington Coast Sustainable Salmon Partnership*
2014	Aquatic Species Enhancement Plan	*Chehalis Basin Work Group Technical Committee*
2017	Analysis of salmonid habitat potential to support the Chehalis Basin Programmatic Environmental Impact Statement	*ICF Portland report for Anchor QEA to Washington Department of Ecology (McConnaha et al. 2017)*
2019	Chehalis Basin Strategy Aquatic Species Restoration Plan, Phase I	*Office of the Chehalis Basin, Washington Department of Ecology, ASRP Steering Committee*
2020	Proposed Chehalis River Basin Flood Damage Reduction Project Draft Environmental Impact Statement	*Washington Department of Ecology*
2021	Modeling Effects of Habitat Change and Restoration Alternatives on Salmon in the Chehalis River Basin Using a Salmonid Life-Cycle Model	*NOAA National Marine Fisheries Service (Beechie et al. 2021a, 2021b, 2021c)*
2022	Aquatic Species Near-Term (2021-2031) Implementation Report	*Office of the Chehalis Basin, Washington Department of Ecology, Publication #22-13-001*

The integrated analysis includes three elements:

Fish Status Assessment – Estimates of current abundance are the basis for further analysis of limiting factors and life cycle effects. This report summarizes the available information on current status of Chehalis Basin salmon and steelhead populations.

Limiting Factors Analysis - This analysis quantifies the impacts of human-related or potentially manageable limiting factors affecting each salmon and steelhead population throughout its life cycle, including freshwater habitat, estuary habitat, dams, fishery, hatchery, and predation. Impacts are defined as a percentage reduction in abundance of natural-origin salmon and steelhead associated with the reduction in productivity or survival due to each limiting factor. Estimates are thus defined in a common currency to show the relative significance of each factor.

Life Cycle Analysis - This analysis examines, at a coarse scale, the individual and combined impacts of limiting factors based on a simple life cycle model which relates fish numbers to productivity or survival at each life stage. Quantifying these relationships allows us to calculate likely changes in fish abundance in response to increases or decreases in any given impact or combinations of changes in impacts. This analysis integrates and applies (rather than replaces) results from other habitat and life cycle modeling efforts developed to inform restoration strategies and assess impacts of a proposed flood retention expandable facility for the Chehalis Basin (MBI 2003; McConnaha et al. 2017; ASRPSC 2019; WDE 2020; Beechie et al. 2021a 2021b).

The integrated analysis is, in effect, a dial-turning exercise which examines how fish numbers are limited by and respond to changes in one or more dials reflecting habitat, harvest, hatcheries, hydropower, predation, and potential climate effects. The analysis addresses the following questions:

- What dials can we turn (i.e., what impacts can we reduce) to increase fish abundance?
- How much do we have to turn the dials (i.e., reduce impacts) to achieve a desired improvement?
- How feasible is it to turn any particular dial (i.e., to reduce any particular impact)?
- What combinations of dial turns get us where we want to go?

Analysis is facilitated by the interactive "Salmon Slider Tool" which allows interested parties to examine high-level strategies for salmon restoration. This feature facilitates exploration of broad hypotheses and strategies as a tool for interactive learning. The Salmon Slider is a simple salmon life cycle computer model which relates fish numbers to changes in impacts of potentially manageable limiting factors. The tool connects the life cycle model to an interface allowing users to "slide" impacts in various threat categories up or down to examine how increased or decreased impact levels change salmon and steelhead abundance for different runs of fish (coho, chum, Chinook and steelhead). Additionally, the Salmon Slider includes check boxes for different scenarios or sensitivities, such as restoring a significant amount of freshwater habitat and ASRP restoration scenarios with associated time scales for future conditions. The Salmon Slider illustrates potential changes in salmon and steelhead abundance based on the relevance of various limiting factors in the Chehalis Basin and provides an example of how changes to one or more limiting factors can have a positive or negative affect on outcomes for fish.

This analytical framework was developed to identify strategies and targets in the ESA recovery plan for Washington Lower Columbia River salmon and steelhead (LCFRB 2010). The approach was subsequently adapted and applied to a region-wide analysis by the National Marine Fisheries Service's Columbia Basin Partnership Task Force (CBPTF 2020). The Salmon Slider Tools is broadly applicable to different systems but will be subject to different levels of uncertainty introduced by the information available in each.

FISH STATUS ASSESSMENT

A total of 28 populations have been defined in WDFW & WWTIT (1992, 2002) and GHLE (2011). Populations are identified as wild (with little or no contribution of hatchery fish to natural spawning) or hatchery-wild (where natural spawners can include significant numbers of hatchery fish) (Table 1). This assessment summarized information by population and by stocks defined as the aggregate of all populations of a species and run (e.g., winter steelhead).

Salmon and steelhead status was assessed based on numbers of natural-origin spawners which reflect the inherent productivity of existing conditions. Natural-origin fish are offspring of parents that spawned in the natural environment rather than the hatchery environment. Parents can include both natural and hatchery-origin fish. The assessment also includes estimates of total and hatchery-origins spawners which contribute to natural spawning in some populations.

Abundance is estimated with a variety of methods appropriate to the species and population. These are primarily spawning ground surveys where observers count fish or redds from shore or by aerial flights. Fish trap or weir counts are also used in some areas. Hatchery-origin fish are typically distinguished from natural-origin fish by the absence of adipose fins which are removed at the hatcheries prior to release as juveniles. This report referenced current information provided by WDFW and also publicly available via online databases including WDFW's Salmon Conservation and Reporting Engine (SCoRE https://fortress.wa.gov/dfw/score/).

Coho and Chum are the most abundant natural-origin stocks in Grays Harbor systems (Figure 2). Fall Chinook and Winter Steelhead are also relative abundant. Spring and Summer Chinook populations are small and very small, respectively. No information is available on a remnant run of natural-origin Summer Steelhead.

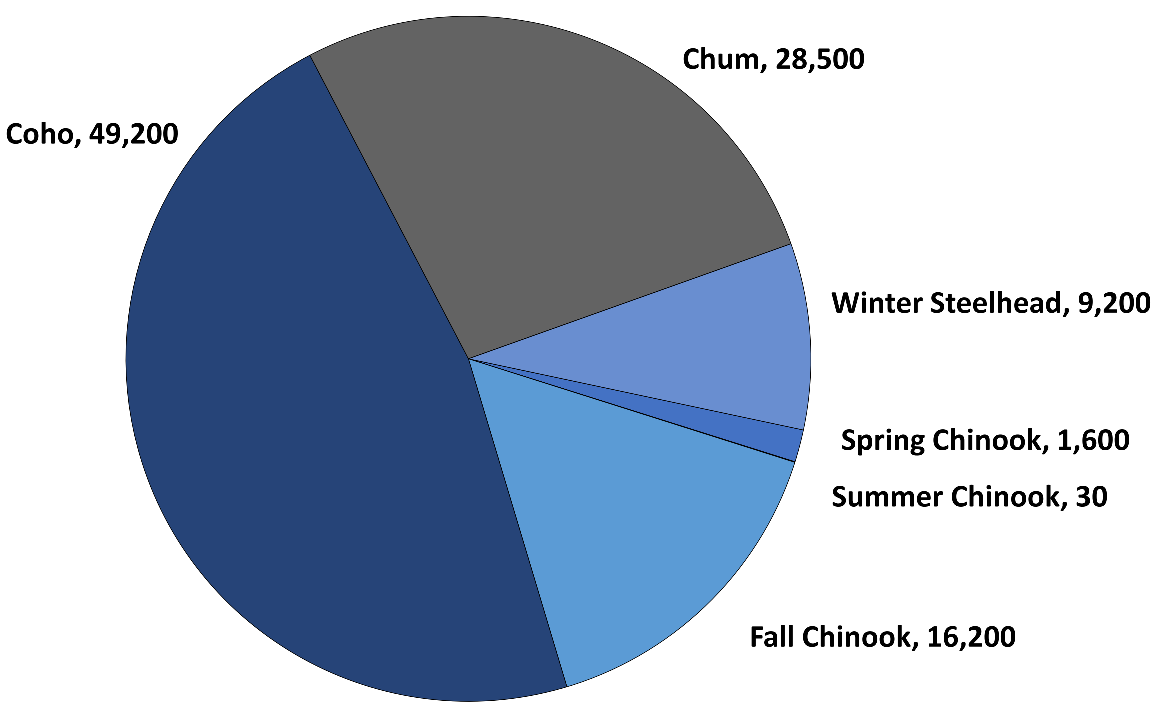

Figure 2. Recent (2011-2020) average abundance of natural-origin spawners in Grays Harbor systems.

Table 2. Chehalis Basin populations of salmon and steelhead.

Species	Run	Population	Production Type
Chinook	Spring	Chehalis	Wild
Chinook	Summer	Satsop	Wild
Chinook	Fall	Humptulips	Hatchery-Wild
		Hoquiam	Wild
		Wishkah	Hatchery-Wild
		Wynoochee	Wild
		Satsop	Hatchery-Wild
		Johns/Elk/South Bay	Wild
		Chehalis	Wild
Coho		Humptulips	Hatchery-Wild
		Hoquiam	Wild
		Wishkah	Hatchery-Wild
		Wynoochee	Wild
		Satsop	Hatchery-Wild
		Johns/Elk/South Bay	Wild
		Chehalis	Hatchery-Wild
Chum	Fall	Grays Harbor	Hatchery-Wild
Steelhead	Summer	Humptulips	Hatchery-Wild
		Chehalis	Wild
Steelhead	Winter	Humptulips	Wild
		Hoquiam	Wild
		Wishkah	Wild
		Wynoochee	Hatchery-Wild
		Satsop	Wild
		Johns/Elk/South Bay	Wild
		Skookumchuck/Newaukum	Hatchery-Wild
		Chehalis	Hatchery-Wild

Spring Chinook

All Spring Chinook returning to the Chehalis basin are considered to belong to a single population (Figure 3). Spring Chinook begin entering the river as early as late January or early February and spawn from early September through mid-October (WDFW & WWTIT 1992, 2002). Most spawning takes place in the Skookumchuck, Newaukum, South Fork Chehalis and the mainstem Chehalis rivers (RM 33.3 to 67.0 and RM 81.3 to 113.4) (WDFW & WWTIT 1992, 2002). Some spawning occurs in the Black River and in Elk and Stillman Creeks.

This is a wild population as no hatchery Spring Chinook are currently released in the Chehalis Basin. Cowlitz River (lower Columbia River basin) hatchery-origin spring Chinook were released into the Wynoochee River in the mid-1970s but returns were minimal and spatial segregation made it is unlikely that there was significant hybridization with the existing native stock (WDFW & WWTIT 1992, 2002; WDFW SCoRE 2022).

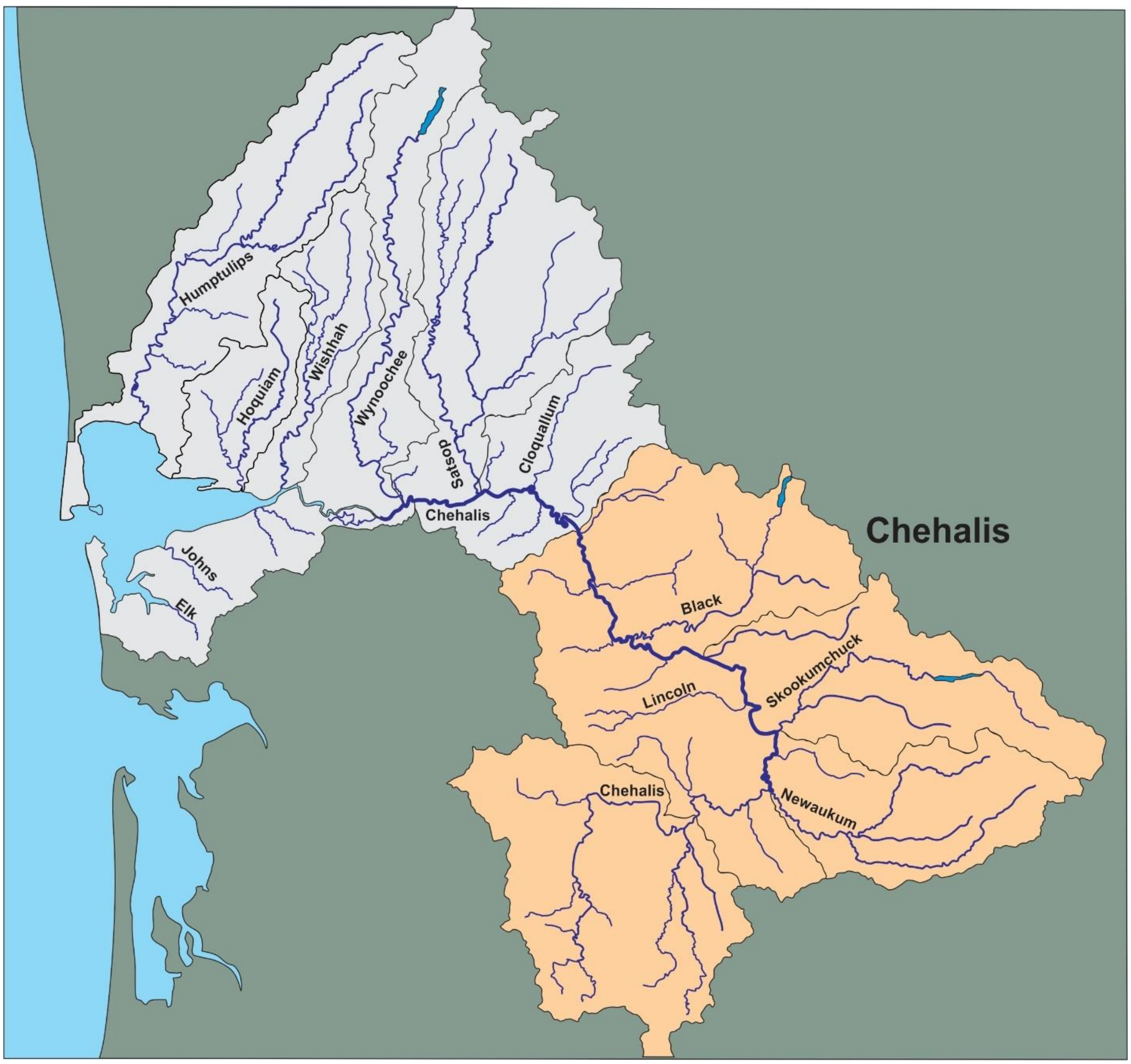

Figure 3. Spring Chinook Salmon population distribution in the Chehalis Basin.

Escapement estimates are based on redd counts within intensive and supplemental index areas. Index areas surveyed include the mainstem Chehalis River (RM 33.3 to 42.1, RM 44.9 to 50.5, and RM 103.7 to 106.2), Black River (RM 4.2 to 8.6), Skookumchuck River (RM 6.4 to 10.9, RM 10.9 to 21.3--supplemental, and RM 21.3 to 21.9), Newaukum River (RM 9.8 to 18.5--supplemental, RM 18.5 to 20.8, RM 20.8 to 27.3--supplemental, and RM 27.3 to 30.3), North Fork Newaukum (RM 0.3 to 2.4--supplemental, RM 2.4 to 6.9, RM 6.9 to 7.9--supplemental, and RM 7.9 to 10.3), and the South Fork Chehalis (RM 3.0 to 4.3, and RM 4.3 to 5.1--supplemental) (WDFW SCoRE 2022). One helicopter flight is also included on the mainstem Chehalis River (RM 25.2 to 67.0 and RM 81.3 to 109.9), Black River (RM 0.0 to 8.6), Newaukum River (RM 0.0 to 10.8), and South Fork Chehalis River (RM 0.0 to 5.1). Surveyed tributaries include Stillman and Elk creeks. Approximately three quarters of spring-run Chinook salmon spawning occurs in the Skookumchuck and Newaukum rivers (ASRPSC 2019).

Spawner abundance averaged 1,594 in 2011-2022 (Table 3). Annual numbers have varied considerably over the period of available data since 1980 (Figure 4). Chehalis River spring Chinook are managed for a natural-origin escapement goal of 1,400 adults (PFMC 2023).

Table 3. Current Status of Spring Chinook Salmon in the Chehalis Basin.

Population	Type	Spawners (2011-2020 avg.)				Escape. goal	Related hatchery production
		Natl.	Hat.	Total	% Hat.		
Chehalis	Wild	1,594	0	1,594	0%	1,400	None

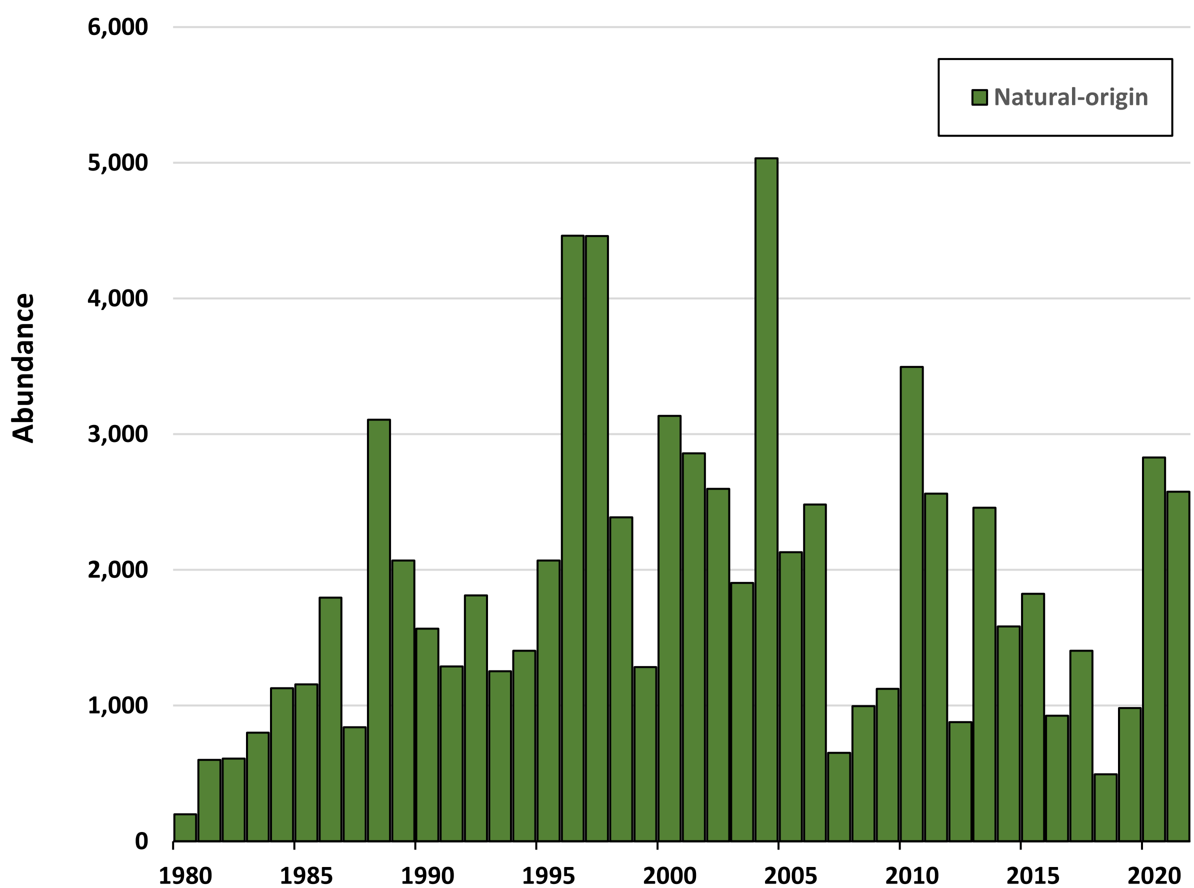

Figure 4. Annual abundance of Spring Chinook Salmon spawners in the Chehalis Basin.

Summer Chinook

A single Summer Chinook population is identified in the Chehalis Basin (WDFW & WWTIT 1992, 2002). This run is believed to enter the river in late July and August, begin spawning in early September and conclude spawning in mid-October (WDFW & WWTIT 1992, 2002). Most spawning taking place in the Mainstem East Fork Satsop River. Occasionally a few spawners are seen in Decker Creek, an east fork tributary.

No hatchery production of Summer Chinook occurs although WDFW SCoRE (2022) notes some potential for overlap with hatchery Fall Chinook produced at Bingham Creek Hatchery.

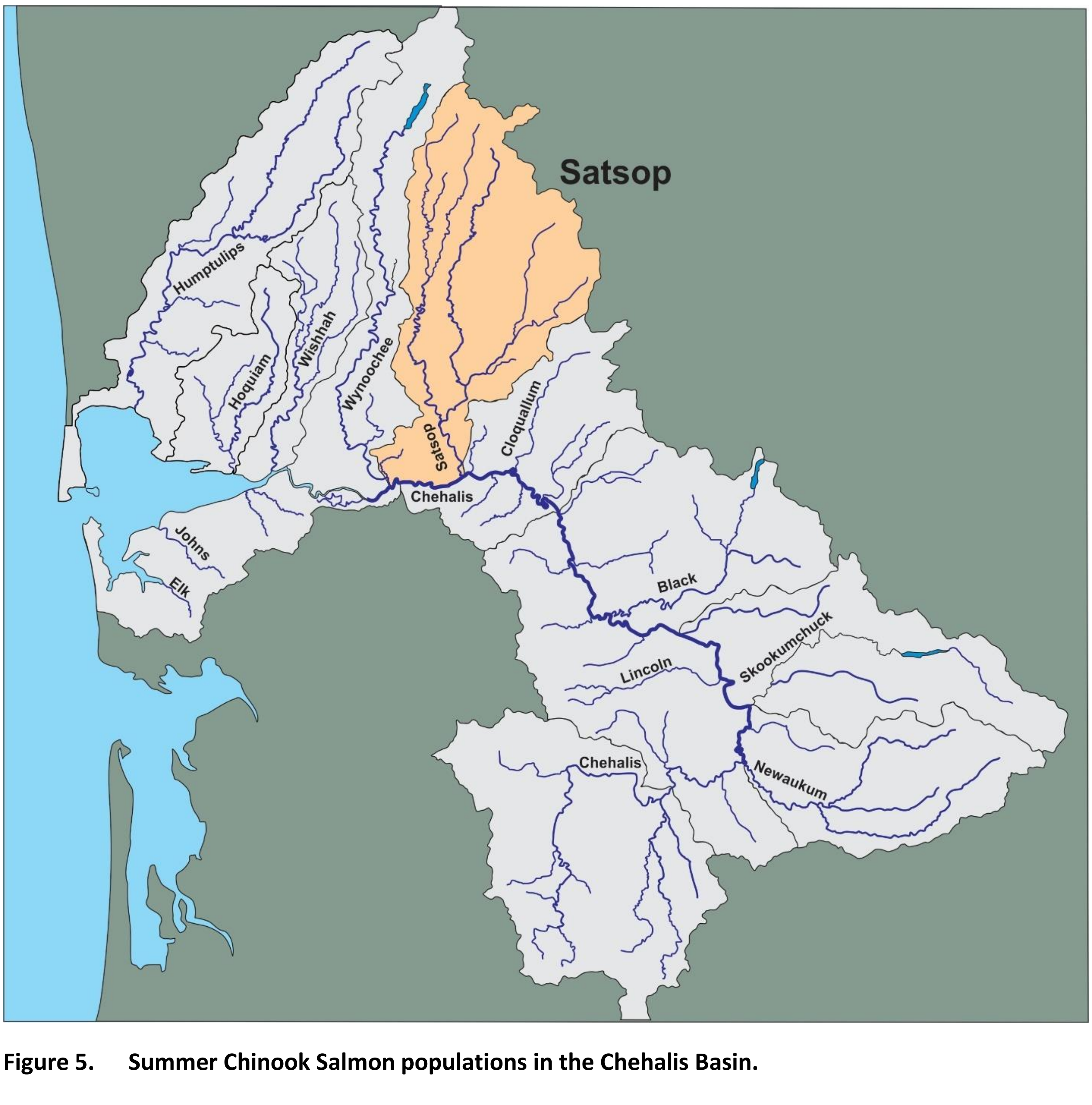

Figure 5. Summer Chinook Salmon populations in the Chehalis Basin.

Data are total escapement estimates based on redd counts within intensive and supplemental index areas expanded to basin-wide escapement numbers. Index areas surveyed include the mainstem Satsop River (RM 2.4 to 6.3--supplemental and RM 6.3 to 11.0), East Fork Satsop River (RM 11.0 to 12.4 and RM 12.4 to 17.5--supplemental) and West Fork Satsop River (RM 7.3 to 17.0--supplemental). Surveyed tributaries include Decker Creek.

Satsop Summer Chinook currently appear to be present at very low levels (Table 4) and exhibit a severe long-term declining trend (Figure 6).

Table 4. Current status of Summer Chinook Salmon in the Chehalis Basin.

Population	Type	Spawners (2011-2020 avg.)				Escape. goal	Related hatchery production
		Natl.	Hat.	Total	% Hat.		
Satsop	Wild	--	--	27	--	None	None

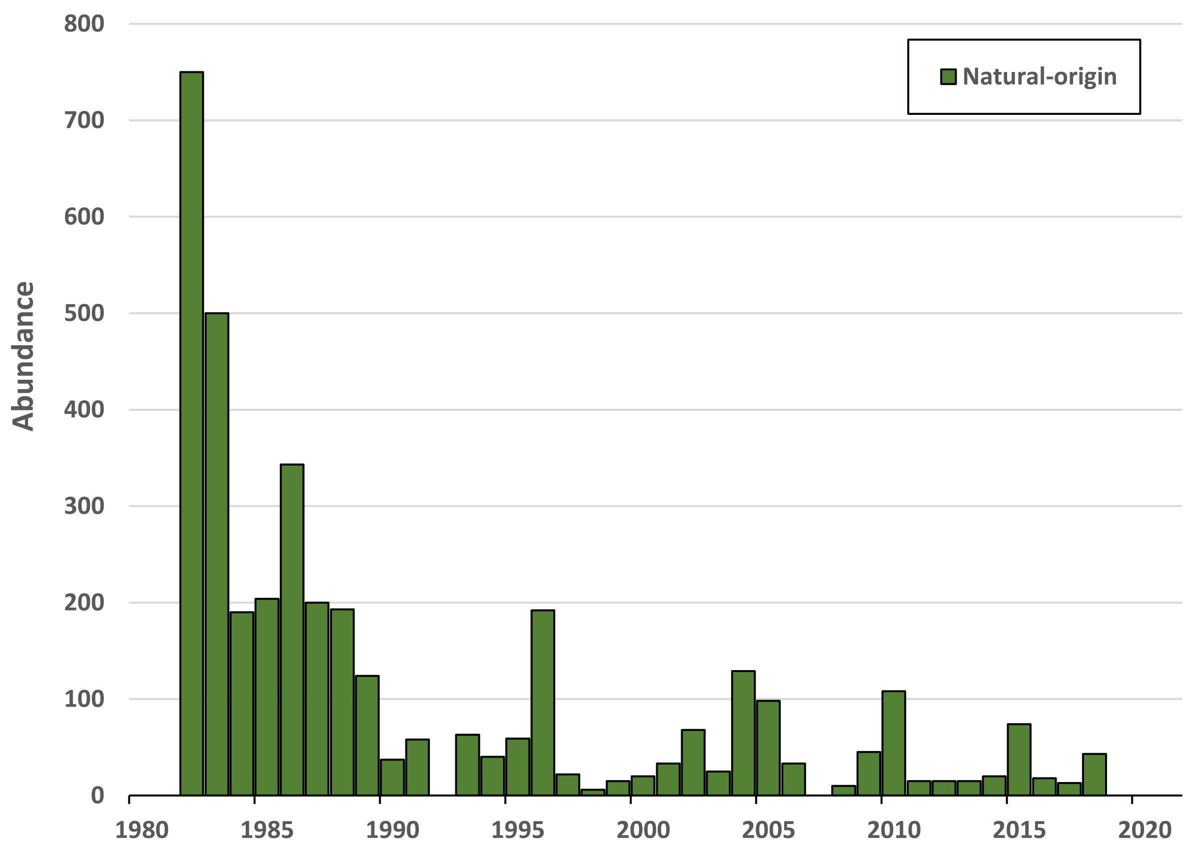

Figure 6. Annual abundance of Summer Chinook Salmon spawners in the Chehalis Basin.

Fall Chinook

Fall Chinook return to streams throughout the basin and seven populations have been identified (Figure 7: WDFW & WWTIT 1992, 2002). Fall Chinook enter the river in early September and continue into October (WDFW & WWTIT 1992, 2002). Spawning begins in October, peaks in late October/early November and is generally completed by late November.

Considerable hatchery releases, including those of non-native stocks, have historically occurred in the Humptulips, Satsop, Wynoochee, Johns/Elk/South Bay, and Chehalis fall Chinook areas (WDFW & WWTIT 1992, 2002). The remaining populations in the Hoquiam, Wishkah, and Wynoochee drainages are considered to be wild, native fall Chinook stocks, with minimal historical hatchery influence. Significant numbers of hatchery-origin fish currently contribute to natural spawning in three populations (Humptulips, Satsop, Wynoochee) (Table 5).

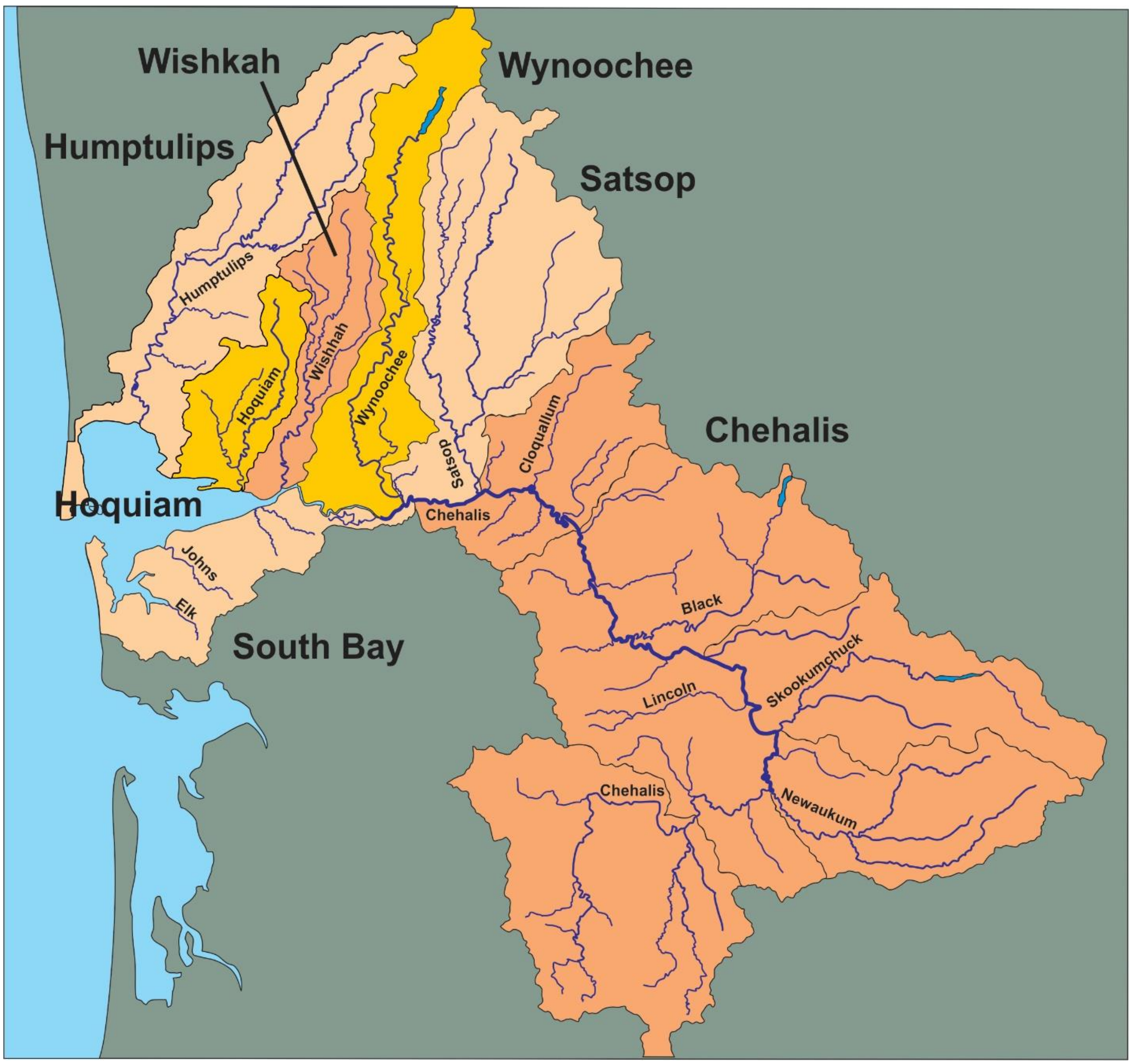

Figure 7. Fall Chinook Salmon populations in the Chehalis Basin.

Spawning escapement is surveyed each year in all populations except in the South Bay which is a minor component of the total run. Total spawners have averaged 16,163 in 2011-2022 of which approximately 15% are hatchery-origin (Table 5). Annual escapements have generally ranged between 10,000 and 30,000 since 1980 (Figure 8). Grays Harbor fall Chinook are managed in aggregate for a natural spawning escapement goal of 13,326 adults (WDFW, unpublished).

Table 5. Current status of Fall Chinook Salmon in the Chehalis Basin.

Population	Type	Spawners (2011-2020 avg.)				Escape. goal	Related hatchery production
		Natl.	Hat.	Total	% Hat.		
Humptulips	Hat.-Wild	3,207	1,555	4,761	31%	3,573	Humptulips (500,000)
Hoquiam	Wild	363	0	363	0%	489	--
Wishkah	Wild	433	59	491	12%	907	--
Wynoochee	Wild	1,455	81	1,537	5%	1,541	Lake Aberdeen (50,000)
Satsop	Hat.-Wild	2,690	739	3,429	22%	2,703	Bingham Creek (500,000)
South Bay	Hat.-Wild	--	--	--	--		--
Chehalis	Wild	5,542	40	5,582	1%	5,209	--
Total		*13,689*	*2,474*	*16,163*	*15%*	*14,422*	*1,050,000*
Total (without Humptulips)		*10,482*	*920*	*11,402*	*8%*	*10,849*	*550,000*

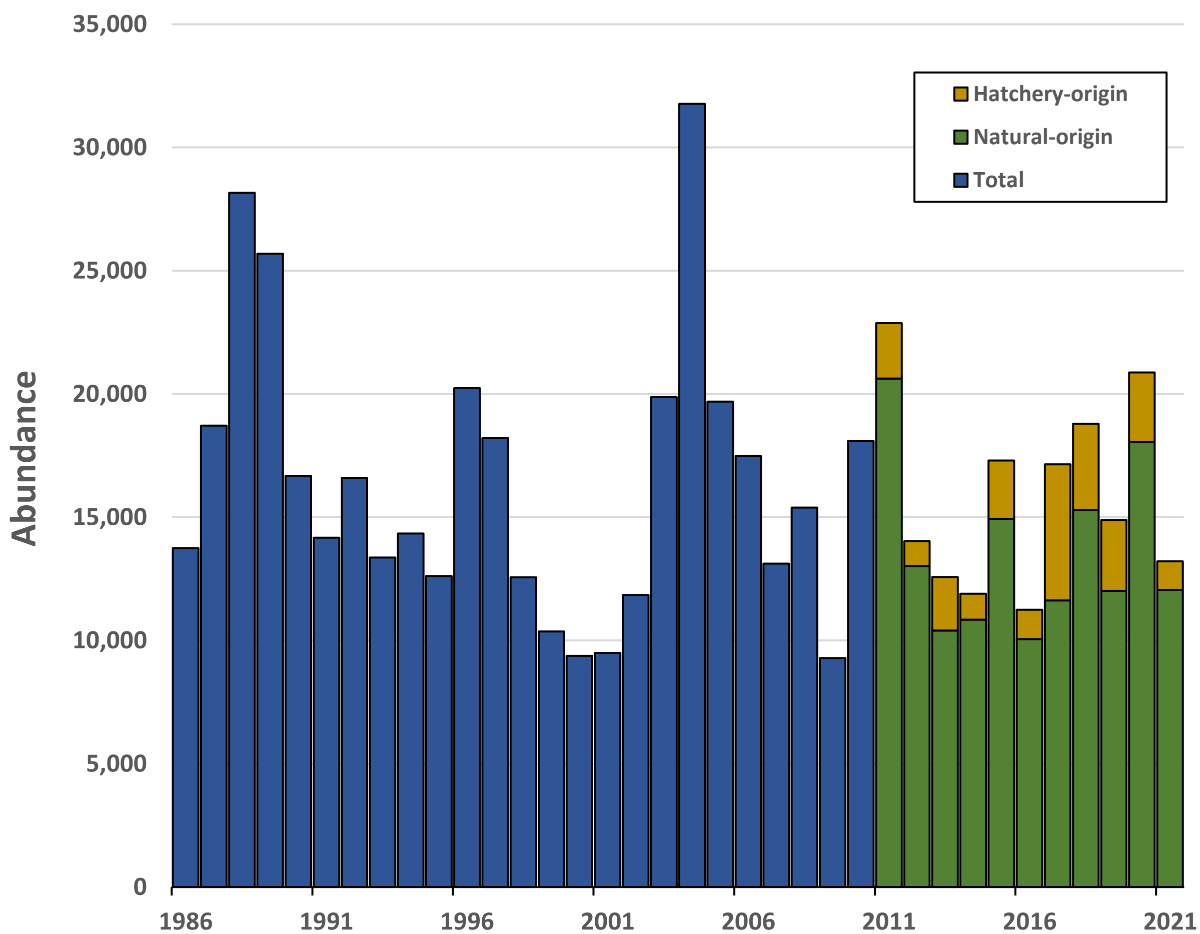

Figure 8. Annual abundance of Fall Chinook Salmon spawners in the Chehalis Basin.

Humptulips Fall Chinook - Most spawning takes place in the Mainstem Humptulips, the East Fork Humptulips (to RM 15.5), the West Fork Humptulips Rivers (to RM 45.8) and in Big, Stevens, Donkey, O'Brien, Newberry, Rainbow, Brittain, and Grouse Creeks (WDFW & WWTIT 2002). Total escapement estimates are based on redd counts within intensive and supplemental index areas expanded to basin-wide totals (WDFW SCoRE 2022). Index areas surveyed include the mainstem Humptulips River (RM 6.9 to 28.1 and RM 16.7 to 19.4), West Fork Humptulips River (RM 28.1 to 45.8 and RM 36.7 to 40.6) and East Fork Humptulips River (RM 0.0 to 15.5 and RM 1.6 to 4.4). Surveyed tributaries include Big, Hansen, Stevens, Britian, Ellwood, Widow, O'Brien, Donkey, Newbury, Rainbow and Grouse creeks. Additional unnamed tributaries surveyed include 22.0066, 22.0067, 22.0069 and 22.0072. Hatchery and natural components are distinguished from carcass sampling data. Juvenile Fall Chinook are released in the subbasin from the Humptulips Hatchery and hatchery-origin fish contributed approximately 31% of natural spawners in 2011-2020. Hatchery releases have occurred since the 1950s and have included stocks ranging from Spring Creek (Columbia River) to Green River (Puget Sound) (WDFW & WWTIT 2002). Willapa Hatchery stock were released from the late 1970s through 1984. After that, the hatchery stock employed local returns. It is likely that a significant amount of interbreeding between local and non-local stocks took place historically (WDFW & WWTIT 2002).

Hoquiam Fall Chinook - Most spawning takes place in the East and West Fork Hoquiam rivers. Occasionally spawning is observed in Davis Creek and less often in the Middle Fork Hoquiam River (WDFW & WWTIT 2002). Total escapement estimates are based on redd counts within intensive and supplemental index areas expanded to basin-wide totals (WDFW SCoRE 2022). Index areas surveyed include the West Fork Hoquiam River (RM 9.4 to 10.7--supplemental, RM 10.9 to 13.3, and RM 13.3 to 14.5--supplemental), East Fork Hoquiam River (RM 7.5 to 9.9--supplemental, RM 9.9 to 12.6, and RM 12.6 to 16.0--supplemental), and Middle Fork Hoquiam River (RM 1.4 to 1.9--supplemental, RM 1.9 to 4.2, and RM 4.2 to 6.1--supplemental). Surveyed tributaries include Davis Creek. No hatchery production of Fall Chinook occurs in the subbasin and hatchery-origin spawners do not occur in significant numbers. Historical records do not indicate any imports of foreign stocks (WDFW & WWTIT 2002).

Wishkah Fall Chinook - Most spawning takes place in the Mainstem Wishkah River. Fewer spawners are observed in the east and west forks of the Wishkah River (WDFW & WWTIT 2002). Total escapement estimates are based on redd counts within intensive and supplemental index areas expanded to basin-wide totals (WDFW SCoRE 2022). Index areas surveyed include the Middle Fork Wishkah River (RM 16.7 to 21.5--supplemental, RM 21.5 to 24.5 and RM 24.5 to 29.4--supplemental), West Fork Wishkah River (RM 0.0 to 1.8--supplemental and RM 8.1 to 9.8) and East Fork Wishkah River (RM 3.2 to 5.9--supplemental). Surveyed tributaries may include Cedar and Hopper creeks. No hatchery Fall Chinook are currently released in the subbasin but hatchery-origin fish contributed approximately 12% of natural spawners in 2011-2020. Large numbers of hatchery fish are released in the Chehalis Basin upstream from the Wishkah River at the Lake Aberdeen and Bingham Creek hatcheries. Historical records do not indicate any imports of foreign stocks (WDFW & WWTIT 1992, 2002).

Wynoochee Fall Chinook - Most spawning takes place in the mainstem Wynoochee River above RM 10.5 and in Carter, Schafer and Helm Creeks. Small numbers of spawners are seen in Big and Anderson Creeks (WDFW & WWTIT 1992, 2002). Total escapement estimates based on redd counts within intensive and supplemental index areas expanded to basin-wide totals (WDFW SCoRE 2022). Index areas surveyed include the mainstem Wynoochee River (RM 1.7 to 47.9), RM 5.6 to 8.1--supplemental, RM 8.1 to 15.4 and RM 29.1 to 31.2). Adults trapped at RM 47.9 and hauled above the Wynoochee Reservoir are also included in the escapement estimate. Surveyed tributaries include Bitter, Helm, Carter, Schafer, Anderson and Big creeks as well as unnamed tributary 22.0298. No hatchery Fall Chinook are currently released in the subbasin but hatchery-origin fish contributed approximately 5% of natural spawners in 2011-2020. Three releases of non-native hatchery fall-run Chinook have previously occurred into the Wynoochee Basin (WDFW & WWTIT 1992, 2002) but numbers were small and potential for hybridization was not great (ASEPTC 2014).

Satsop Fall Chinook - Most spawning takes place in the Mainstem Satsop River, Canyon River and the east and west forks of the Satsop River. Spawning also occurs in Bingham, Decker and Black Creeks as well as unnamed tributaries 22.0366 and 22.0372 (WDFW & WWTIT 2002). Total escapement estimates are based on redd counts within intensive and supplemental index areas and expanded to basin-wide totals (WDFW SCoRE 2022). Index areas surveyed include the mainstem Satsop River (RM 2.5 to 6.3--supplemental and RM 6.3 to 11.0), East Fork Satsop River (RM 11.0 to 12.4, RM 12.4 to 14.7 and RM 14.7 to 17.5--supplemental). Adults trapped and placed upstream above the Bingham hatchery complex located at the confluence of the East Fork Satsop and Bingham Creek (RM 17.5) and those fish collected at the Bingham Creek Trap (RM 0.9) were included in the escapement estimate. Surveyed tributaries include Black, Canyon, Decker, Dry Run and Bingham creeks as well as unnamed tributary 22.0459. Juvenile Fall Chinook are released in the subbasin from the Bingham Creek Hatchery and hatchery-origin fish contributed approximately 22% of natural spawners in 2011-2020. Extensive releases of non-native fall hatchery Chinook including Humptulips, Willapa Bay, Puget Sound, Columbia River and Oregon coastal stocks, into the Satsop Basin have occurred beginning in 1952, but genetic evidence from the East Fork Satsop River stock indicates a more native profile (ASEPTC 2014).

South Bay Fall Chinook - Most spawning takes place in the lower Johns River (WDFW & WWTIT 1992, 2002). This population is not currently monitored (WDFW SCoRE 2022). No hatchery production of Fall Chinook currently occurs in the subbasin although releases have occurred in the past. Imported stocks of hatchery fish were released from the early 1950s to the early 1970s (WDFW & WWTIT 1992, 2002).

Chehalis Fall Chinook - The Chehalis stock includes all fall Chinook upstream of the confluence of the Satsop River. Major spawning areas include the mainstem Chehalis River (RM 28 to 67 and RM 88 to 108), Black, Newaukum and Skookumchuck rivers as well as Cloquallum and Porter Creeks. Spawning also takes place in Cedar Creek, Stillman Creek and the South Fork Chehalis River (WDFW & WWTIT 1992, 2002). Total escapement estimates are based on redd counts within intensive and supplemental index areas expanded to basin-wide totals. Index areas surveyed include the mainstem Chehalis River (RM 25.2 to 67.0 and RM 81.3 to 109.0, RM 33.3 to 42.2, RM 47.0 to 52.5--supplemental, and RM 103.7 to 106.2), Black River (RM 0.0 to 8.6 and RM 4.2 to 8.6), Skookumchuck River (RM 6.4 to 10.9, RM 14.3 to 21.3--supplemental, RM 21.3 to 21.9), Newaukum River (RM 0.0 to 10.8), South Fork Newaukum River (RM 16.3 to 18.5--supplemental, RM 18.5 to 20.8 and RM 27.3 to 29.6), North Fork Newaukum River (RM 4.5 to 6.9--supplemental, and RM 7.9 to 10.3--supplemental) and South Fork Chehalis River (RM 0.0 to 5.1, RM 3.0 to 4.3 and RM 4.3 to 5.19--supplemental). Adults trapped and placed upstream at the Elk Creek trap are included in the escapement estimate. Surveyed tributaries include Cloquallum, Wildcat, Porter, Cedar, Waddell, Stillman, Elk, Big and Jones creeks. No hatchery production of Fall Chinook occurs in the subbasin and hatchery-origin spawners do not occur in significant numbers. Various non-native hatchery fall-run Chinook stocks were introduced into the Chehalis Basin from the early 1950s through the mid-1970s although information regarding these releases is poor (WDFW & WWTIT 1992, 2002). Potential for hybridization between native and non-native stock did exist.

Coho

Coho return to streams throughout the basin and seven populations have been identified (Figure 11: WDFW & WWTIT 1992, 2002). There is rich genetic diversity among populations of coho in the basin (Seamons et al 2020). Adults enter the harbor from mid to late September through mid-December and spawn from November through February. There has been considerable discussion as to whether the late-spawning component (January-February) represents a separate stock or the later portion of a single stock (WDFW and WWTIT 1992, 2002). Hiss and Knudsen (1992) suggested that the late component of the run spawning in January and February consists of wild fish and the early run spawning in November and December has more historical hatchery influence (ASEPTC 2014).

Substantial numbers of hatchery Coho are released from the basin hatcheries and hatchery-origin fish make significant contributions to natural spawning in four populations where releases occur (Table 6). Three populations are almost entirely natural origin.

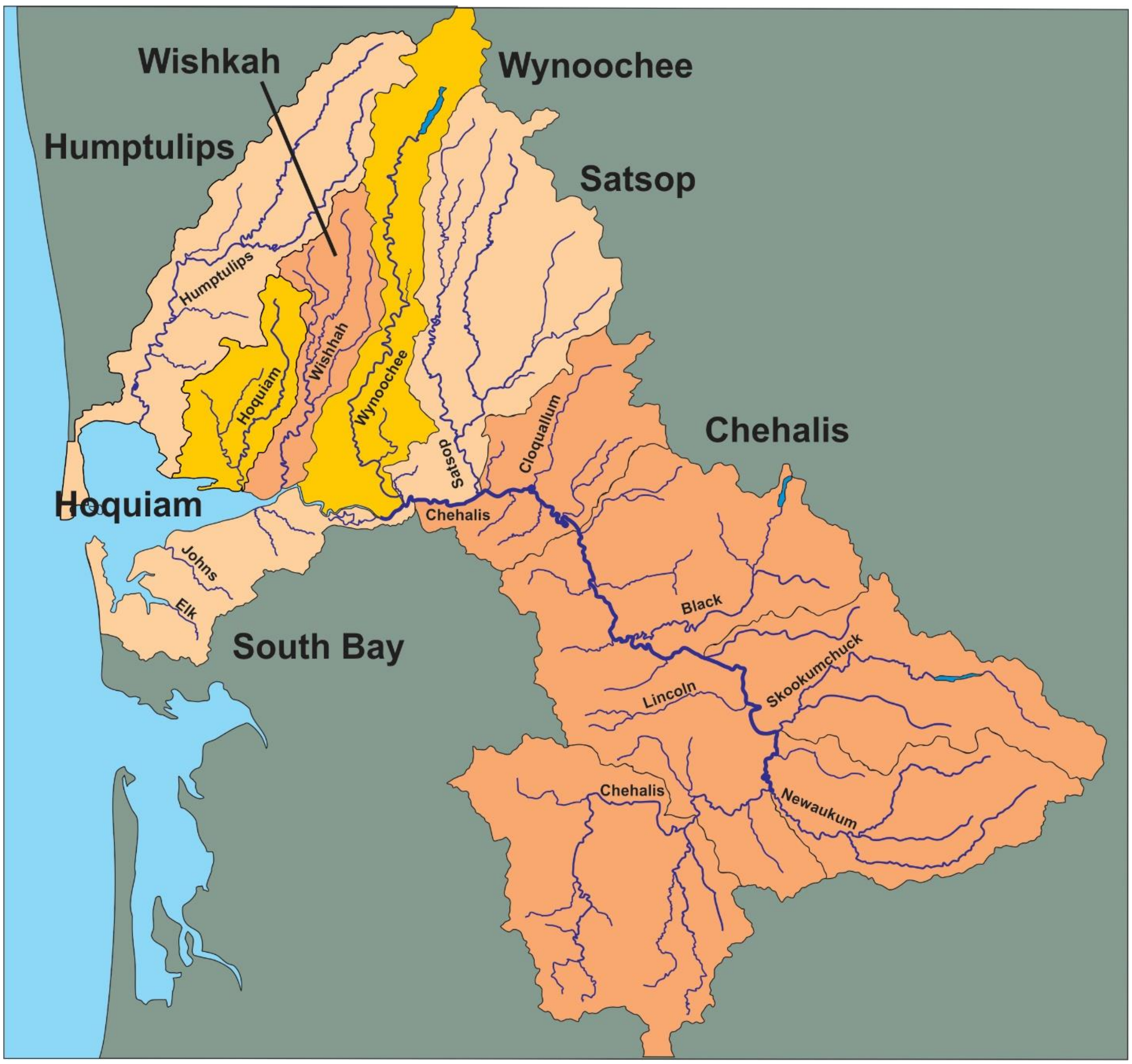

Figure 9. Distribution of Coho Salmon populations in the Chehalis Basin.

Spawning escapement is surveyed each year in all populations. Total spawners averaged 49,180 in 2011-2022 of which approximately 15% are hatchery-origin (Table 6). Grays Harbor coho are managed for natural production with a spawning escapement goal of 35,400 (PFMC 2023). Annual escapements have varied between 10,000 and 110,000 since 1980 (Figure 9).

Table 6. Current status of Coho Salmon in the Chehalis Basin.

Population	Type	Spawners (2011-2020 avg.)				Escape. goal	Related hatchery production
		Natl.	Hat.	Total	% Hat.		
Humptulips	Hat.-Wild	2,688	936	3,624	33%	6,894	Humptulips (1,000,000)
Hoquiam	Wild	1,885	15	1,900	3%	1,788	--
Wishkah	Hat.-Wild	1,025	705	1,730	35%	2,778	Mayr Brothers Ponds (300,000)
Wynoochee	Wild	3,693	0	3,693	0%	7,168	Lake Aberdeen (55,000)
Satsop	Hat.-Wild	5,589	2,769	8,357	30%	8,628	Bingham Creek (1,050,000)
South Bay	Wild	2,146	149	2,175	5%		Westport Net Pens (100,000)
Chehalis	Hat.-Wild	24,714	2,986	27,700	9%	8,134	Skookumchuck (325,000)
Total		*41,739*	*7,561*	*49,180*	*15%*	*35,390*	*2,830,000*
Total (w/o Humptulips)						*28,496*	*1,830,000*

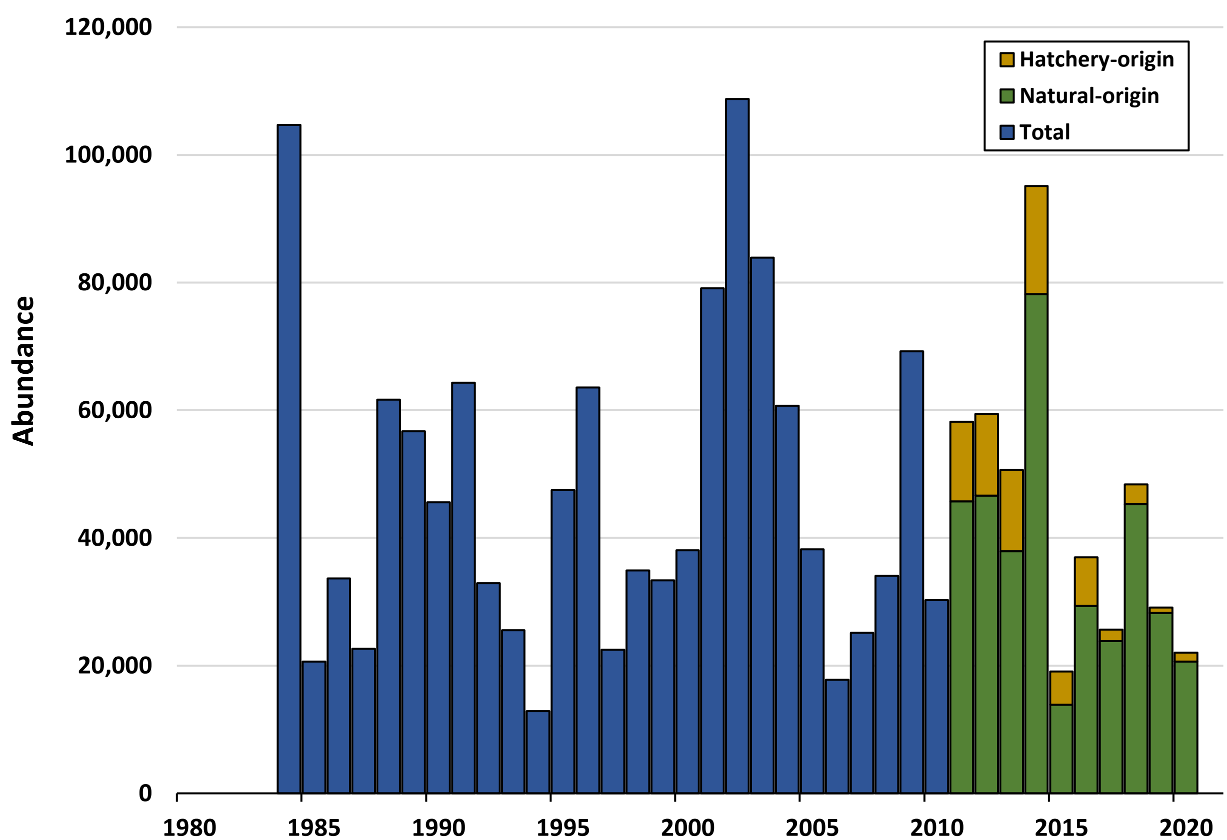

Figure 10. Annual abundance of Coho Salmon spawners in the Chehalis Basin.

Humptulips Coho - Spawning takes place in over sixty tributaries scattered throughout the Humptulips watershed. Spawning primarily occurs in Big, Hansen, Fairchild, Stevens, Ellwood, O'Brien, Donkey, and Newbury Creeks. Some spawning also takes place in the lower Mainstem Humptulips and in both the east and west forks of the Humptulips River (WDFW & WWTIT 1992, 2002). Data are total escapement estimates based on redd counts within intensive and supplemental index areas expanded to basin-wide totals (WDFW SCoRE 2022). Index areas surveyed include the mainstem Humptulips River (RM 16.7 to 19.4), West Fork Humptulips River (RM 36.7 to 40.6) and East Fork Humptulips River (RM 1.6 to 4.4). Surveyed tributaries include Big, Hansen, Stevens, Britian, Ellwood, Widow, O`Brien and Donkey creeks. Natural and hatchery-origin spawners are identified using mark rates of carcasses encountered during spawning ground surveys. Juvenile Coho are released in this river from the Humptulips Hatchery and hatchery-origin fish contributed approximately 33% of natural spawners in 2011-2020. Hatchery fish have been released beginning in the 1950s and historically included from a mixture of local and non-local stocks (WDFW & WWTIT 1992, 2002). Since 1977, releases have occurred from Humptulips hatchery.

Hoquiam Coho - Most spawning takes place in the Mainstem and east and west forks of the Hoquiam River. Spawning also occurs in accessible tributaries such as Berryman, Polson, and Davis Creeks as well as unnamed tributaries 22.0148-0151 (WDFW & WWTIT 1992, 2002; GHLE 2011). Data are total escapement estimates based on redd counts within intensive and supplemental index areas expanded to basin-wide totals (WDFW SCoRE 2022). Index areas surveyed include the West Fork Hoquiam River (RM 9.4 to 10.7), East Fork Hoquiam River (RM 9.9 to 12.6), Middle Fork Hoquiam River (RM 1.9 to 4.2) and unnamed tributary 22.0138A (RM 0.0 to 0.2). Natural and hatchery-origin spawners are identified using mark rates of carcasses encountered during spawning ground surveys. No hatchery Coho are released in this subbasin but hatchery strays contributed 3% of natural spawners in 2011-2020. Hatchery fish have been released from the 1950s through the 1980s and historically included from a mixture of local and non-local stocks (WDFW & WWTIT 1992, 2002). Hatchery releases have been discontinued. As a result of the historical movement of stocks and the size and frequency of hatchery releases, this stock is no longer considered to be native (WDFW & WWTIT 1992, 2002).

Wishkah Coho - Most spawning takes place in the Mainstem and East and West Forks of the Wishkah River. Spawning also occurs in accessible tributaries such as Bear, Big, Cedar, Raney and Hopper Creeks (WDFW & WWTIT 1992, 2002). Data are total escapement estimates based on redd counts within intensive and supplemental index areas and expanded to basin-wide totals (WDFW SCoRE 2022). Hatchery-origin spawners identifed using mark rates of carcasses encountered during spawning ground surveys. Index areas surveyed include the Middle Fork Wishkah River (RM 21.5 to 24.5), West Fork Wishkah River (RM 8.1 to 9.8) and East Fork Wishkah River (RM 3.2 to 5.9). Natural and hatchery-origin spawners are identified using mark rates of carcasses encountered during spawning ground surveys. Juvenile Coho are released in this river from the Mayr Brothers Ponds and hatchery-origin fish contributed approximately 35% of natural spawners in 2011-2020. Hatchery fish have been released from the 1950s through the 1980s and historically included from a mixture of local and non-local stocks (WDFW & WWTIT 1992, 2002). Releases are now solely from local stock. As a result of the historical movement of stocks and the size and frequency of hatchery releases, this stock is no longer considered to be native (WDFW & WWTIT 1992, 2002).

Wynoochee Coho - Most spawning takes place in tributaries such as Black, Bitter, Helm, Carter, Schafer Anderson and Big Creeks. Some spawning also occurs in the upper mainstem and west branch of the Wynoochee River (WDFW & WWTIT 1992, 2002). total escapement estimates based on redd counts within intensive and supplemental index areas and expanded to basin-wide totals (WDFW SCoRE 2022). Index areas surveyed include the mainstem Wynoochee River (RM 29.1 to 31.2), Bitter Creek (RM 1.3 to 2.5), Helm Creek (RM 0.6 to 2.3), Schafer Creek (RM 1.3 to 4.9) as well as unnamed tributary 22.0298 (RM 0.0 to 1.3). Adults trapped at RM 47.9 and hauled above Wynoochee Reservoir are also included in the escapement estimate. No hatchery Coho are currently released in this subbasin and hatchery-origin fish do not contribute to natural spawning. Releases of hatchery-reared coho yearlings were continuous in the 1950s. In the late 1970s to 1980s a large-scale fingerling program was carried out utilizing stocks from Soos Creek, Samish, Dungeness, Satsop, Minter Creek and Sol Duc and Humptulips hatcheries. As a result of the historical movement of stocks and the size and frequency of hatchery releases, this stock is no longer considered to be native (WDFW & WWTIT 1992, 2002).

Satsop Coho - Most spawning takes place in tributaries such as Still, Canyon, Smith, Rabbit, Decker, Dry Run, Bingham, Outlet and Stillwater Creeks. Spawning also occurs in the Mainstem, East, and West Forks of the Satsop River (WDFW & WWTIT 1992, 2002). Total escapement estimates are based on redd counts within intensive and supplemental index areas expanded to basin-wide totals (WDFW SCoRE 2022). Index areas surveyed include the East Fork Satsop River (RM 12.4 to 14.7), Black Creek (RM 0.0 to 0.9), Rabbit Creek (RM 1.3 to 2.3), Decker Creek (RM 10.9 to 11.4), Dry Run Creek (RM 0.0 to 2.3) and unnamed tributary 22.0459 (RM 0.0 to 0.5). Adults trapped and placed upstream above either the Bingham Hatchery complex (RM 17.5) and Bingham Creek Trap (RM 0.9) were included in the escapement estimate. Natural and hatchery-origin spawners are identified using mark rates of carcasses encountered during spawning ground surveys. Juvenile Coho are released in this river from the Bingham Creek Hatchery and hatchery-origin fish contributed approximately 30% of natural spawners in 2011-2020. Releases of hatchery-reared coho yearlings extend back to the 1930s and 1940s. In the late 1970s and through the 1980s, a large-scale fingerling release program was carried out. Stocks origins for these releases include Soos Creek, Samish, Dungeness, Minter Creek, Sol Duc, and Satsop hatcheries. As a result of the historical movement of stocks and the size and frequency of hatchery releases, this stock is no longer considered to be native (WDFW & WWTIT 1992, 2002).

South Bay Coho - Most spawning takes place in the mainstem upper Johns River as well as in the North and South Fork Johns River. Spawning also occurs in Elk River, the west branch of Elk River and in Newskah and Andrews Creeks (WDFW & WWTIT 1992, 2002). Data are total escapement estimates based on redd counts within intensive and supplemental index areas expanded to basin-wide totals (WDFW SCoRE 2022). Index areas surveyed include the North Fork Johns River (RM 9.5 to 10.7). In 1999, four supplemental surveys were conducted that also included Elk River, Alder and Andrews creeks. No hatchery Coho are released in South Bay streams but fish are released nearby from net pens near Westport. Hatchery-origin fish comprise 5% of spawners in natural production areas of South Bay streams. Hatchery fish have been released from the 1950s through the 1980s and historically included from a mixture of local and non-local stocks (WDFW & WWTIT 1992, 2002). Hatchery releases into these streams have been discontinued. As a result of the historical movement of stocks and the size and frequency of hatchery releases, this stock is no longer considered to be native (WDFW & WWTIT 1992, 2002).

Chehalis Coho - Most spawning takes place in over 195 mainstem rivers and tributaries scattered throughout the Chehalis Basin. Spawning takes place in accessible tributaries such as Delezene, Cloquallum, Mox-Chehalis, Mima, Waddell, Scatter, Hanaford, Lucas, Kearney, Stillman, South Fork Lincoln, Smith and Swem Creeks. Spawning also occurs in the Upper Mainstem and the East Fork of the Chehalis River, Skookumchuck River, and Newaukum River (WDFW & WWTIT 1992, 2002). Total escapement estimates based redd counts within intensive and supplemental index areas expanded to basin-wide totals (WDFW SCoRE 2022). Index areas surveyed include the mainstem Chehalis River (RM 103.7 to 106.2), Fry Creek (spawn pad at RM 1.4), Mill Creek (RM 1.0 to 1.1), Delezene Creek (RM 3.2 to 4.0), Cloquallum Creek (RM 3.5 to 6.0), Rock Creek (RM 0.0 to 1.0), East Fork Wildcat Creek (RM 4.8 to

6.4), Mox-Chehalis (RM 9.5 to 10.1), Porter Creek (RM 2.6 to 3.1), Cedar Creek (RM 5.9 to 7.9), Waddell Creek (RM 6.8 to 7.2), Scatter Creek (RM 0.4 to 3.2), Skookumchuck River (RM 21.3 to 21.9), Hanaford Creek (RM 10.8 to 11.3), Thompson Creek (RM 5.0 to 5.7), South Fork Newaukum Creek (RM 27.3 to 29.6), Kearney Creek (RM 1.4 to 2.6), South Fork Chehalis River (RM 25.9 to 27.0), Hanlan Creek (RM 1.0 to 2.0), South Fork Lincoln Creek (RM 13.1 to 14.6), Dillenbaugh Creek (RM 4.3 to 6.0), Smith Creek (RM 0.3 to 1.4), Swem Creek (RM 0.0 to 1.5), Big Creek (RM 0.0 to 1.0) and George Creek (RM 0.0 to 1.0). Adults trapped and placed upstream at the Elk Creek trap are included in the escapement estimate. Natural and hatchery-origin spawners are identified using mark rates of carcasses encountered during spawning ground surveys. Juvenile Coho are released in this river from the Chehalis Hatchery and hatchery-origin fish contributed approximately 9% of natural spawners in the Chehalis populations for 2011-2020. Releases of hatchery-reared coho yearlings were continuous from 1950 to 1970. In the late 1970s and through the 1980s, a large-scale fingerling release program was carried out utilizing stocks from Soos Creek, Samish, Dungeness, Satsop, Minter Creek, Sol Duc and Humptulips hatcheries. As a result of the historical movement of stocks and the size and frequency of hatchery releases, this stock is no longer considered to be native (WDFW & WWTIT 1992, 2002).

Chum

Grays Harbor Chum are currently identified as a single fall run population (Figure 11: Edwards & Zimmerman 2018; Ronne et al. 2022; WDFW SCoRE 2022). Chehalis and Humptulips river populations were previously distinguished (WDFW & WWTIT 1992, 2002). However, WDFW combined the two SaSI populations in 2015 based on existing management criteria that used single escapement goal for the combined populations (Edwards & Zimmerman 2018).

Adults enter freshwater from early October through November and spawn from late October through early December (WDFW & WWTIT 1992, 2002). Most spawning occurs in the mainstem Humptulips, Hoquiam, Wishkah, Wynoochee, and Satsop rivers and their tributaries (WDFW & WWTIT 1992, 2002; GHLE 2011; Edwards & Zimmerman 2018; Ronne et al. 2022). Additional spawning is observed in Black River, Cloquallum Creek and other smaller main stem tributaries, as well as in the south harbor tributaries, such as Elk and Johns rivers.

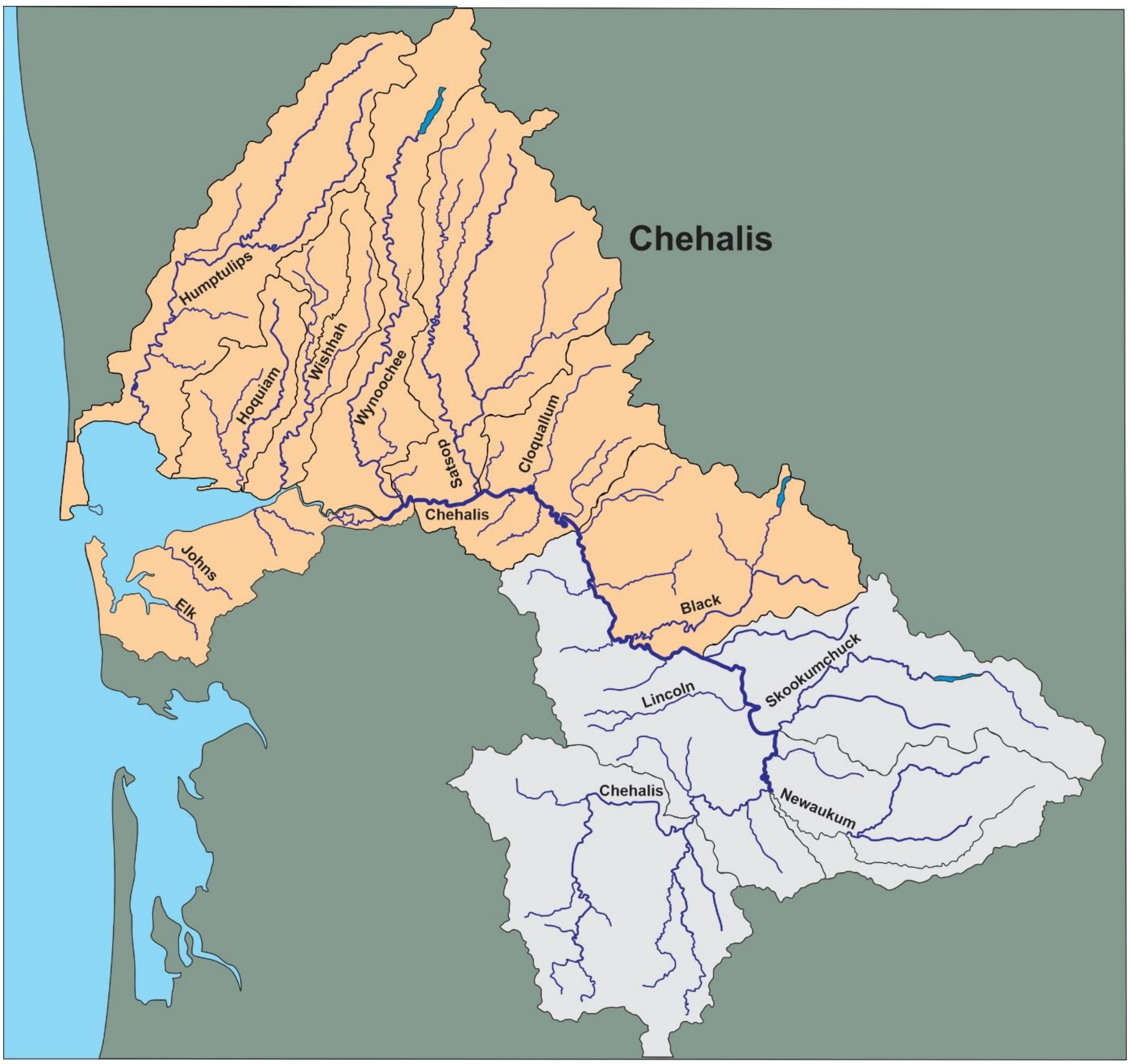

Figure 11. Chum Salmon population in the Chehalis Basin.

Spawning escapement has been surveyed each year since the 1970s. Estimates were historically based on total live counts in four index reaches (three in the Chehalis River basin) then expanded to basin escapement based on relationship of current year index count to base year total live index counts associated with the escapement goal (WDFW SCoRE 2022). For estimation purposes, the four survey indexes were assumed to contain 10.8% of the population (Ronne et al. 2022). A multi-year study was initiated in 2015 to improve methods for spawner abundance estimation and to better describe distribution of Chum Salmon in the lower Chehalis River Basin (Ronne et al. 2022). This study suggested that the historic/current method may underestimate actual escapement by up to 50%.

Total spawners have averaged 28,543 in 2011-2022 based on historical assessment methods (Table 7). Grays Harbor fall Chinook are managed for a natural spawning escapement goal of 21,000 (Ronne et al. 2022). Spawning escapement varies widely from year to year with no significant trend during the period of record (Figure 12). Hatchery-origin Chum are reported to comprise 3% of the total run, on average (ASEPTC 2014).

Table 7. Current status of Chum Salmon in the Chehalis Basin based on historical survey methodology (WDFW SCoRe 2022).

Population	Type	Spawners (2011-2020 avg.)				Escapement goal	Related hatchery production
		Natl.	Hat.	Total	% Hatchery		
Grays Harbor	Hat.-Wild	na	na	28,543	3%	21,000	Bingham Creek, Mayr Brothers Ponds (500,000)

na = not available

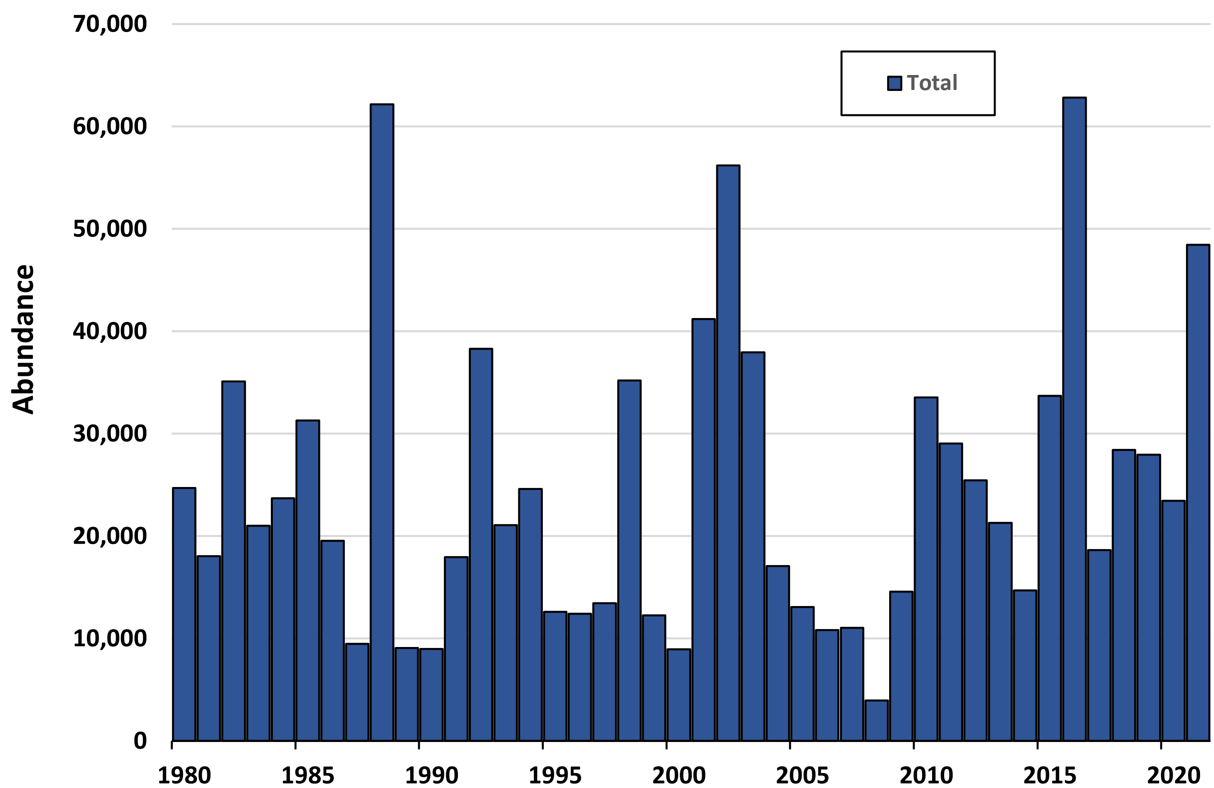

Figure 12. Annual abundance of Chum Salmon spawners in the Chehalis Basin.

Summer Steelhead

Two Summer Steelhead populations have been identified in the Chehalis Basin (Table 8: WDFW & WWTIT 1992, 2002). Run timing is generally believed to be from May through October with spawning from February through April (WDFW & WWTIT 1992, 2002).

Distribution and abundance of natural-origin spawners is unclear. This is an unknown stock with wild production. A native stock originally returned to the Chehalis River system, but now there is uncertainty about natural production by hatchery summer steelhead spawning in the wild. Hiss and Knudsen (1993) reported that hatchery-origin fish comprise almost all natural spawners but that an undetermined but limited natural production occurs. Escapement goals have not been identified (WDFW & WWTIT 1992, 2002).

Humptulips Summer Steelhead - Specific spawning locations in the Humptulips basin are unknown (WDFW & WWTIT 2002; GHLE 2011). Escapement is not currently monitored (WDFW SCoRE 2022).

Chehalis Summer Steelhead - Specific spawning locations are unknown (WDFW & WWTIT 1992, 2002; GHLE 2011). Escapement is not currently monitored (WDFW SCoRE 2022).

Table 8. Current status of Summer Steelhead in the Chehalis Basin.

Population	Type	Spawners (2011-2020 avg.)				Escape. goal	Related hatchery production
		Natl.	Hat.	Total	% Hat.		
Humptulips	Hat.-Wild	Na	na	na	95%[a]	na	Humptulips (30,000)
Chehalis	Wild	Na	na	na	95% [a]	na	Lake Aberdeen (60,000)
Total		--	--	--	*95%* [a]	*na*	*90,000*

[a] *Assumed for the purposes of this analysis.*

Winter Steelhead

Winter Steelhead return to streams throughout the basin and eight populations have been identified (Figure 13: WDFW & WWTIT 1992, 2002). Run timing is December through May with spawning from mid-February through early June (WDFW & WWTIT 1992, 2002). Genetic population structure has been assessed by Seamons et at. (2017).

Substantial numbers of hatchery winter steelhead are released from the basin hatcheries and hatchery-origin fish make significant contributions to natural spawning in two populations where releases occur (Table 9). Total natural spawning escapement is surveyed each year in all populations except the South Bay. Hatchery-origin percentages of total spawners are not directly estimated from spawning ground surveys of marked and unmarked steelhead but are reported in Marston and Huff (2022) based on modeling.

Total spawners in surveyed systems averaged 9,203 in 2011-2022 (Table 9). Annual escapements have varied between 5,000 and 20,000 since 1984 (Figure 9). The basinwide natural escapement goal for Winter Steelhead is 8,600 (QINDF & WDFW 2021).[1]

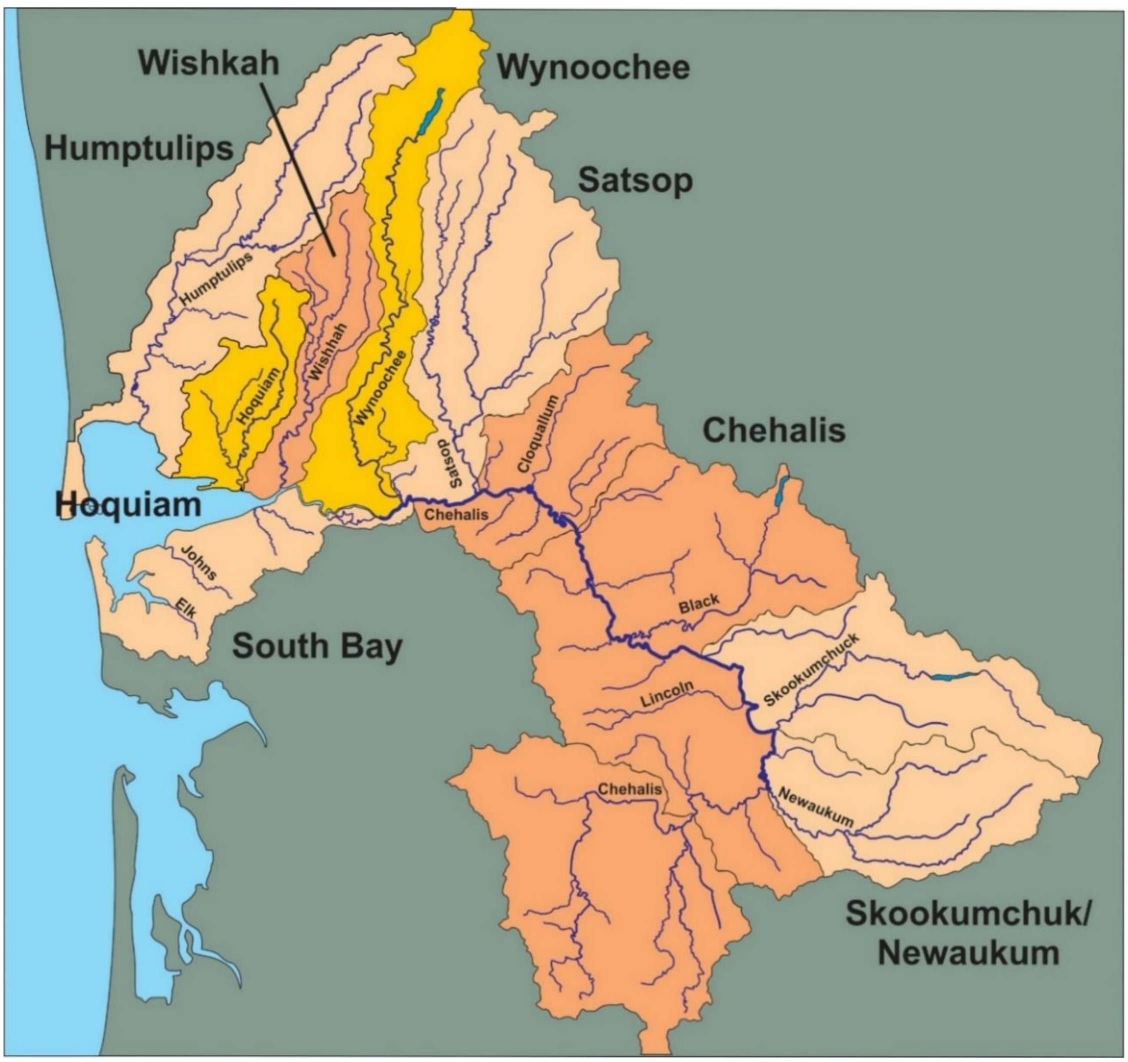

Figure 13. Distribution of Winter Steelhead populations in the Chehalis Basin.

[1] *Goal includes Hoquiam, Wishkah, Wynoochee, Satsop, Chehalis, and Skookumchuk/Newaukum populations.*

Table 9. Current status of Winter Steelhead in the Chehalis Basin.

Population	Type	Spawners (2011-2020 avg.)				Escape. goal	Related hatchery production
		Natl.	Hat.	Total	% Hat.		
Humptulips	Wild	na	na	1,836	2%	1,600	Humptulips (125,000)
Hoquiam	Wild	na	na	352	na	450	
Wishkah	Wild	na	na	409	1%	412	Humptulips (15,000)
Wynoochee	Hat.-Wild	na	na	1,322	45%	1,260	Lake Aberdeen (170,000)
Satsop	Wild	na	na	2,225	5%	2,800	Bingham Creek (55,000)
South Bay	Wild	na	na	na	na	na	
Skookumchuck/Newaukum	Hat.-Wild	na	na	1,007	20%	1,429	Skookumchuck (105,000)
Chehalis	Hat.-Wild	na	na	2,053	1%	2,700	Skookumchuck (32,000)
Total		na	na	*9,203*	*12%*	*10,651*	*502,000*
Total (without Humptulips)		na	na	*7,367*		*9,051*	*377,000*

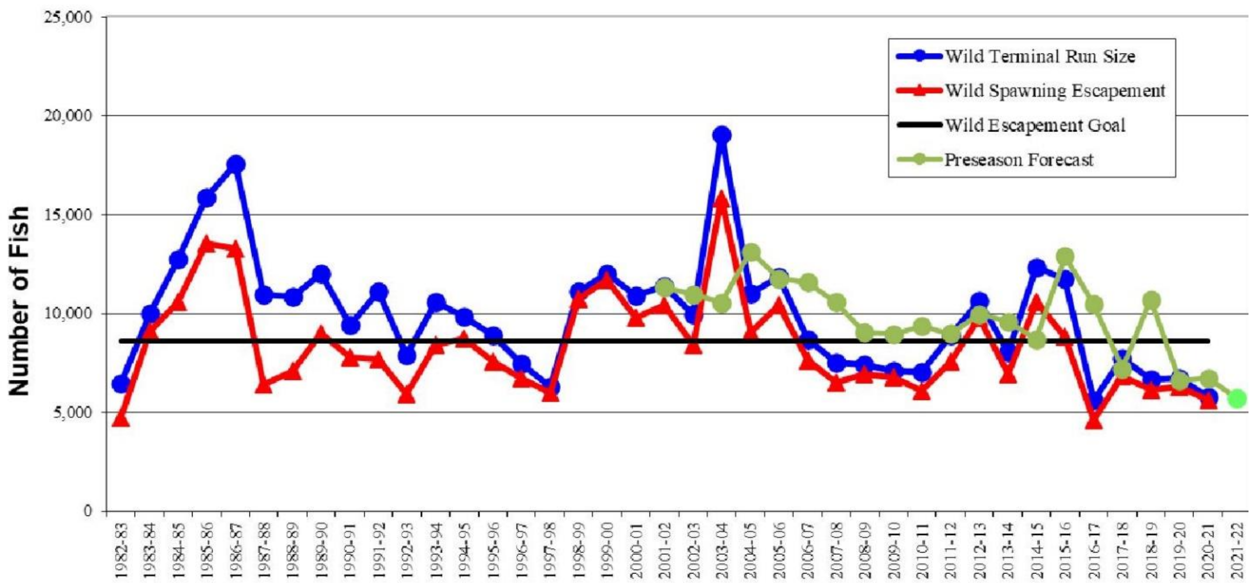

Figure 14. Annual abundance of Winter Steelhead spawners in the Chehalis Basin (QINDF & WDFW 2021).

Humptulips Winter Steelhead - Most spawning takes place in the Mainstem Humptulips and east and west forks of the Humptulips River. Spawning also occurs in tributaries such as Brittian, Stevens, Donkey and Newberry Creeks (WDFW & WWTIT 1992, 2002; GHLE 2011). Total natural spawners are estimated based on redd counts in index areas (WDFW SCoRE 2022). Spawning ground surveys on the Humptulips River are conducted by the Quinault Tribe, with limited supplemental surveys by WDFW (Marston and Huff 2022). The natural-origin spawning escapement goal is 1,600 (Marston and Huff 2022). Winter Steelhead (segregated early run program) are currently released on-station from Humptulips Hatchery (Marston and Huff 2022).

Hoquiam Winter Steelhead - Most spawning takes place in the east and west forks of the Hoquiam River. Spawning also occurs in the middle fork of the Hoquiam River and Davis Creek (WDFW & WWTIT 1992, 2002; GHLE 2011). Total escapement estimates are based on redd counts in index areas (WDFW SCoRE 2022). There where historically outplants of early winter steelhead in the drainage, but no hatchery plants have occurred since 2006 (Marston and Huff 2022).

Wishkah Winter Steelhead - Most spawning takes place in the mainstem and in the west and east forks of the Wishkah River. Spawning also occurs in Cedar, Big and Raney Creeks (WDFW & WWTIT 1992, 2002; GHLE 2011). Total escapement estimates are based on redd counts in index areas (WDFW SCoRE 2022). The natural-origin spawning escapement goal is 412 (Marston and Huff 2022). Winter Steelhead (segregated early run program) from Humptulips Hatchery are currently released from the Mayr Brothers Ponds in the Wishkah River (Marston and Huff 2022).

Wynoochee Winter Steelhead - Most spawning takes place in the Mainstem Wynoochee River, above and below Wynoochee Lake and in Shafer and Big Creeks. Spawning also occurs in tributaries such as Bitter, Helm, Carter, Anderson and Neil Creeks (WDFW & WWTIT 1992, 2002; GHLE 2011). Total escapement estimates are based on redd counts in index areas (WDFW SCoRE 2022). The natural-origin spawning escapement goal is 1,260 (Marston and Huff 2022). Winter Steelhead (integrated late run program) from Lake Aberdeen Hatchery are currently released off-station in the Wynoochee River (Marston and Huff 2022). This stock has been supplemented with hatchery smolts including Chambers Creek winter-run steelhead (ASEPTC 2014). Substantial interbreeding between hatchery and wild fish is thought to have occurred since the early 1980s (ASEPTC 2014).

Satsop Winter Steelhead - Most spawning takes place in the mainstem Satsop, West Fork Satsop, Middle Fork Satsop, East Fork Satsop and Canyon rivers as well as Decker and Bingham Creeks. Limited spawning also occurs in Dry Run, Phillips, Black, and Rabbit Creeks (WDFW & WWTIT 1992, 2002; GHLE 2011). Total escapement estimates are based on redd counts in index areas (WDFW SCoRE 2022). The natural-origin spawning escapement goal is 2,800 (Marston and Huff 2022). Hatchery steelhead are currently released on-station from the integrated late run program at Bingham Creek Hatchery (Marston and Huff 2022).

South Bay Winter Steelhead - Most spawning takes place in the north and south fork of the Johns River. Fewer spawners are observed in the Elk River and in Andrews, Hall and Newskah Creeks (WDFW & WWTIT 1992, 2002; GHLE 2011). This population is not currently monitored (WDFW SCoRE 2022). John River received early winter steelhead outplants until 2007 and the Elk River received early winter steelhead outplants until 2006 (Marston and Huff 2022).

Skookumchuck/Newaukum Winter Steelhead - Most spawning takes place in the Skookumchuck, Newaukum, North, Middle and South Forks Newaukum rivers. Spawning also takes place in tributaries such as North Hanaford, Thompson, Lucas, Bernier, Mitchell, and Kearney Creeks (WDFW & WWTIT 1992, 2002; GHLE 2011). Total escapement estimates based on redd counts in index areas within the Newaukum and lower Skookumchuck rivers plus dam counts for the upper Skookumchuck River (WDFW SCoRE 2022). The Skookumchuck and Newaukum rivers are currently managed as a single population with a combined escapement goal of 1,429 (Marston and Huff 2022). There is currently an on-station integrated late run hatchery program at Skookumchuck Hatchery and off station releases at Carlisle Lake on the Newaukum River (Marston and Huff 2022). Hybridization with hatchery adults originating from native Skookumchuck River fish has likely been occurring since 1976 due to similar timing of spawning in native and hatchery stocks in both rivers (ASEPTC 2014).

Chehalis Winter Steelhead - Spawning takes place in more than 70 locations scattered throughout the Chehalis basin. Most spawning takes place in the mainstem Chehalis, East and West Fork Chehalis rivers and in tributaries such as Cloquallum, Porter, Rock, Crim, Cinnabar, Hanlan and Stillman Creeks (WDFW & WWTIT 2002; GHLE 2011). Total escapement estimates are based on redd counts in index areas (WDFW SCoRE 2022). Some hatchery influence occurs from the current Eight Creek integrated late winter steelhead program (Marston and Huff 2022).

LIMITING FACTOR ANALYSIS

This analysis quantifies the impacts of human-related or potentially manageable limiting factors affecting each Chehalis salmon and steelhead stock or population throughout its life cycle. Factors include tributary habitat, estuary habitat, major dams, selected predators, fisheries, and hatcheries.

Impacts are defined as a percentage reduction in abundance of natural-origin salmon and steelhead associated with the reduction in productivity or survival due to each limiting factor. Estimates are thus defined in a common currency which facilitates comparisons of the relative significance of each factor (Figure 15, Table 10). For some factors, impact definitions are intuitively easy to understand. For instance, fishery impacts are readily defined as fishing mortality rate. However, definitions may be somewhat less intuitive for other impacts. For instance, freshwater habitat impacts are defined for the purposes of this analysis based on the reduction in capacity to produce natural-origin fish relative to the pre-development condition. This is opposite how we commonly reference habitat conditions based on desired percentages of improvement relative to current degraded conditions. However, impacts and improvements are directly relatable based on simple arithmetic.

Estimates of impacts were based on a review of the related scientific literature including information specific to the Grays Harbor system and inferences from general information in other areas. Impact estimates were based information available for each factor. The available information includes a mixture of quantitative and qualitative information. For some impacts, the available data includes explicit empirical estimates (fishing mortality for instance). Information also includes model-derived values. For instance, capacity to support fish production under changing habitat conditions is based on habitat models which relate habitat quantity and quality to fish numbers. In other cases, values were inferred from a synthesis of a variety of related information. The analysis did not attempt to resolve key uncertainties where significant but rather identified a range of values consistent with alternative assumptions and hypotheses.

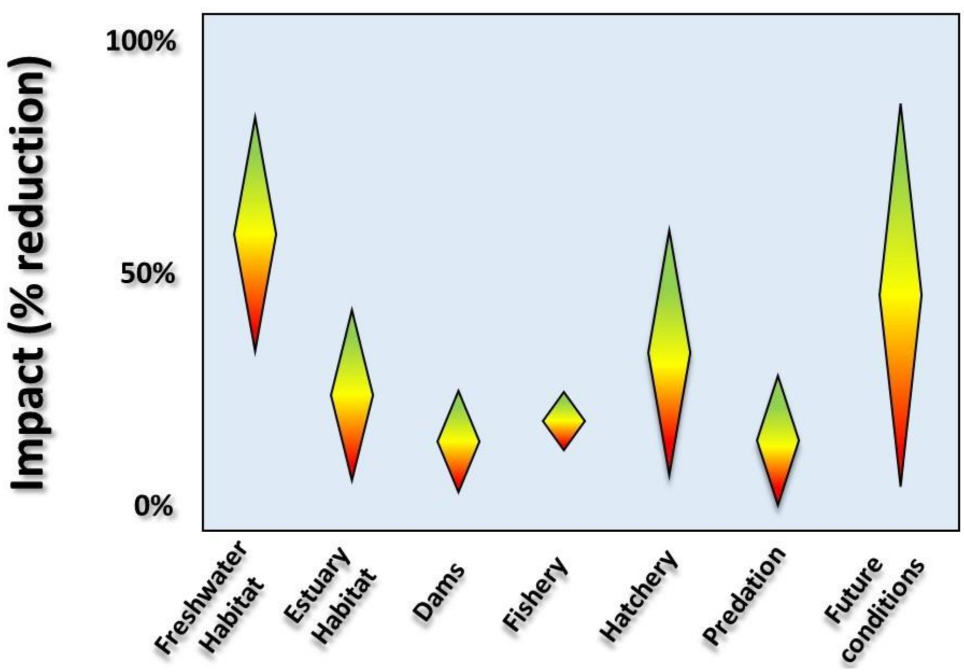

Figure 15. Conceptual depiction of factor effects expressed in a common currency of impacts with varying levels of confidence in individual estimates.

Table 10. Definitions of impacts as quantified for integrated analysis of factors limiting Chehalis salmon and steelhead.

Factor	Definition
Tributary Habitat	Percentage reduction in capacity to produce natural-origin fish due to habitat degradation in tributary production areas
Estuary Habitat	Percentage reduction in available habitat due to filling and diking
Dams	Reduction in potential production associated with construction and operation of dams including loss of access to upstream production areas, inundation of historically accessible habitat and passage mortality of juveniles and adults through dam facilities and associated reservoirs where applicable.
Fisheries	Mortality occurring in or as a result of harvest or handling including catch-and-release.
Hatchery	Defined as the percentage reduction in natural productivity due to the effects of hatchery fish on natural population diversity, productivity, and fitness, as well as effects on fish health and effects resulting from complex ecological interactions
Predation	Percentage mortality due to potentially manageable predators including birds, pinnipeds and introduced fish species.
Future conditions	Percentage reduction in productivity due to declines in freshwater productivity resulting from assumptions for climate change and future development

Tributary Habitat

For the purposes of this analysis, impacts are defined as the percentage reduction in capacity to produce natural-origin fish due to habitat degradation in tributary production areas. This includes local and cumulative effects of habitat loss and degradation in spawning, incubation, rearing, and overwintering habitats. Impact is the aggregate effect of changes in all habitat features that affect the fish including streamflow, water quality, channel morphology, substrate, etc.

Background

Extensive information is available on current habitat conditions and limitations throughout the Chehalis Basin (Smith & Wegner 2001; MBI 2003; GHLE 2011; ASEPTC 2014; McConnaha et al. 2017; ASRPSC 2019; Beechie et al. 2021a, 2021b, 2021c). Aquatic habitat throughout the Chehalis Basin has been extensively altered by humans since the 1850s through a variety of activities including agriculture, logging, gravel mining, dredging, dams, water diversions, transportation infrastructure, and point and non-point source pollution. Spawning and rearing habitat has been caused by factors such as increased streambed scour and erosion and deposition of fine sediments, loss of channel complexity and floodplain and habitat connectivity, loss of riparian forests, land conversion, loss of in-channel large wood and logjams, wetland and swamp drainage, stream channelization, and water quality degradation due to increased summer temperatures.

Estimation Methods

In this analysis, the net impact of habitat degradation on salmon and steelhead was quantified by comparing current to historical (pre-development or intrinsic) production potential of the habitat estimated in numbers of fish:

Impact = 1 – (current abundance/historical abundance)

The historical condition is a valuable reference against which to compare current conditions and to understand the capability of the watershed to support salmon and steelhead (ASRPSC 2019). Numeric records of pre-development fish abundance in the basin are lacking. However, it is possible to get an idea of historical production potential of the basin using fish-habitat models.

Estimates of historical and current production potential of Chehalis Basin habitat for salmon and steelhead are reported from two fish-habitat modeling analyses: Ecosystem Diagnosis and Treatment model (EDT) and NOAA Fisheries Life Cycle Model (LCM). Both of these analyses include detailed depictions of habitat conditions and relate salmon and steelhead life cycle processes to those habitat conditions (ASEPTC 2014; ASEPSC 2019; WDE 2020; Beechie et al. 2021a, 2021b, 2021c). The two models are organized in slightly different ways but both provide a systematic means of estimating fish effects of habitat changes. Lestelle & Morishima (2020) discuss similarities and differences between the two models.

The most robust application of these models is from a relative standpoint where model results are compared with model results. In our application, model estimates of equilibrium fish abundance (Neq) under current conditions are compared with model estimates of historical conditions. Conditions reflect habitat quality and quantity as well as fish passage barriers. Abundance is estimated in the absence of terminal harvest.

Both models have also been employed in other applications to identify the significance of specific habitat limiting factors and to project the effects of various future habitat scenarios. Both models produce constant or steady-state conditions over a period of years to estimate equilibrium abundance. The NOAA life cycle model can also account for stochastic change related to stage-specific survival or climate change.

These models can be configured to include effects of fishery harvest, hatchery-wild interactions, inter-specific interactions or estuarine conditions but Chehalis applications have focused on habitat applications to date (Lestelle & Morishima 2020).

Ecosystem Diagnosis and Treatment – EDT is a spatially explicit deterministic model that relates habitat conditions in river reaches to salmonid species population performance. In other words, changes in habitat conditions affect a salmon population (Lestelle 2005; Blair et al. 2009; ASEPSC 2019). The model includes the system geometry (or river network), habitat attributes, and the life history elements of the salmonid species. The system geometry is defined by stream reaches, their lengths, how reaches are connected to one another, and the locations of any obstructions. The habitat attributes describe how dozens of environmental and biological habitat descriptors (e.g., riparian condition, maximum temperature pattern, bed scour, habitat composition, predators) vary by reach and over time at a monthly time-step. Inputs for the physical habitat metrics are preferably based on empirical data, but this data is not always available and for attributes where direct empirical data is not available inputs are inferred from similar areas where empirical data exists or using expert opinion. The life history component of the model describes and defines, for each species evaluated, where the species can spawn, the timing of life stage transitions, and the rate of movement through the system per each life stage. To evaluate changes from historical to current conditions or the benefits of restoration scenarios, the habitat attributes are modified to reflect the type of changes proposed. Each life stage is then affected in its productivity and capacity by the proposed changes to habitat attributes (conditions). The model incorporates a density-dependent Beverton-Holt survival function to estimate capacity, productivity, and equilibrium abundance.

EDT has been widely applied to rivers throughout the Pacific Northwest, particularly in the Columbia Basin (Rawding 2004; Allen & Connolly 2005; Dominguez 2006). EDT modeling of the Chehalis Basin has occurred over multiple years beginning in 2001, with new iterations incorporating new and updated data as well as answering different, specific questions to aid in guidance of restoration for progress towards species recovery (MBI 2003; ASEPTC 2014; McConnaha et al. 2017). Most recently EDT has been applied to modeling of future scenarios in the Aquatic Species Restoration Plan (ASRPSC 2019) and alternative actions in the Environmental Impact Statement for (WDE 2020).

The EDT model provides estimates of current (patient) and historical (template) abundance. The historical/template condition is defined as ideal, pristine habitat conditions that are representative of a pre-Euro-American settlement historic condition for a specific watershed. The template condition is not an estimate of historical abundance *per se* but rather a model-derived estimate of the relative number of fish that might be produced under historical habitat conditions. These scenarios are generally characterized by environmental attributes that would reasonably represent historical or undisturbed conditions. The most recently available patient and template values for the Chehalis basin as applied in ASRPSC (2019) were provided by C. McConnaha (1/25/23 personal communication). EDT results are also reported by ecological diversity region (ASRPSC 2019). In our analysis, we assigned population-level habitat impacts based on the ecological diversity region(s) where each population was located.

NOAA Fisheries Life Cycle Model - The NOAA analysis uses three separate models to take raw GIS data and ultimately produce life-cycle model results for each salmonid species under different diagnostic or restoration scenarios (ASRPSC 2019; Beechie et al. 2021a, 2021b, 2021c). The components are spatial analysis, habitat analysis, and life-cycle models for salmonid species. Inputs are included from multiple available sources of historic and current landscape and temperature data for a basin (spatial analysis), and then a detailed mapping and analysis of observable habitat characteristics (habitat analysis) is conducted that can then be changed for various scenarios. These data are then input into the life-cycle component of the model to evaluate which habitat factors have the most effect on fish species life-stage capacities and productivities. The model outputs include estimates of the equilibrium spawner abundance, as well as cumulative life-cycle productivity and cumulative life-cycle capacity. The outputs can be used to identify which habitat factors have the most effect on abundance, productivity, and capacity of each species and how fish population parameters have changed relative to historical conditions. The NOAA model documentation reports equilibrium adult abundance under current and historical conditions in aggregate of all populations by salmon and steelhead species and run.

Impact Estimates

Habitat impacts were substantial for all stocks (Figure 16). Estimates were generally similar between EDT and NOAA models with EDT estimates of impact consistently higher to a varying degree than those of the NOAA model. For the purposes of this analysis, we used the average value of the two models for the aggregate of populations of each stock. The averaged habitat impacts ranged from 35% for Chum to about 80% for Spring Chinook and Coho.

Impacts available from EDT vary among populations depending on conditions in the ecological diversity region where each population occurs (Table 11).

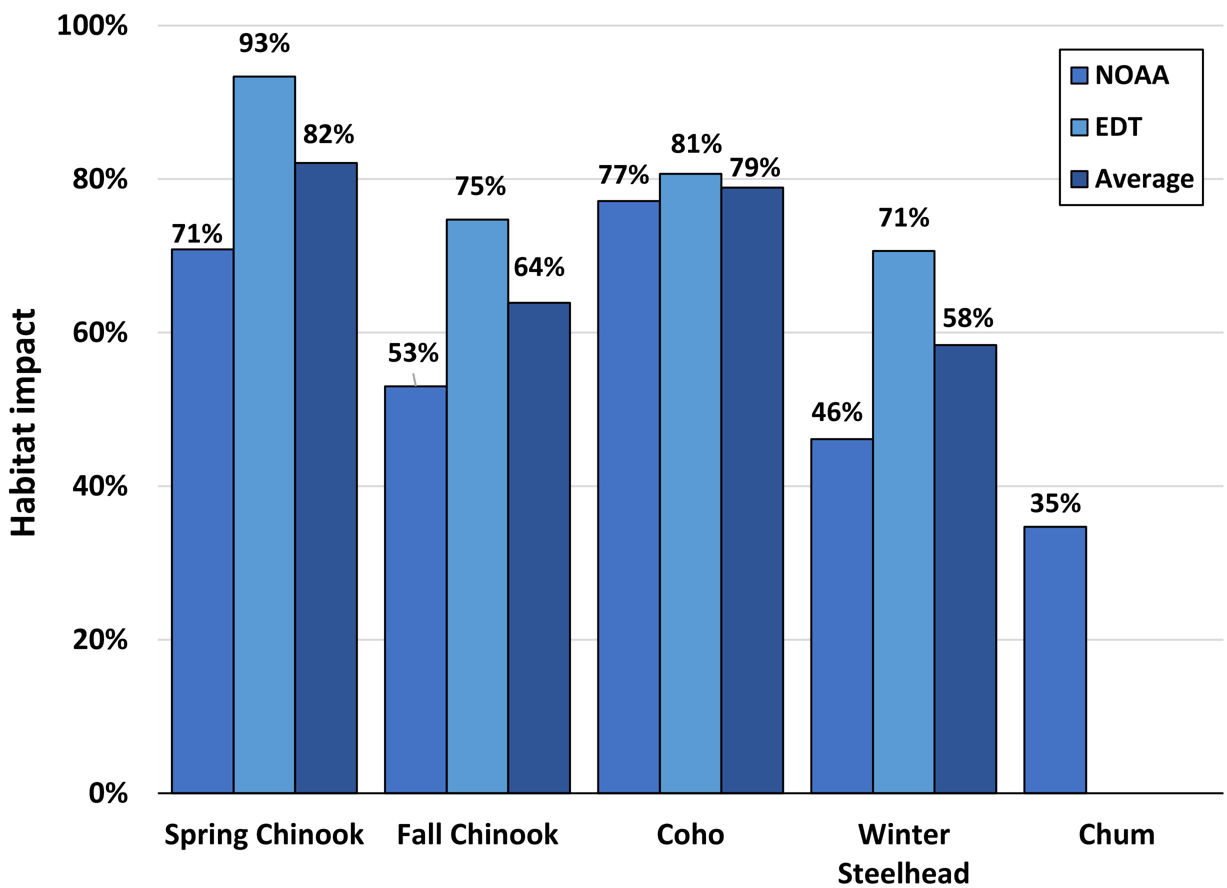

Figure 16. Habitat impacts for Chehalis basin salmon and steelhead stocks based on Ecosystem Diagnosis and Treatment (EDT: ASEPTC 2014) and NOAA Life Cycle Model (LCM: Beechie et al. 2021a, 2021b) analysis of fish numbers produced by current habitat conditions relative to assumed pre-development values.

Table 11. Habitat impacts for Chehalis basin salmon and steelhead stocks and populations based on Ecosystem Diagnosis and Treatment (EDT: ASEPTC 2014) and NOAA Life Cycle Model (LCM: Beechie et al. 2021a, 2021b) analysis of fish numbers produced by current habitat conditions relative to assumed pre-development values.

Species	Population	Model	Current	Intrinsic	Impact
Spring Chinook	Chehalis	EDT	1,722	25,908	93%
	Chehalis	NOAA	1,035	3,551	71%
Summer Chinook	Satsop	--	na	na	na
Fall Chinook	Humptulips Hoquiam Wishkah	EDT	9,597	28,404	66%
	Wynoochee Satsop	EDT	17,055	64,076	73%
	Johns/Elk/South Bay	EDT	na	na	na
	Chehalis	EDT	13,938	68,154	80%
	Total	EDT	40,590	160,635	75%
	Total	NOAA	31,746	67,570	53%
Coho	Humptulips Hoquiam Wishkah	EDT	24,920	79,986	69%
	Wynoochee Satsop	EDT	17,055	64,076	73%
	Johns/Elk/South Bay	EDT	na	na	na
	Chehalis	EDT	27,316	68,154	60%
	Total	EDT	71,435	369,875	81%
	Total	NOAA	90,625	396,226	77%
Chum	Grays Harbor	EDT	131,755	na	na
	Grays Harbor	NOAA	82,442	126,259	
Summer Steelhead	Humptulips	--	na	na	na
	Chehalis	--	na	na	na
Winter Steelhead	Humptulips Hoquiam Wishkah	EDT	4,298	11,814	64%
	Wynoochee Satsop	EDT	5,496	17,386	68%
	Johns/Elk/South Bay	EDT	na	na	na
	Skookumchuck/Newaukum	EDT	2,184	9,461	77%
	Chehalis	EDT	3,597	14,349	75%
	Total	EDT	15,575	53,010	71%
	Total	NOAA	16,092	29,867	46%

Future Habitat Scenarios

The Aquatic Species Restoration Plan developed as part of the Chehalis Basin Strategy provides projections of conditions that could be achieved under three habitat restoration scenarios (ASRPSC 2019). Scenarios were based on a prioritization process which identified areas within each of the basin's ecological regions with the best opportunities for protection and improvement of salmon and steelhead. These habitat scenarios are summarized in this report as the basis for further analysis considering combinations of changes in habitat and other factors.

Habitat Scenario 1 protects and enhances existing core habitats for all aquatic species (ASRPSC 2019). It protects and restores more than 200 miles of river/stream habitat; corrects 200 fish passage barriers, improving access to approximately 200 miles of river/tributary habitat; and restores more than 9,000 acres of riparian and floodplain habitats. Scenario 1 would generally halt the species declines that are projected to occur from climate change in the mid-century time frame.

Habitat Scenario 2 builds on Scenario 1 to protect and enhance existing core habitat areas, with the additional focus of restoring the best opportunities to benefit multiple species and increase spatial distribution (ASRPSC 2019). Adding more enhancement opportunities, this scenario protects and restores more than 300 miles of river/stream habitat; corrects 300 fish passage barriers, improving access to more than 300 miles of river/tributary habitat; and restores more than 10,200 acres of riparian and floodplain habitats. Scenario 2 would provide modest improvements and focuses on important smaller sub-basins that historically produced healthy runs of coho salmon, chum salmon, and steelhead.

Habitat Scenario 3 builds on Scenario 2, with an added focus of increasing spatial and life history diversity and distribution of species throughout more of the basin (ASRPSC 2019). It protects and restores 450 miles of river/stream habitats; corrects 450 fish passage barriers, improving access to more than 400 miles of river/tributary habitat; and restores more than 15,300 acres of riparian and floodplain habitats. Scenario 3 would provide more substantial habitat gains and also expands spatial diversity (or distribution of local populations) for coho salmon, spring- and fall-run Chinook salmon, and steelhead into more geographic areas of the basin.

To understand the potential benefits of conducting restoration, ASRPSC (2019) compared the three habitat scenarios to current conditions throughout the basin and to projected future conditions which reflect potential negative effects from climate change and development pressures, as well as anticipated positive effects from the maturation of riparian forests within managed forest lands as presently required under the Washington Forest Practices Act.

Figure 17 excerpted from (ASRPSC 2019) shows the projected numbers of Chehalis salmon and steelhead resulting from the combined effects of habitat protection and improvement scenarios with future climate change and development pressure. Table 12 isolates the relative effects of habitat protection and improvement scenarios independent of future climate change and development for use in salmon slider model scenarios involving various combinations of factors.

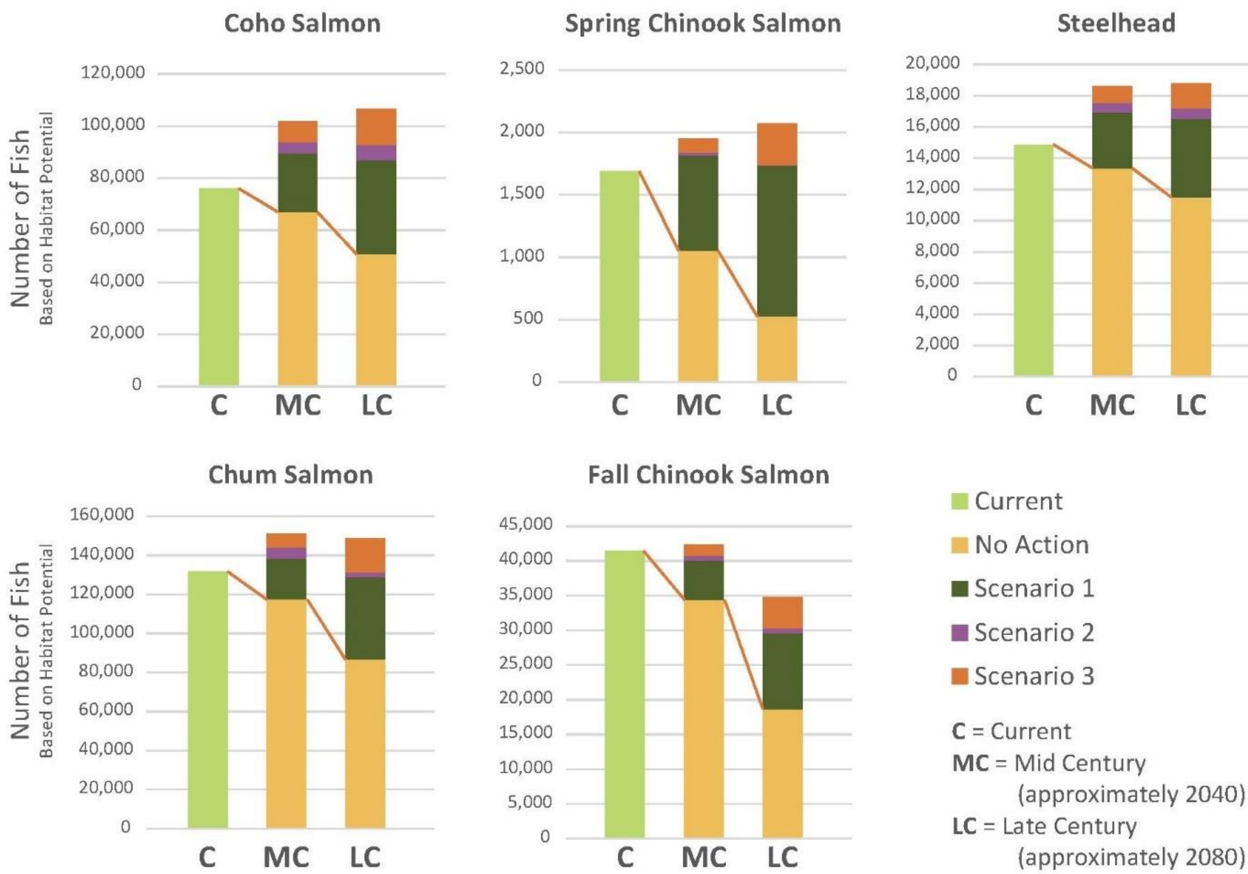

Figure 17. **Projected numbers of Chehalis salmon and steelhead resulting from the combined effects of habitat protection and improvement scenarios with future climate change and development pressure (Figure 5-3 in ASRPSC 2019).**

Table 12. **Projected improvement in salmon and steelhead abundance for habitat protection and improvement scenarios relative to the no-action alternative (derived from values in ASRPSC 2019).**

Species/run	Period	Habitat scenario		
		1	2	3
Spring Chinook	Mid-century	62%	64%	70%
	Late-century	200%	210%	270%
Fall Chinook	Mid-century	16%	19%	23%
	Late-century	50%	70%	90%
Coho	Mid-century	33%	40%	50%
	Late-century	70%	80%	110%
Chum	Mid-century	20%	30%	30%
	Late-century	50%	50%	70%
Winter Steelhead	Mid-century	30%	30%	40%
	Late-century	40%	50%	60%

Table 13. Projected late-century improvement in salmon and steelhead abundance by population for habitat protection and improvement scenarios relative to the no-action alternative (derived from values in ASRPSC 2019).

Species	Population	Habitat scenario		
		1	2	3
Spring Chinook	Chehalis	200%	210%	270%
Summer Chinook	Satsop	na	na	na
Fall Chinook	Humptulips Hoquiam Wishkah	34%	39%	39%
	Wynoochee Satsop	72%	74%	111%
	Johns/Elk/South Bay	na	na	na
	Chehalis	67%	70%	112%
Coho	Humptulips Hoquiam Wishkah	49%	63%	63%
	Wynoochee Satsop	75%	78%	112%
	Johns/Elk/South Bay	na	na	na
	Chehalis	96%	114%	170%
Chum	Grays Harbor	50%	50%	70%
Summer Steelhead	Humptulips	47%	58%	58%
	Chehalis	48%	52%	74%
Winter Steelhead	Humptulips Hoquiam Wishkah	47%	58%	58%
	Wynoochee Satsop	38%	41%	61%
	Johns/Elk/South Bay	na	na	na
	Skookumchuck/Newaukum	79%	79%	95%
	Chehalis	33%	39%	63%

Estuary Habitat

For the purpose of this analysis, estuary habitat impacts are defined based on the percentage reduction in available habitat due to filling and diking.

Background

Juvenile salmon and steelhead rear in the Grays Harbor estuary for periods of time which vary with species (Hiss & Knudsen 1993; ASRPSC 2019). Intertidal and shallow areas are particularly important during early rearing. Chum salmon are most dependent on estuarine habitats due to their short residence in freshwater. Upon emergence from the gravel, fry immediately migrate downstream to the estuary where they feed and rear for several months before migrating to the ocean. Almost all Chinook salmon in the basin exhibit ocean-type life histories, and juveniles emigrate seaward within their first year. Both fall-run and spring-run Chinook salmon rely on estuarine habitats as they spend extended time feeding and growing in the estuary as juveniles prior to migrating to the ocean. Coho typically migrate seaward as age 1 smolts but have been observed to spend considerable time in the estuary before moving to the ocean. The estuary is also a critical transition area during seaward migration as smolts but residence time in estuary habitats is likely less than other species.

Extensive rearing habitat for Chum, Chinook and Coho salmon in the Grays Harbor estuary has been removed by fill in Grays Harbor tidelands from dredging of navigation channel and harbor areas (Hiss & Knudsen 1993). Diking and rail line construction have also contributed to losses. NRC (1996) reported that about 30% of historic wetlands habitat in Washington has been lost and HSRG (2004) referenced this value in relation to loss of Grays Harbor estuary habitat. Modeling conducted by NOAA for the ASRP quantified delta habitat areas within the Chehalis basin to estimate change in habitat area and potential rearing capacity for out-migrating juvenile salmonids (Beechie et al. 2021a). The NOAA analysis estimated an approximately 20% loss in tidal channel habitat important to rearing of salmonids in the Grays Harbor estuary.

Juvenile salmonids are also potentially affected by historical contaminants while rearing in the estuary but the current significance of this factor is unclear (Hiss & Knudsen 1993).

Estimation Methodology

Our analysis used estimates of estuary habitat loss provided by NOAA in Beechie et al. (2021a) as an index of estuary habitat impacts on Grays Harbor salmon and steelhead. NOAA estimated river delta habitat areas for each of the six major rivers that flow into Grays Harbor. Delta habitats were classified into four distinct habitat types: main channel, tidal channel, small tidal channel, and mudflat. Current and historical habitat availability was assessed using aerial imagery and the Washington Department of Natural Resources Levee inventory GIS database. Habitat loss was estimated based on changes in tidal channel areas which were chosen to represent the areas known to be used by out-migrating juvenile salmonids.

For the purposes of this analysis, survival through the estuary was assumed to depend on the quantity of available habitat. Thus, survival would be reduced in proportion to the loss in habitat. We applied the same proportional impacts to each species assuming an X% reduction in habitat produces an X% reduction in fish numbers regardless of species-specific survival rates through the estuary.

Lacking specific information for estuary effects on Chehalis salmon and steelhead, this was deemed to be a more parsimonious approach than assuming that estuary habitat has no effect on salmon and steelhead survival. It is also likely that different species will be more or less dependent on estuary habitat but we lack the information needed to make species-specific estimates. Therefore, estimates of estuary “impacts” in this analysis are presented to illustrate the relative scale of reported changes in habitat conditions and their interpretation should be qualified accordingly.

Impact Estimates

Estuary habitat impacts inferred from NOAA estimates of tidal channel losses are summarized in Figure 18 and Table 14.

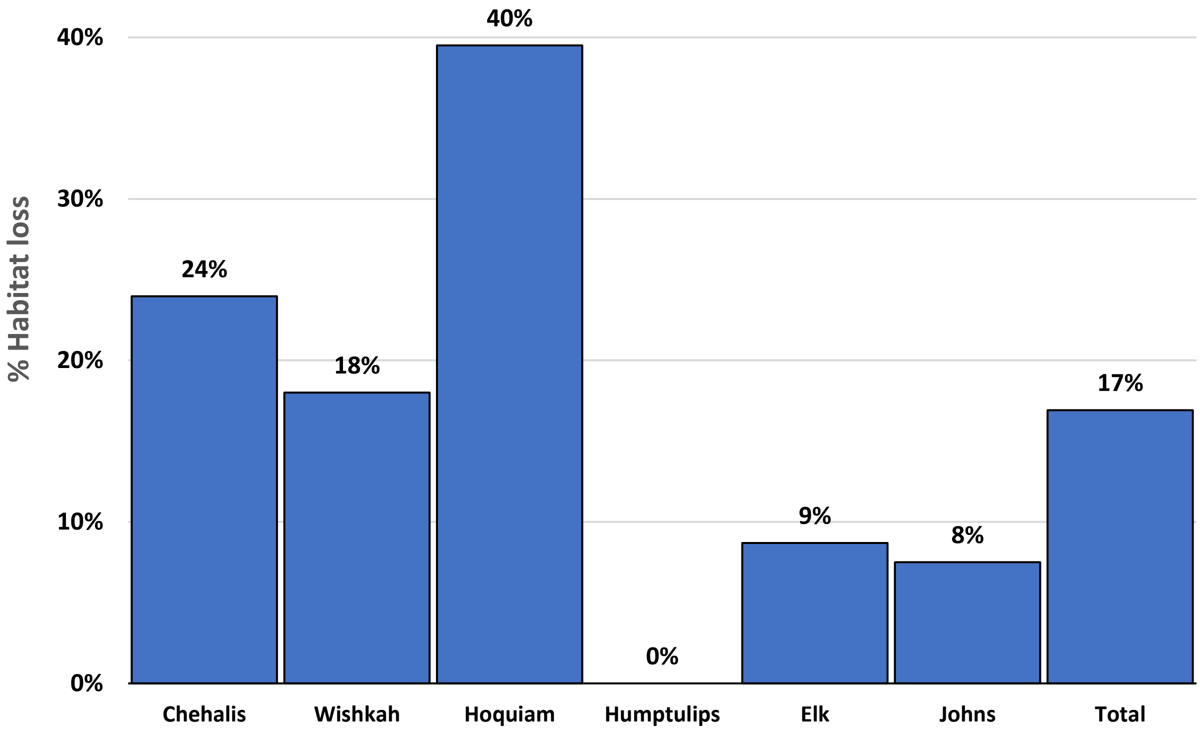

Figure 18. **Percent change in tidal channel area from historic to current conditions in Grays Harbor (Beechie et al. 2021a).**

Table 14. **Current and historical area and percentage loss of tidal channel habitats of river deltas in Grays Harbor (Beechie et al. 2021a).**

Area	Habitat area (ha)		% loss
	Current	Historical	
Chehalis	449	590	24%
Wishkah	6	8	18%
Hoquiam	9	15	40%
Humptulips	31	31	0%
Elk	420	460	9%
Johns	20	22	8%
Total	935	1,126	17%

Dams

For the purposes of this analysis, impacts are defined as the reduction in potential production associated with construction and operation of dams. These impacts include loss of access to upstream production areas, inundation of historically accessible habitat and passage mortality of juveniles and adults through dam facilities and associated reservoirs where applicable.

Background

The basin has two significant dams and a number of smaller diversions. In addition, a new flood retention structure has also been considered for future construction.

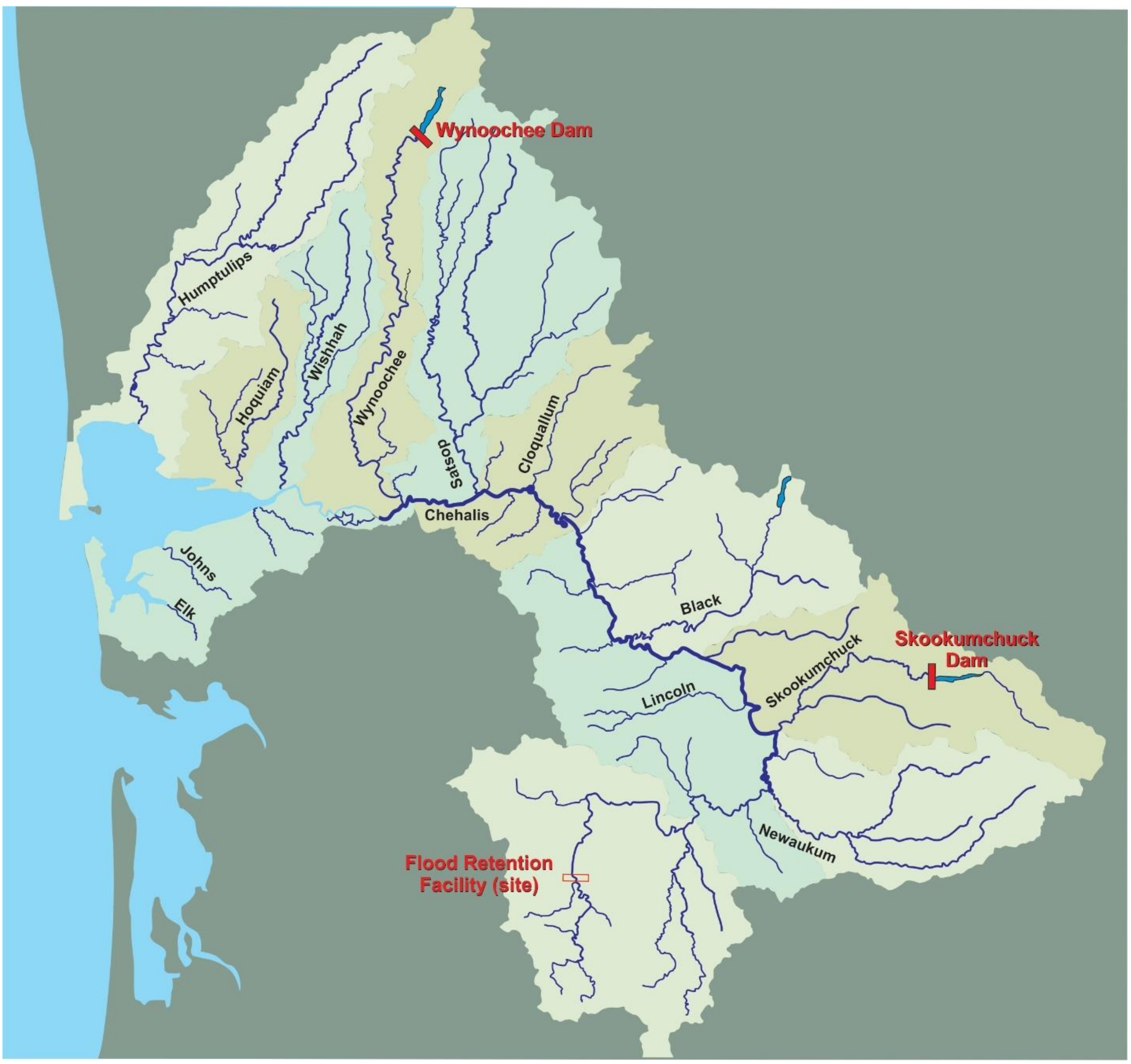

Figure 19. Major dams (current and potential) in Gray Harbor systems.

Skookumchuck Dam

The following description was excerpted from ASEPTC (2014):

> *The Skookumchuck Dam was built at RM 10 (RKm 16.1) in 1970. It inundated about 2 miles (3.2 km) of former spawning habitat and blocked access to 12 miles (19.3 km) of additional spawning habitat upstream from the reservoir. The loss of fish habitat was estimated to include that necessary to support 500 spring-run Chinook salmon, 311 fall-run Chinook salmon (Oncorhynchus tshawytscha), 1,800 coho salmon, and 700 winter-run steelhead spawners (Finn 1973; WDG 1970). The dam has no facilities to pass fish around the dam in either direction.*

Skookumchuck Hatchery produces Coho Salmon and Steelhead to mitigate for lost harvest opportunity caused by Skookumchuck Dam (ASRPSC 2019). Skookumchuck Dam was constructed with adult fish collection and handling facilities (collectively called the fish trap) at the dam and protective facilities at the downstream water intake (Ferguson et al. 2021). The fish handling facilities were intended to be used for collection of adult fish for hatchery propagation or to transport for natural spawning or for other purposes agreed to by the parties (e.g., provided to the Chehalis Tribe or local food banks). The trap is operated annually from early January to mid-March to collect adult steelhead for hatchery broodstock. Fish collected at the trap that are in excess of hatchery broodstock requirements can be transported and released upstream of the reservoir (this was conducted up until 2008 and then stopped due to a disease outbreak at the hatchery; limited transport above the reservoir once again occurred in 2021). WDFW did not use the trap to pass coho because other aspects of mitigation were considered to be sufficient (Hiss & Knudsen 1993).

Opportunities for downstream passage of juvenile steelhead produced by adults collected at the dam and transported above the reservoir appear to be limited. Ferguson et al. (2021) concluded that the design and location (vertical and horizontal) of the three existing intakes to the combined dam outlet works will not pass juvenile steelhead due to their location (the intakes are too deep, and steelhead will not find them). Any juvenile steelhead entering the intakes would likely be killed. Downstream passage could occur from the spillway and associated fish sluice but this passage would only occur at high reservoir levels. No quantitative estimates of current downstream passage are available.

The Aquatic Species Restoration Plan identifies restoration options which include evaluation of the potential benefits and costs of Skookumchuck Dam removal or operational changes to benefit aquatic species (ASRPSC 2019). Ferguson et al. (2021) review a range of fish passage options for Skookumchuck Dam including removal.

Wynoochee Dam

The following description was excerpted from ASEPTC (2014):

> *The U.S. Army Corps of Engineers built the Wynoochee Dam at RM 50 (RKm 80.5) of the Wynoochee River in 1972. Prior to construction, it was estimated that 1,500 coho salmon and 1,400 winter-run steelhead spawned at or upstream from the inundated portion of the river. In 1994, Tacoma Power added a hydroelectric power facility to the existing Wynoochee Dam. To protect the fishery, Tacoma Power shuts down the power plant for a certain period each spring to allow salmon and steelhead smolts to pass safely downstream through outlets in the dam. Tacoma Power also operates a fish collection facility 2 miles (3.2 km) downstream from Wynoochee Dam at a low barrier dam. Here, salmon and steelhead are separated from other species, and most of the collected fish are loaded into a tank truck and hauled 5 miles (8 km) upstream, past Wynoochee Lake, and released back into the Wynoochee River to spawn.*

Of the historical spawning escapement upstream from the dam site, 1,000 Steelhead and zero Coho were estimated to spawn in the area inundated by the dam (Hiss & Knudsen 1993). Chinook also spawned upstream from the dam site prior to construction but numbers were not estimated and this species was not considered in the initial mitigation agreement (Hiss and Knudsen 1993). Construction of Wynoochee Dam eliminated spawning habitat for the remnant spring run Chinook salmon that were nearly extirpated from the river by the 1970s (ASRPSC 2019). Subsequent evaluations showed that some Coho and Steelhead smolts were killed during passage and the project also delayed migration past the dam (Hiss and Knudsen 1993). Downstream juvenile fish passage is currently allowed during a 77-day period of run-of-the-river operation each spring when no turbines operate. Passage mortality rates reportedly vary between 14-60%.[2] Hatchery programs were funded to mitigate for historical production of Steelhead and Coho lost to inundation.

<u>Flood Retention Facility</u>

The Washington Department of Ecology has prepared a Draft Environmental Impact Statement under the State Environmental Policy Act requirements for a Chehalis River Basin Flood Damage Reduction project proposed by the Chehalis River Basin Flood Control Zone District (WDE 2020). A flood retention facility and associated temporary reservoir would be constructed on the upper Chehalis River. The project would also make changes to the Chehalis-Centralia Airport levee to reduce flood damage in the Chehalis-Centralia area. The flood retention facility would store floodwaters in a temporary reservoir during major or larger floods. The temporary reservoir would hold 65,810 acre-feet of water and extend 6.4 miles. For normal conditions and for smaller floods, the river and fish would pass through the outlets at the base of the flood retention structure. When the reservoir is holding water, fish would have to move upstream using a fish ladder and/or a trap-and-transport process.

Modeling was done to identify impacts on salmon and steelhead in two areas of the Chehalis Basin near the proposed flood retention facility (WDE 2020). These analyses determined that construction and operation would have significant adverse impacts on spring-run Chinook salmon, fall-run Chinook salmon, coho salmon, and steelhead from degraded habitat, noise, and fewer fish surviving passage around the FRE facility.

<u>Other Diversions</u>

The following description was excerpted from ASEPTC (2014):

> *Other smaller diversions and intakes have also been constructed causing significant reductions in in-stream flows, which have resulted in decreased water quality in spawning and rearing habitats (Fraser 1986). Consumptive users include local municipalities. For example, Aberdeen draws municipal water from the Wishkah River; Centralia and Chehalis obtain water from North Fork Newaukum River; Chehalis draws water from the Chehalis River; Hoquiam obtains water from the Hoquiam River. Non-consumptive users include hatcheries throughout the basin.*

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[2] *https://twinharborswaterkeeper.org/2020/06/16/remember-the-wynoochee/*

Estimation Methods

This analysis was based estimates of dam impacts on the number of adult salmon and steelhead estimated to have been supported upstream of the Wynoochee and Skookumchuck Dams at the time of dam construction as reported ASEPTC (2014) and summarized above. This are the same numbers that were considered in the development of hatchery mitigation agreements for these dam projects. These impact estimates effectively capture the combined direct effects of the loss of access to upstream production areas, inundation of historically accessible habitat and passage mortality of juveniles and adults through dam facilities and associated reservoirs.

Adult salmon and/or steelhead are currently trapped, transported and released upstream from both Wynoochee and Skookumchuck Dams. However, neither facility includes dedicated juvenile bypass systems. Downstream passage mortality is not well quantified but is reportedly very high. Our estimate effectively assumes that juvenile passage survival is negligible. To the extent that some downstream juvenile passage might occur, our analysis would overestimate the net impact of direct dam effects. This potential overestimation is offset by estimation of dam impacts from direct effects without also considering indirect effects on downstream habitats.

Dams produce significant downstream effects which can reduce the salmon habitat quantity and quality. For instance, ASRPSC (2019) reported that dams, such as those on the Wynoochee and Skookumchuck rivers, have reduced the natural sediment and wood supply to downstream reaches, promoting channel incision, which reduces the natural processes that form and sustain aquatic habitat; inundated many miles of salmon spawning and rearing habitat upstream of the dams, eliminating production from these habitats; and created barriers to fish passage and upstream and downstream movements. These downstream effects are not included in this analysis because of a lack of available information with which to quantify the corresponding impacts in terms of fish abundance and the difficulty of distinguishing dam-related and land use-related effects.

This analysis of passage impacts is focused on large-scale dam effects. Smaller-scale blockages due to culverts and effects of water diversions are addressed in the freshwater habitat impact category.

Impacts are calculated in relation to total fish abundance that includes dammed and undammed portions of the system:

$$\text{Impact} = \frac{\text{no. upstream from project}}{\text{(no. upstream from project) + (no. downstream from the project)}}$$

Ideally, downstream numbers would be referenced to the same period for which upstream numbers were derived in order to provide a common currency. However, because downstream numbers were not consistently available for the period when upstream numbers were derived, this analysis used current spawning escapement goals as a proxy value. This effectively assumes that spawning escapement goals represent the equilibrium production capacity of the currently-accessible habitats. Impacts are estimated relative to the fish population in which the dams are located and relative to the entire stock of each species in all Grays Harbor systems. While this approach obviously introduces uncertainty in corresponding impact estimates, the intent is to approximate reasonable order-or-magnitude estimates to place dam impacts in context with other limiting factors.

Modeled scenarios in our analysis also considered the potential impacts of construction and operation of the proposed Flood Retention Facility as reported in the draft Environmental Impact Statement for this project (WDE 2020). The EIS estimated project effects on fish species and habitats at and above the proposed facility at RM 108 and in the Chehalis River and tributaries downstream. The EIS estimated impacts using the Ecosystem Diagnosis and Treatment (EDT) and NOAA Life-Cycle (LCM) models.

Impact Estimates

Dam impacts due to blocked habitat, inundation and lack of downstream passage can be significant when considered on a populations scale but are relatively modest at the basin level due to the relatively small affected area (Table 15, Figure 20). The greatest impacts occur for Spring Chinook where Skookumchuck Dam affects an historically-productive area.

Table 15. Estimates of dam impacts based on numbers of fish produced by areas upstream from and downstream from projects including population-specific and basin-wide totals.

Project	Species	Adult number		Impact	
		Upstream	Downstream	Population	Basin-wide
Wynoochee Dam	Spring Chinook	na	--	--	--
	Fall Chinook	na	--	--	--
	Coho	1,500	7,168	17%	4%
	Winter Steelhead	1,400	1,260	53%	11%
Skookumckuck Dam	Spring Chinook	500	1,400	26%	26%
	Fall Chinook	311	5,209	6%	2%
	Coho	1,800	8,134	18%	5%
	Winter Steelhead	700	2,700	21%	5%
Combined	Spring Chinook	500	1,400	--	26%
	Fall Chinook	311	13,326	--	2%
	Coho	3,300	35,400	--	9%
	Winter Steelhead	2,100	10,651	--	16%

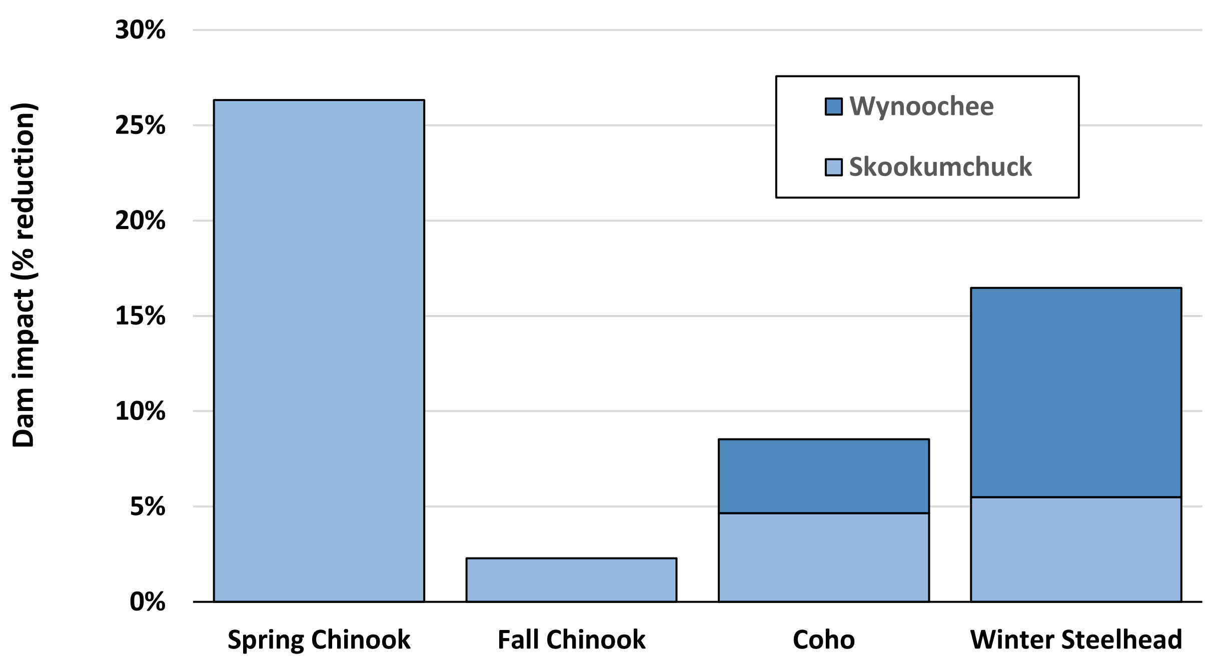

Figure 20. Estimates of dam impacts based on numbers of fish produced by areas upstream from projects relative to basin-wide totals for each species.

Impacts of construction of the proposed upper Chehalis flood control project are summarized in Table 16 and Figure 21. For the purposes of our analysis, impacts were calculated for the combined area above and below the project site downstream to Rainbow Falls as documented in WDE (2020). Impacts were also calculated in relation to the affected population and the basin-wide total numbers reported for each species in the EDT and integrated/NOAA models.

While models projected significant effects in the project area, impacts were smaller in relation to the affected populations and the basin-wide numbers owing to the relatively small area of direct effect. As noted in WDE (2020), the EDT model results were similar in pattern to the integrated model but decreases in estimated abundance were higher than the integrated model. These differences are most likely due to adults in the integrated model returning during construction from earlier brood years, where adults from pre-construction brood years support the population through one generation (WDE 2020). Because our all-H analysis considers the equilibrium impacts of each factor, we used the EDT results which better match that construct.

Table 16. Impacts of proposed flood control project construction on abundance of salmon and steelhead relative to numbers in the project area, the affected population and the entire Grays Harbor basin based on modeling reported in the draft Environmental Impact Statement (WDE 2020).

Species	Model	Abundance				Impact		
		Project area		Population	Basin wide	Project area	Population	Basin wide
		Pre-	Post-					
Spring Chinook	EDT	113	45	1,722	1,722	60%	4%	4%
	Integrated	107	68	na	1,035	36%	na	4%
Fall Chinook	EDT	427	324	13,938	40,590	24%	1%	0%
	Integrated	428	341	na	31,746	20%	na	0%
Coho	EDT	915	243	4,921	71,435	73%	14%	1%
	Integrated	872	360	na	90,625	59%	na	1%
Winter Steelhead	EDT	848	394	3,597	15,575	54%	13%	3%
	Integrated	758	374	na	16,092	51%	na	2%
Total	EDT	2303	1006	24,177	129,321	56%	5%	1%
	Integrated	2165	1143	na	139,498	47%	na	1%

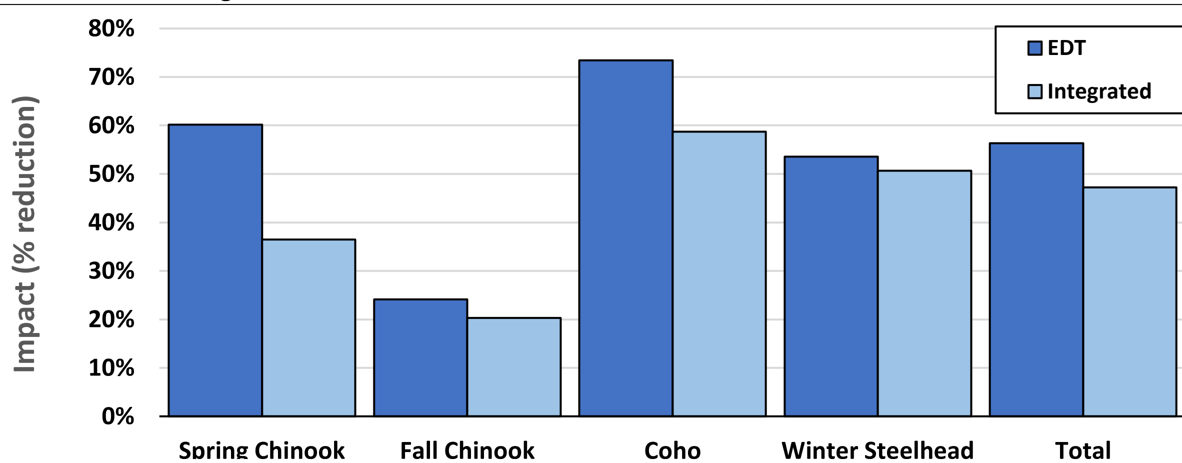

Figure 21. Impacts of proposed flood control project construction on abundance of salmon and steelhead within the project area (above and below project site downstream to Rainbow Falls) based on modeling reported in the draft Environmental Impact Statement (WDE 2020).

Fishery

For the purposes of this analysis, fishery impacts are defined as mortality occurring in or as a result of harvest or handling. Fishery impacts include harvest and indirect mortalities. Harvest refers to fish that are caught and retained. Indirect mortalities are fish that are not retained but die due to handling or encounter in the fishery. Fishery impacts are reported as adult equivalent rates in relation to the ocean abundance prior to any fishery removals.

Grays Harbor salmon and steelhead range widely throughout the north Pacific Ocean and are subject to different fisheries and fishing rates depending on the distribution and timing of migration (Figure 22). Key fisheries harvesting Grays Harbor salmon and steelhead are summarized as follows:

Alaska/Canada Ocean – Grays Harbor Chinook and Coho are harvested in commercial troll and sport fisheries in outside waters along the coasts of Southeast Alaska and British Columbia. These fisheries harvest a mixture of Alaska, Canadian and Pacific Northwest stocks and are managed under the U.S.-Canada Pacific Salmon Treaty.

Washington Ocean - Treaty Indian and non-Indian commercial troll and recreational fisheries harvest Grays Harbor Chinook and Coho in Washington ocean waters. The fisheries are regulated through the federal Pacific Fishery Management Council process in conjunction with state and tribal co-managers.

Grays Harbor Non-Indian Gillnet – This commercial fishery harvests Chinook, Coho and Chum Salmon during fall seasons. The fishery is regulated by WDFW.

Grays Harbor Treaty Indian Gillnet - Usual and accustomed fishing areas reserved through treaty by the Quinault Indian Nation, include coastal rivers, the Humptulips and extend into the Chehalis Basin. Treaty fisheries occur in Grays Harbor rivers and the estuary during spring, summer and fall. The tribes cooperatively manage fisheries resources of the Grays Harbor Basin with the WDFW.

Chehalis Tribe Gillnet - The Chehalis Tribe fishes the mainstem Chehalis on-reservation near the town of Oakville. The tribes cooperatively co-manage fishery resources of the Grays Harbor Basin with the WDFW.

Grays Harbor Recreational - Grays Harbor is a very popular small boat fishery, especially for Chinook and Coho salmon. Most fishing occurs in September and early October before the commercial fishery commences.

Freshwater Recreational – Sport fishing for salmon and steelhead occurs in rivers throughout the Chehalis basin.

Stock-specific impact estimates are available for most fisheries because they are the basis for fishery management objectives and allocation. Estimates are made by the management bodies responsible for the various fisheries. For ocean fisheries, these include the Pacific Salmon Commission and the Pacific Fishery Management Council. Terminal fishery information in Grays Harbor and freshwater is provided by the state of Washington, and the Quinault and Chehalis tribes.

This report summarizes rates reported by the management entities and, in cases where rates are not otherwise reported, infers rates from the available information. Fishery impact rates vary with species and run (Table 17, Figure 23). Rates are highest for Fall Chinook which are harvested in widespread fisheries and lowest for Spring Chinook and steelhead where fisheries are quite limited.

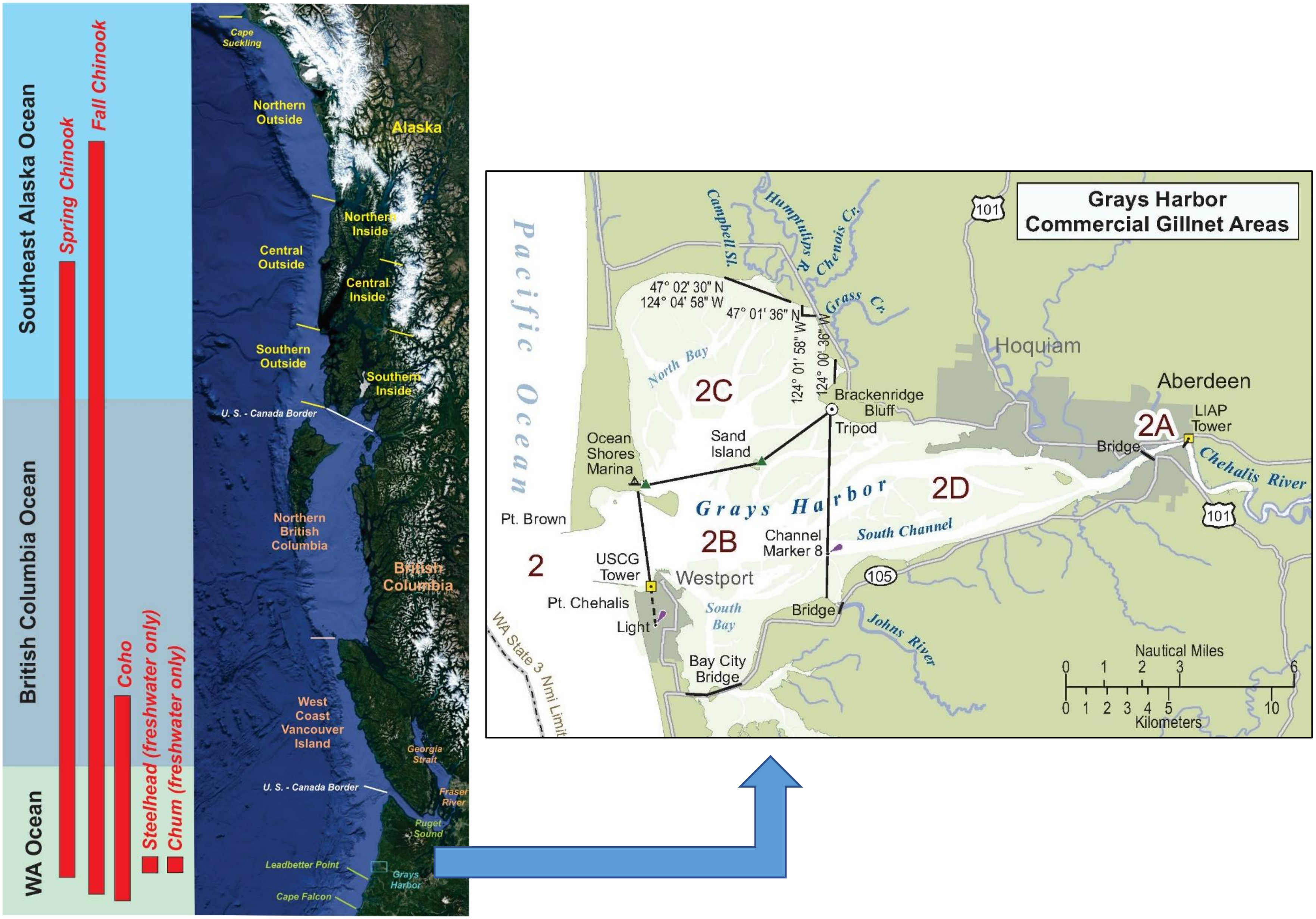

Figure 22. Fishery harvest areas for Grays Harbor salmon and steelhead stocks.

Table 17. Fishery impact rates for natural-origin Chehalis Basin salmon and steelhead (2011-2020 average).

	Fishery	Spring Chinook	Summer Chinook	Fall Chinook	Coho	Chum	Summer Steelhead	Winter Steelhead
Ocean	Alaska		na	27%	--	--	--	--
	Canada	<5%	na	19%	--	--	--	--
	WA-OR ocean		na	1%	7%	--	--	--
Terminal[a]	Non-Indian Commercial	0%	na	1%	3%	9%	--	--
	Quinault Tribe Gillnet	<1%	na	9%	15%	22%	--	6%
	Chehalis Tribe Gillnet	5%	na	0%	1%	0%	--	4%
	Sport	2%	na	2%	10%	1%	<8%	1%
	Total	***<7%***	***na***	***59%***	***35%***	***32%***	***<8%***	***11%***

[a]*Terminal includes Grays Harbor and freshwater fisheries.*
na = not available

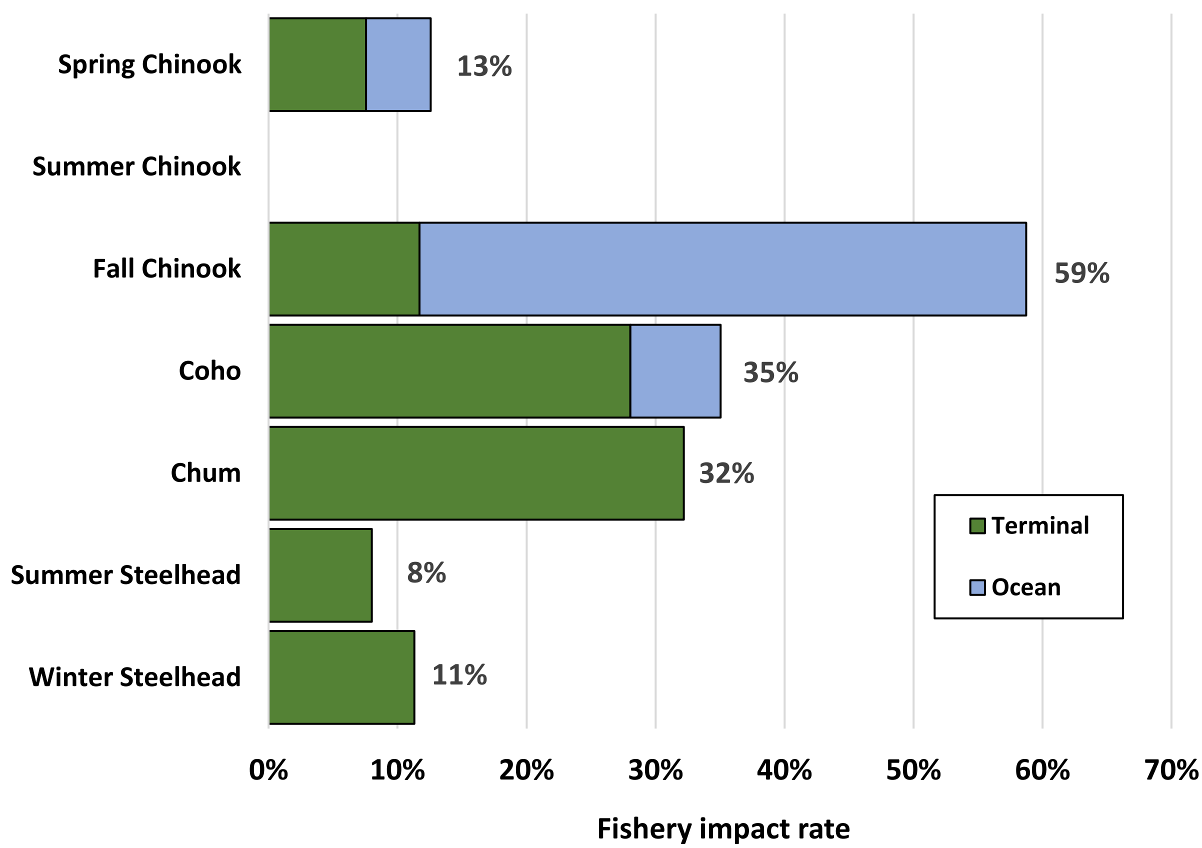

Figure 23. Fishery impact rates for natural-origin Chehalis Basin salmon and steelhead (2011-2020 average).

Spring Chinook

Chehalis Spring Chinook were historically harvested in freshwater and ocean fisheries but fisheries have been substantially reduced in response to low fish numbers. Harvest previously occurred during spring and summer in small Grays Harbor treaty Indian and Chehalis River tribal gillnet fisheries. However, the Quinault Indian Nation has not conducted any commercial gillnet fishery on the Chehalis River or in Grays Harbor commercial fishing areas 2A, 2A-1, or D since 2018 because of forecasts of low Spring/Summer Chinook stock abundances (PFMC 2023). Small gillnet fisheries targeting other species have occurred in marine area 2C and the lower Humptulips River but no Spring Chinook catch is reported since 2017 (Table 18). The Chehalis Tribe has not conducted a Spring Chinook commercial fishery in recent years (PFMC 2023). Non-Indian recreational fisheries previously harvested spring Chinook but retention has been prohibited during the spring Chinook management period in recent years.

Information on ocean catches of Chehalis spring Chinook is not available (WDFW & WWTIT 1992, 2002). Catches in Washington and Oregon commercial, tribal and recreational ocean fisheries are likely low due to the early return timing of this run. Like other spring/summer Chinook stocks along the coast, it is likely that Chehalis Spring/Summer Chinook contribute to southeast Alaska and Canada commercial and sport fisheries (WDFW & WWTIT 1992, 2002). However, ocean fishery impact rates are not estimated directly for Grays Harbor or any other coastal Washington/Oregon Spring Chinook stock (PSC-CTC 2023).

Recent 10-year average fishery impacts have averaged 8% in terminal areas which include Grays Harbor tribal gillnet and freshwater sport fisheries (Figure 24, Table 18). Terminal fishing rates have varied considerably over the years with a high incidence of closures in recent years. Our analysis assumed a recent average ocean impact rate of approximately 5% in combined Alaska, Canada and southern US ocean fisheries based on rates reported for other Washington/Oregon Spring Chinook stocks from Puget Sound and the Columbia River. Historical impact rates prior to recent restrictions in Alaska-Canada fisheries were likely substantially greater.

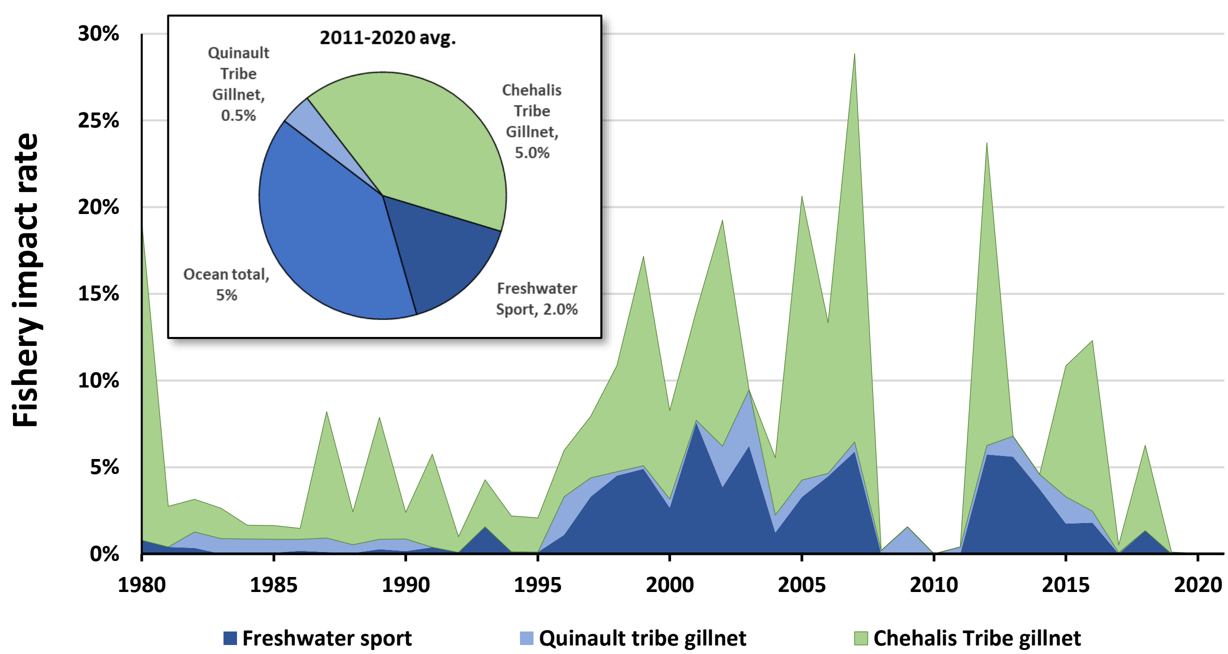

Figure 24. Annual fishery impact rates for Chehalis Spring Chinook in terminal tribal gillnet and sport fisheries (retained catch only) and the distribution of recent average rates among ocean and terminal fisheries (PSC-CTC 2023 and PFMC 2023 data).

Table 18. Grays Harbor Spring Chinook terminal catch, spawning escapement, and run size in numbers of fish (PFMC data).

Year	Harvest			Spawning escapement	Terminal run size
	Treaty Indian gillnet	Chehalis Tribal gillnet	Sport		
1980		587		600	3,167
1981		70	12	924	2,987
1982	<50	50	9	610	2,651
1983	<50	50	0	800	2,833
1984	<50		2	1,128	3,114
1985	<50		2	1,157	3,144
1986	<50	24	7	1,795	3,812
1987	<50	225	3	841	3,056
1988	<50	100	2	3,106	5,196
1989	<50	310	12	2,068	4,379
1990	<50	56	6	1,567	3,619
1991	0	187	13	1,289	3,480
1992	0	35	3	1,813	3,843
1993	0	92	53	1,254	3,392
1994	0	72	4	1,403	3,473
1995	0	82	4	2,070	4,151
1996	104	127	52	4,462	4,745
1997	52	172	160	4,460	4,844
1998	6	164	121	2,388	2,679
1999	3	187	76	1,285	1,551
2000	17	174	91	3,135	3,417
2001	4	210	252	2,860	3,326
2002	76	419	124	2,598	3,217
2003	68	0	131	1,904	2,103
2004	54	177	65	5,034	5,330
2005	26	439	88	2,129	2,682
2006	5	249	128	2,481	2,863
2007	5	205	54	651	915
2008	2	0	0	995	997
2009	18	0	0	1,132	1,150
2010	0	0	0	3,495	3,495
2011	10	0	0	2,563	2,573
2012	6	201	66	878	1,151
2013	31		148	2,459	2,638
2014	14		62	1,583	1,659
2015	32	156	36	1,841	2,065
2016	7	104	19	926	1,056
2017	1	6	0	1,384	1,391
2018	0	26	7	493	526
2019	0	1	0	983	984
2020	0	1	0	2,828	2,829
2021	0	1	0	2,573	2,574

Summer Chinook

No fishery information is available for Chehalis Summer Chinook. Summer Chinook are not known to contribute to any local fishery (WDFW & WWTIT 1992, 2002). They may be taken in the July/August net fishery and/or the Chehalis River sport fishery, however these contributions have not been clearly documented. Like other spring/summer Chinook stocks along the coast, it is highly probable that Chehalis Spring/Summer Chinook contribute to southeast Alaska and Canada troll fisheries but corresponding impact rates are not estimated (WDFW & WWTIT 1992, 2002).

Fall Chinook

Grays Harbor Fall Chinook range in ocean waters far to the north. As a result, they are harvested in fisheries from Alaska to their rivers of origin and the aggregate harvest of this stock is substantial (WDFW & WWTIT 1992, 2002; PSC-CTC 2023; PFMC 2023).

Ocean fisheries in Alaska and Canada account for a large portion of the Fall Chinook harvest (Figure 25). Grays Harbor Fall Chinook are harvested in commercial troll and sport fisheries in outside waters along the coasts of Southeast Alaska and British Columbia. These fisheries are managed under the U.S.-Canada Pacific Salmon Treaty based on aggregate abundance of a broad mixture of Chinook stocks. Grays Harbor Fall Chinook comprise a very small portion of the total Chinook catch in these fisheries but the fisheries catch significant numbers of this stock. Harvest also occurs in Washington ocean troll and sport fisheries although harvest numbers are small due to the respective timing and distribution patterns of the fish and the fishery. Ocean commercial and sport fisheries harvesting Grays Harbor Fall Chinook harvest both unmarked and marked Chinook – they are not generally mark-selective for hatchery-origin fish.

Non-Indian commercial gillnet fisheries in Grays Harbor historically harvested significant numbers of Fall Chinook but timing of this fishery is currently designed to avoid Chinook and concentrate effort when coho and chum are more abundant. The fishery has been quite limited in recent years. The fishery currently allows retention of all Fall Chinook or requires release of unmarked wild/natural Chinook during in different times and areas over the course of the season.

The Quinault Indian Nation conducts a fall gillnet fishery in Grays Harbor from late September until November. Fishing occurs in Humptulips and Chehalis areas at various points in the season and is generally open for two to five days per week in recent years (PFMC 2021, 2022). Area restrictions, weekly closures and gillnet mesh restrictions (6 ½-inch maximum mesh size) are regularly employed to manage the catch of Chinook Salmon. The fishery harvests both marked (hatchery) and unmarked (wild/natural) Fall Chinook.

Recreational fisheries for salmon in Grays Harbor generally occur from August through November depending on fish numbers (PFMC 2021, 2022). The fishery is mark-selective and requires release of wild Chinook and Coho during August and September. Beginning in late September, a Coho target fishery requires release of all Chinook. Recreational fisheries for Fall Chinook can also occur in basin rivers depending on fish numbers. A mark-selective recreational Chinook fishery occurred on the Humptulips River from September 1 through October 31 in recent years. Recreational fisheries targeting Chinook have not occurred in recent years in the Chehalis River or any of the tributaries, including the Hoquiam and Wishkah basins.

Fishery impact rates are available for Grays Harbor Fall Chinook in ocean, bay and freshwater fisheries. Impacts include harvest and non-retention mortalities where applicable. Exploitation rate estimates for Grays Harbor fall Chinook in ocean fisheries were available through 2019 (PSC-CTC 2023) and calculated using Queets River fall Chinook CWTs as a surrogate for ocean fishery exploitation rates (PFMC 2023).

Terminal fishery harvest in Grays Harbor and basin rivers are reported through 2021 in PFMC (2023). Adjustments were made to terminal harvest rates calculated from the Grays Harbor return in order to express values in a common currency of adult equivalent rates.

Recent 10-year average fishery impacts have averaged 60% in combined fisheries (Figure 25, Table 19). Fisheries in Alaska and Canada account for three quarters of this impact. Annual rates have varied between 35 and 75% since 1986 (Figure 25). Impacts of terminal fisheries in Grays Harbor and freshwater have been reduced by over half since 2000 by wild/natural Fall Chinook protection measures. Alaska-Canada impacts were reduced in the late 1990s but increased substantially after 2000 during a period of stronger Chinook runs. Ocean rates have not yet been published for 2020-2022 but have likely been reduced by restrictions in Alaska and Canada fisheries due to low abundance of many Chinook stocks.

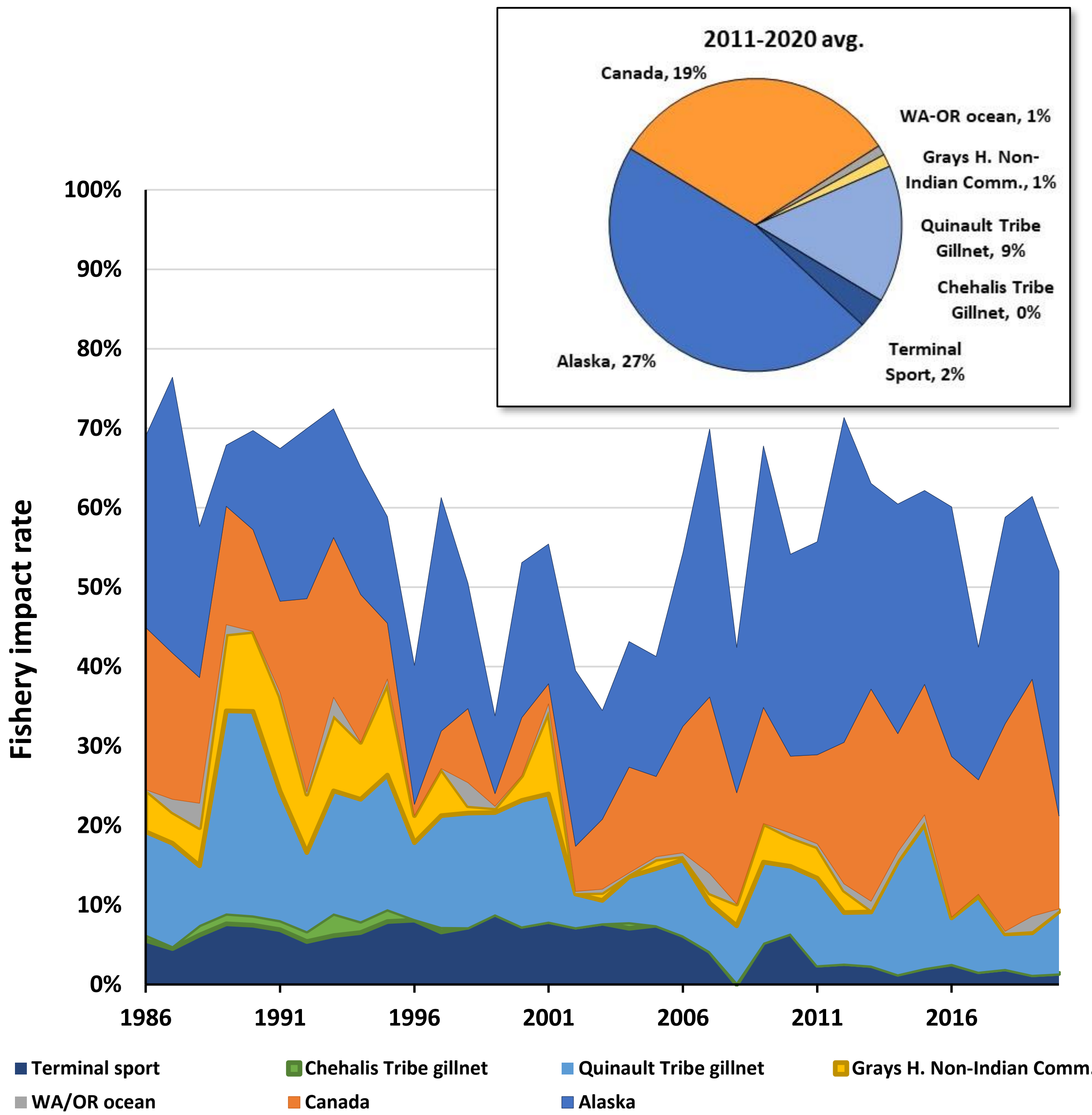

Figure 25. Annual and recent average fishery impact rates for Grays Harbor Fall Chinook in ocean and terminal fisheries (PSC-CTC 2023 and PFMC 2023 data).

Table 19. Grays Harbor Fall Chinook terminal catch, spawning escapement, and run size in numbers of fish (PFMC data).

Year	Harvest					Escapement		Terminal run size
	Early non-local catch	Non-Indian gillnet	Treaty Indian gillnet	Chehalis Tribal gillnet	Sport	Natural	Hatchery	
1980	1,511	5,014	5,620	815	1,128	NA	413	NA
1981	1,516	1,781	3,516	672	117	NA	765	NA
1982	605	2,764	4,627	687	163	NA	413	NA
1983	126	90	3,289	346	72	NA	627	NA
1984	495	65	903	294	365	NA	841	NA
1985	270	118	5,286	328	622	NA	1,065	NA
1986	193	2,210	5,401	306	374	13,808	1,071	23,170
1987	248	2,954	9,723	232	229	19,013	1,882	34,033
1988	725	3,126	4,861	829	2,011	28,158	1,560	40,545
1989	1,272	7,013	18,548	977	2,080	25,677	1,176	55,471
1990	1,030	5,306	13,537	640	2,007	16,995	906	39,391
1991	246	5,886	8,036	599	3,696	14,392	1,431	34,040
1992	753	4,955	6,645	893	2,775	16,592	4,519	36,379
1993	30	5,414	8,807	1,602	3,497	13,349	2,387	35,056
1994	0	3,662	7,865	725	3,600	14,320	3,320	33,492
1995	0	5,085	7,399	687	5,401	12,727	3,374	34,673
1996	148	1,441	4,068	49	7,456	16,988	4,307	34,309
1997	24	2,796	6,630	311	2,687	16,342	2,416	31,183
1998	5	267	4,135	0	2,912	11,476	1,921	20,711
1999	0	87	1,926	1	114	9,196	1,990	13,315
2000	671	647	3,289	0	1,714	8,081	1,450	15,182
2001	0	2,523	3,885	0	3,210	8,340	1,121	19,079
2002	40	26	963	0	2,955	10,621	2,006	16,570
2003	0	295	851	0	1,031	17,808	2,858	22,842
2004	0	183	3,498	476	6,158	29,461	3,584	43,360
2005	0	379	2,260	3	465	17,040	3,536	23,683
2006	0	195	3,738	0	1,635	15,955	2,845	24,368
2007	0	514	2,472	19	1,719	11,264	1,072	17,060
2008	0	717	1,878	72	0	13,570	1,631	17,868
2009	0	1,193	2,485	0	860	7,215	1,125	12,878
2010	0	1,495	3,403	0	1,995	16,951	2,217	26,061
2011	0	2,298	6,402	0	3,086	22,870	1,363	36,019
2012	0	1,731	3,988	3	4,490	14,032	862	25,106
2013	0	103	2,875	0	3,618	12,503	701	19,800
2014	0	73	5,094	2	1,124	11,893	1,676	19,862
2015	0	166	10,496	0	3,644	17,305	2,182	33,793
2016	0	36	2,060	2	2,837	11,248	990	17,173
2017	0	107	3,578	0	2,781	17,145	2,404	26,015
2018	0	78	2,608	0	3,685	20,741	1,225	28,337
2019	0	98	2,374	0	1,734	14,880	1,295	20,381
2020	0	58	3,688	0	1,454	20,879	1,049	27,128
2021	0	104	2,408	0	NA	13,207	1,823	NA
2022	0	3	NA	0	NA	NA	NA	NA

Coho

Grays Harbor Coho generally rear of local ocean waters where they contribute to coastal fisheries from northern Oregon to British Columbia (WDFW & WWTIT 1992, 2002; PSC-JCTC 2013; PFMC 2023). This stock is primarily caught in British Columbia troll, net and sport fisheries, Oregon and Washington ocean troll and sport fisheries, Grays Harbor net and sport fisheries, and freshwater sport fisheries. Small numbers can also occur in Southeast Alaska and Puget Sound fisheries (WDFW & WWTIT 1992, 2002).

Canadian fisheries historically accounted for over half of the total harvest of Grays Harbor Coho (WDFW & WWTIT 1992; Hiss & Knudsen 1993). The large majority of the Canadian catch was taken by the troll sector, particularly along the west Coast of Vancouver Island, with the remainder harvested by commercial net fisheries (PSC-JCTC 2013). Coho catches on the south coast of B.C. have declined since the mid-1980s, initially due to declining abundance and more recently because of severe conservation measures in response to the declining abundance (PSC-JCTC 2013). Coho fishery exploitation rates in Canada were reduced from 75 to 80% in the mid-1980s to 60% in 1995, 37% in 1997, 5% in 1998, and are currently estimated by Backwards Coho FRAM at less than 10%. Conservation measures have included annual limits on fishing mortality based on abundance and the health of the naturally-spawning stocks, fishery timing and non-retention restrictions.

Harvest also occurs in Washington ocean troll and sport fisheries although harvest of natural-origin coho is low due to implementation of mark-selective fisheries (PFMC 2023). Coho-directed recreational fisheries in the ocean the U.S./Canada border to southern Oregon have been mark-selective since 1999 with the exception of a nine-day fishery between the mouth of the Queets River and Leadbetter Point, Washington in 2004. Non-Indian commercial troll fisheries have been mostly restricted to mark-selective Coho retention since 2000. Treaty Indian fisheries in the Ocean are not restricted to mark-selective retention of Coho Salmon.

Non-Indian commercial gillnet fisheries in Grays Harbor have also been reduced from historical levels and currently concentrate effort when coho abundant. Annual openings depend on the availability of fish for harvest. The non-Indian gillnet fishery in Humptulips commercial Area 2C was limited to just five days in 2021 (PFMC 2023). Retention of all Fall Chinook, Coho, and Chum was allowed. The Area 2C fishery did not occur in 2020 (PFMC 2021). Chehalis River commercial Areas 2A and 2D were open for only four and five 12-hour days in 2020 and 2021, respectively, and release of unmarked wild/natural Chinook and Coho was required. Live boxes were required to allow recovery of fish prior to release.

The Quinault Indian Nation conducts a fall gillnet fishery in Grays Harbor from late September until November. Fishing occurs in Humptulips and Chehalis areas at various points in the season and is generally open for two to five days per week in recent years (PFMC 2021, 2023). Area restrictions, weekly closures and gillnet mesh restrictions (6 ½-inch maximum mesh size) are regularly employed to manage the catch relative to species-specific goals. The fishery harvests both marked (hatchery) and unmarked (wild/natural) Coho.

The Chehalis Tribe harvests Coho in the Chehalis River upper mainstem fishery. This fishery has been quite limited in recent years due to low forecasts for natural origin coho and Chehalis River steelhead. The Chehalis Tribe did not conduct a commercial fishery for coho in 2019 or 2020.

Recreational fisheries for salmon in Grays Harbor generally occur from August through November depending on fish numbers (PFMC 2021, 2023). The fishery is mark-selective and requires release of wild Chinook and Coho during August and September. Beginning in late September, a Coho target fishery allows retention of both marked (hatchery) and unmarked (wild/natural) Coho but requires release of all Chinook.

Recreational fisheries for Coho also occur in the Humptulips River, Chehalis River and Chehalis River tributaries from August through December. Retention of all Coho may be allowed or release of unmarked (wild/natural) Coho may be required depending on time and area.

Fishery impact rates are available for Grays Harbor Coho in ocean, bay and freshwater fisheries. Impacts include harvest and non-retention mortalities where applicable. Rates are estimated in ocean fisheries based on catch sampling and coded-wire tag recoveries (PFMC 2023). Terminal fishery harvest in Grays Harbor and basin rivers are reported through 2021 in PFMC (2023) and corresponding impact rates are available from WDFW. To calculate approximate rates by terminal fishery for the purpose of this exercise, the aggregate terminal harvest rate was apportioned among terminal fisheries based on their share of the aggregate terminal harvest of all coho.

Recent 10-year average fishery impacts have averaged 35% in combined fisheries (Figure 26). The Treaty terminal gillnet fishery accounts for the largest share, followed by terminal sport and combined ocean troll and sport fisheries. Harvest and impacts of terminal fisheries in Grays Harbor and freshwater have been substantially reduced since 2000 by wild/natural Coho protection measures (Figure 26, Table 20). Even greater reductions have occurred as a result of ocean fishery conservation measures in British Columbia and Washington waters (not shown).

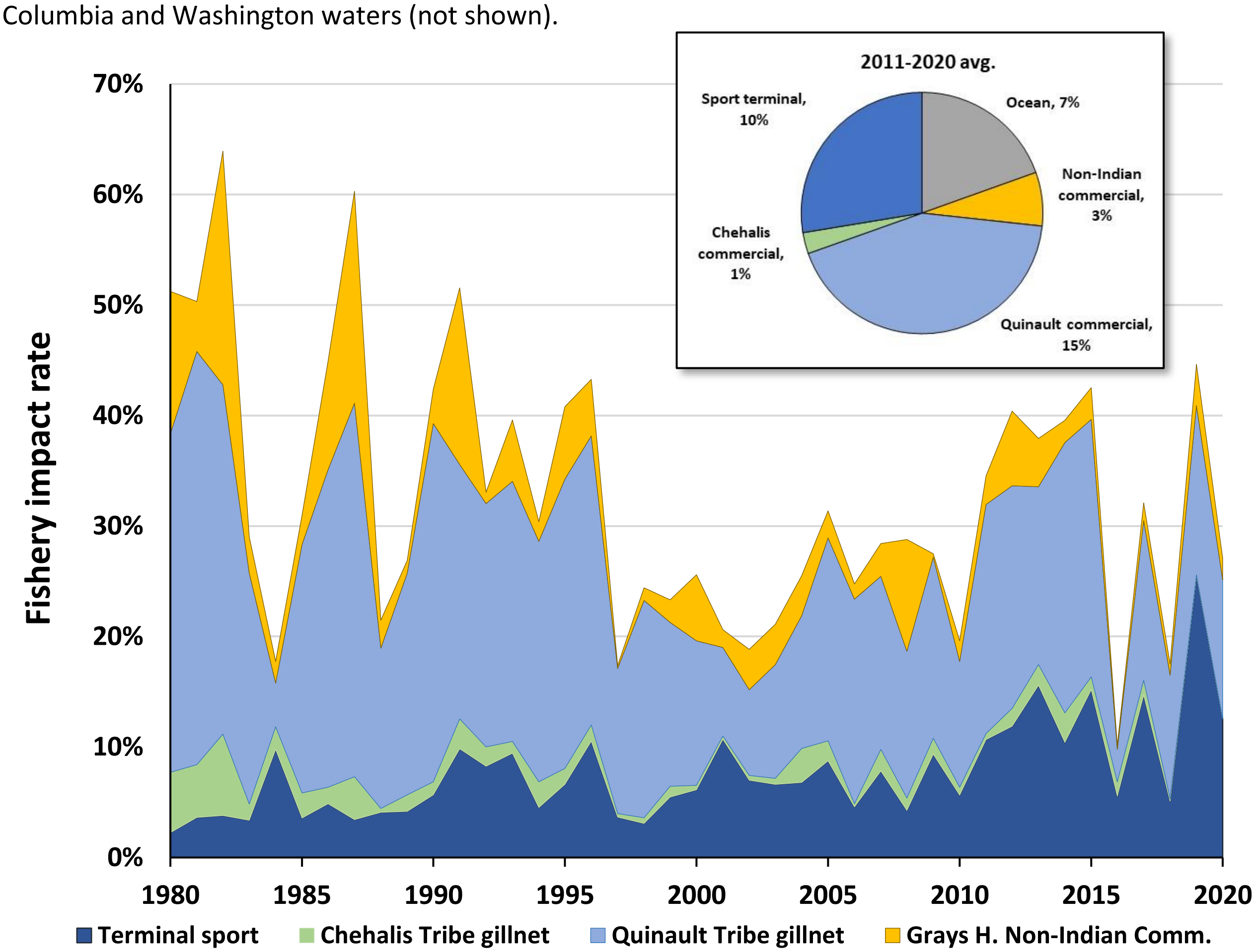

Figure 26. Annual fishery impact rates for Chehalis Coho in terminal gillnet and sport fisheries and the distribution of recent average rates among ocean and terminal fisheries (PFMC and WDFW data).

Table 20. Grays Harbor Coho terminal harvest, spawning escapement, and run size (PFMC data).

Year	Harvest				Escapement		Terminal run size	
	Non-Indian gillnet	Treaty Indian gillnet	Chehalis Tribal Gillnet	Sport	Natural	Hatchery	Natural	Hatchery
1980	10,009	23,782	4,247	1,743	29,700	8,701	59,810	17,814
1981	3,000	24,779	3,164	2,408	13,000	23,960	18,013	48,274
1982	17,378	25,980	6,036	3,128	18,100	11,369	45,676	36,497
1983	1,821	11,549	808	1,865	25,300	13,909	31,841	23,434
1984	3,218	6,556	3,391	16,198	105,741	30,374	120,930	44,650
1985	1,080	9,204	925	1,460	22,092	6,656	29,348	11,557
1986	12,506	36,586	1,898	6,186	33,683	36,314	52,691	74,545
1987	17,355	30,616	3,516	3,112	22,642	13,228	46,220	44,361
1988	3,537	20,105	495	5,654	61,958	46,855	61,749	76,870
1989	1,352	23,277	1,717	4,841	56,695	28,013	67,467	48,480
1990	3,827	39,961	1,461	6,982	45,603	25,404	66,047	57,234
1991	47,764	68,893	8,142	29,408	61,034	79,773	83,815	215,375
1992	666	14,059	1,129	5,264	32,906	9,362	43,982	19,879
1993	3,759	15,875	718	6,363	25,406	14,726	34,436	33,022
1994	715	8,612	916	1,789	12,360	14,799	13,542	26,033
1995	9,604	38,389	2,142	9,690	47,422	37,861	58,970	87,708
1996	10,096	51,784	2,672	20,846	63,571	48,607	83,514	116,068
1997	115	5,395	125	1,547	22,470	13,074	19,928	22,982
1998	795	13,468	305	2,123	34,892	17,432	36,426	33,088
1999	1,674	12,062	68	4,507	33,348	25,375	35,528	41,964
2000	4,995	10,797	7	5,122	38,054	33,875	39,088	54,314
2001	3,152	15,520	82	20,868	80,100	80,142	71,442	129,181
2002	6,853	14,132	666	13,083	110,066	53,161	104,128	94,562
2003	6,623	12,041	1,000	12,026	84,952	66,654	85,122	98,847
2004	5,162	17,681	1,741	9,847	60,690	52,134	74,748	73,357
2005	3,238	23,260	2,286	10,919	38,297	51,450	75,110	55,293
2006	649	8,685	127	2,151	17,767	17,223	21,779	25,142
2007	1,687	8,926	1,108	4,450	25,121	15,236	26,833	30,080
2008	7,766	10,204	869	3,266	34,054	20,039	41,999	34,808
2009	567	28,513	2,519	16,288	69,222	55,864	80,867	93,334
2010	4,090	25,163	1,542	12,455	102,237	74,069	112,930	107,644
2011	3,517	28,267	742	14,569	64,403	23,757	80,488	55,886
2012	10,279	30,670	2,470	18,069	66,836	22,301	94,191	58,048
2013	5,935	21,957	2,515	21,246	56,785	26,732	73,263	62,936
2014	5,504	67,252	7,322	28,595	105,039	59,840	140,428	134,341
2015	1,540	12,544	610	8,172	21,278	9,646	28,953	24,825
2016	232	2,063	891	3,868	38,595	24,464	33,284	36,248
2017	1,170	10,554	955	10,721	26,907	22,617	36,260	36,646
2018	802	8,950	177	4,087	49,622	16,199	57,980	22,043
2019	2,000	8,207	0	13,666	30,468	14,089	36,012	17,479
2020	1,014	6,541	0	6,538	23,814	14,392	30,099	21,923
2021	1,504	13,888	180	NA	NA	NA	NA	NA

Chum

Chum Salmon are harvested in non-tribal and Quinault tribal gillnet fisheries in Grays Harbor and in the freshwater sport fishery. Small harvests were also reported historically in the Chehalis Tribal fishery. Gillnet harvest occurs in October and early November fishing seasons that also harvest Fall Chinook and Coho. Harvest occurs in sport fisheries from September through November, primarily in the Satsop and Humptulips rivers with small numbers also reported from the Chehalis, Wynochee and Wishkah Rivers. Hatchery and wild Chum salmon cannot be distinguished at capture because hatchery fish are released as fry where ad-clipping is not practical. Therefore, the sport fishery harvests both hatchery and wild Chum Salmon. Grays Harbor Chum are not harvested in significant numbers by ocean fisheries.

Fishery impact rates for the aggregate hatchery and wild Chum run are estimated as catch divided by total return to the basin (catch, hatchery escapement and natural escapement). Annual catch in gillnet fisheries is from WDFW unpublished data. Annual catch in sport fisheries is reported in catch record cards (e.g., Kraig & Scalici 2022). Annual escapement is reported to area hatcheries (WDFW 2022) and to natural spawning grounds (WDFW SCoRE 2022). Impact rates estimated with historical population estimates are likely overestimates of actual rates based on recent stock assessments which suggest that Chum Salmon escapement is underestimated by up to 50% (Ronne et al. 2022).

Recent 10-year average fishery impacts have averaged 32% in terminal areas which include Grays Harbor tribal gillnet and freshwater sport fisheries (Figure 27, Table 21). Annual rates have varied considerably over the years but the average total has been reduced by approximately half since 1990. Estimated rates are likely overestimates due to underestimation of Chum run sizes recently reported by Ronne et al. (2022).

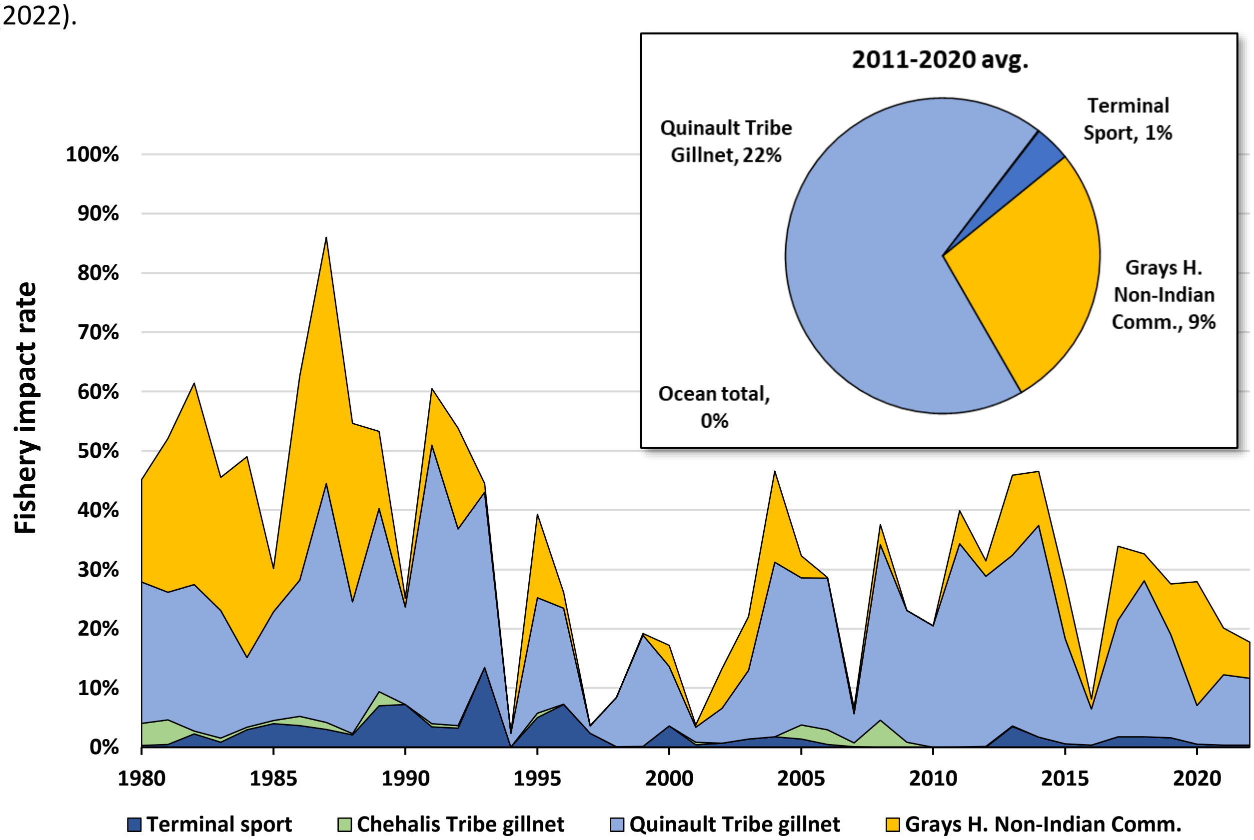

Figure 27. Annual fishery impact rates for Grays Harbor Chum in terminal tribal gillnet and sport fisheries and the distribution of recent average rates in ocean and terminal fisheries (PSC-CTC 2023 and PFMC 2023 data).

Table 21. Grays Harbor Chum terminal catch, spawning escapement, and run size in numbers of fish (WDFW data).

Year	Harvest				Spawning escapement		Terminal run size
	Non-Indian gillnet	Treaty Indian gillnet	Chehalis Tribe gillnet	Sport	Hatchery	Natural	
1980	8,800	12,175	1,903	150	3,300	24,700	51,028
1981	10,300	8,565	1,644	185	1,000	18,050	39,744
1982	33,650	24,423	491	2,232	3,100	35,100	98,996
1983	9,000	8,614	288	344	850	21,000	40,096
1984	16,450	5,699	210	1,446	1,050	23,700	48,555
1985	3,400	8,546	249	1,856	1,300	31,300	46,651
1986	18,150	12,131	827	1,916	150	19,550	52,724
1987	29,300	28,461	824	2,132	400	9,475	70,592
1988	41,252	30,478	342	2,831	0	62,175	137,078
1989	2,522	5,998	467	1,357	0	9,080	19,424
1990	174	1,975	0	864	0	8,972	11,985
1991	4,332	21,317	259	1,560	0	17,936	45,404
1992	14,107	27,523	350	2,664	0	38,300	82,944
1993	554	11,191	16	5,102	0	21,059	37,922
1994	0	580	1	12	0	24,592	25,185
1995	2,932	4,052	149	1,043	0	12,616	20,792
1996	441	2,714	11	1,211	0	12,413	16,790
1997	1	176	0	330	0	13,456	13,963
1998	2	3,218	23	6	227	35,188	38,664
1999	37	2,875	4	22	117	12,260	15,315
2000	387	1,081	0	390	0	8,936	10,794
2001	111	688	114	116	1,295	24,898	27,222
2002	4,434	3,902	0	464	1,351	56,175	66,326
2003	4,494	5,790	0	682	866	37,947	49,779
2004	5,026	9,620	10	571	379	17,063	32,669
2005	814	5,464	526	309	425	14,490	22,028
2006	14	4,038	389	77	442	10,826	15,786
2007	118	598	78	12	291	11,051	12,148
2008	238	2,069	320	0	423	3,938	6,988
2009	0	4,395	165	0	631	14,585	19,776
2010	0	8,938	0	1	1,107	33,537	43,583
2011	2,783	17,202	8	2	1,058	29,043	50,096
2012	1,063	11,670	53	0	2,424	25,452	40,662
2013	5,617	11,981	43	1,464	1,235	21,284	41,624
2014	2,625	10,266	0	491	667	14,711	28,760
2015	4,644	8,506	0	282	882	33,705	48,019
2016	1,165	4,312	0	253	1,893	62,811	70,434
2017	3,711	5,831	0	523	986	18,627	29,678
2018	1,979	11,459	0	771	901	28,413	43,523
2019	3,377	6,880	0	646	752	27,930	39,585
2020	7,066	2,217	0	179	951	23,457	33,870
2021	5,104	7,718	0	243	3,426	48,458	64,949
2022	5,580	10,263	0	356	2,313	72,744	91,256

Summer Steelhead

Summer steelhead are harvested primarily by sport fisheries targeting hatchery fish released in the Humptulips and Wynochee rivers. Small harvests also occur in limited tribal gillnet fisheries during the summer steelhead migration period. Summer steelhead are harvested from June until October. Retention of unmarked summer steelhead is prohibited in the sport fishery so impacts on natural-origin summer steelhead are limited to catch-and-release mortality. Tribal fisheries are not mark-selective for steelhead so harvest both wild/natural and hatchery fish. Steelhead are not harvested in significant numbers by ocean fisheries.

Apparent fishery impact rates for natural-origin summer steelhead are estimated for modeling purposes from information on hatchery summer steelhead returning to Grays Harbor streams. No information is available on catch or escapements of wild/natural Summer Steelhead in this system. Annual catch of unmarked hatchery summer steelhead in sport fisheries is reported in catch record cards (e. g., Kraig and Scalici 2022). Annual returns of summer steelhead to area hatcheries are similarly reported (e. g., WDFW 2022a). Apparent exploitation rate of hatchery-origin fish is estimated as catch divided by total hatchery return to the basin (catch plus hatchery collections). This value overestimates exploitation rate because hatchery fish spawning in the wild are not assessed. Trap collection efficiencies for hatchery Summer Steelhead are estimated to be just 20-30% in the Wynoochee trap and 70-80% in the Humptulips trap (Marston & Huff 2022). Impact rates on wild summer steelhead assume a catch rate equivalent to the hatchery-origin exploitation rate and a standard 10% catch-and-release mortality rate. These estimates should be considered "order-of-magnitude" values.

Apparent fishery impact rates on the aggregate hatchery Summer Steelhead run averaged 83% in 2011-2020 (Figure 27). These "apparent" rates are overestimates because a substantial portion of the hatchery Summer Steelhead return is not collected at the hatcheries. Corresponding impacts on wild/natural Summer Steelhead are less than 10%. Catch and impacts in tribal fisheries are negligible in recent years as gillnet fisheries during the summer period have been greatly restricted in recent years.

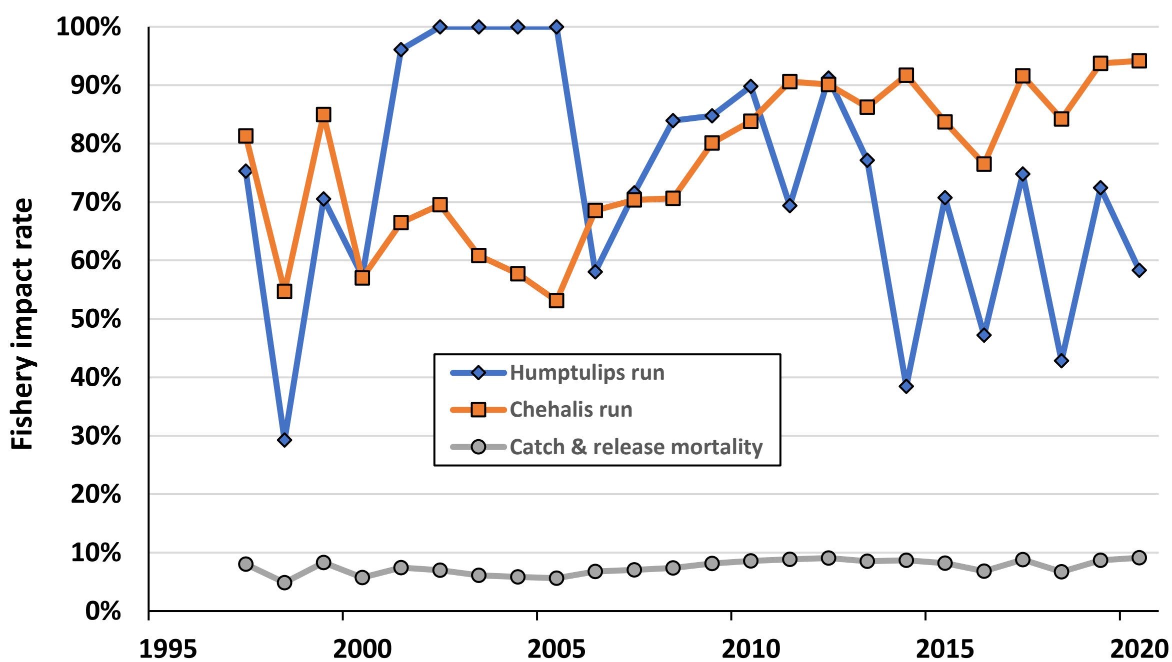

Figure 28. Annual fishery impact rates for Grays Harbor Summer Steelhead in terminal tribal gillnet and sport fisheries (WDFW unpublished data).

Table 22. Humptulips and Chehalis Summer Steelhead harvest, hatchery escapement, and run size in numbers of fish (WDFW unpublished data).

Year	Sport harvest		Tribal harvest		Hatchery escape.		Run size	
	Hump.	Chehalis	Hump.	Chehalis	Hump.	Chehalis	Hump.	Chehalis
1980	40	669	2	18				
1981	50	531	4	66				
1982	196	570	17	42				
1983	123	1091	2	68				
1984	400	958	1	6				
1985	212	608	10	27				
1986	172	534	19	28				
1987	65	278	8	13				
1988	75	325	21	18				
1989	65	690	9	19				
1990	76	636	29	162				
1991	60	327	2	10				
1992	118	284	37	95				
1993	97	1309	10	43				
1994	128	853	1	97				
1995	33	471	9	68				
1996	58	1,096	13	138				
1997	122	1,015	12	17	44	237	178	1,269
1998	63	484	40	143	249	519	352	1,146
1999	56	577	11	51	28	111	95	739
2000	233	1151	13	91	183	936	429	2,178
2001	261	507	9	36	11	274	281	817
2002	18	1257	2	128	0	607	20	1,992
2003	28	1402			0	903	28	2,305
2004	25	831			0	609	25	1,440
2005	63	470			0	415	63	885
2006	54	920			39	422	93	1,342
2007	199	1066			79	449	278	1,515
2008	382	991			73	412	455	1,403
2009	624	1607			112	399	736	2,006
2010	439	809			50	156	489	965
2011	170	2,270			75	235	245	2,505
2012	1,310	2,713			126	297	1,436	3,010
2013	223	1,782			66	285	289	2,067
2014	80	1,965			128	178	208	2,143
2015	428	2,949			177	573	605	3,522
2016	316	1,286			353	395	669	1,681
2017	415	2,032			140	186	555	2,218
2018	389	1,074			519	201	908	1,275
2019	134	375			51	25	185	400
2020	105	1,856			75	115	180	1,971

Winter Steelhead

Winter Steelhead are harvested in non-tribal and treaty tribal gillnet fisheries in Grays Harbor and in the freshwater sport fishery. The treaty fishery, conducted by the QIN, typically occurs in the lower Chehalis as well as in Areas 2A, 2A-1, and 2D in the estuary. Most of the treaty commercial steelhead effort is concentrated in the lower three river miles of the Chehalis River (QINDF & WDFW 2021). The Confederated Tribes of the Chehalis Reservation (Chehalis Tribe) conducts a commercial fishery on its reservation near Oakville in the upper Chehalis. The non-treaty sport fishery typically takes place in all the major tributaries as well as the mainstem. Steelhead are not harvested in significant numbers by ocean fisheries.

Hatchery steelhead are distinguished by adipose clips from and wild/natural steelhead. Tribal gillnet fisheries harvest both hatchery and wild/natural steelhead. The sport fishery retains only hatchery fish which are 100% ad-clipped and releases unmarked wild/natural fish. As a result, sport fishery impacts on wild/natural fish are limited to catch-and-release mortality. Gillnet harvests also include estimates of non-retention (drop out) mortalities.

Fishery impact rates for Chehalis system run are estimated as catch divided by total return to Grays Harbor (catch plus escapement). Gillnet fisheries is reported by the tribes. Sport catch is reported to WDFW in catch record cards (e.g., Kraig and Scalici 2022). Escapement is estimated to area hatcheries (WDFW 2022a) and to natural spawning grounds (WDFW SCoRE 2022).

Recent 10-year average fishery impacts on wild/natural winter steelhead have averaged 11% (Table 23). Annual rates have generally varied between 1 and 24% since 1995 (Figure 29). Hatchery steelhead are harvested at a substantially higher rate in aggregate, in the sport fishery and also in some degree by tribal gillnet fisheries.

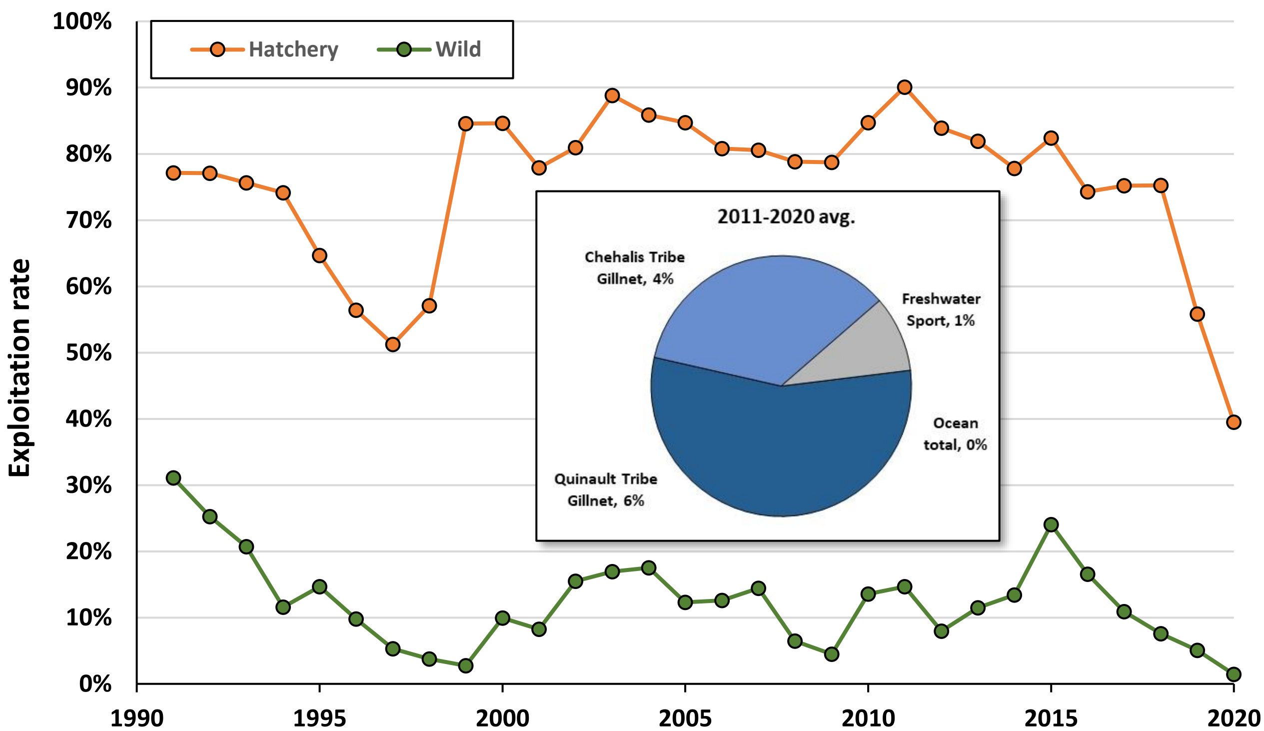

Figure 29. Annual fishery impact rates for Chehalis Winter Steelhead in terminal tribal gillnet and sport fisheries and the distribution of recent average wild/natural rates among fisheries (QINDF & WDFW 2021).

Table 23. Commercial and sport catches, spawner escapements and run sizes of Chehalis River system Winter Steelhead (QINDF & WDFW 2021).

Run year	Commercial catch				Sport catch		Spawner escapement		Run size		
	Wild		Hatchery								
	Quinault	Chehalis	Quinault	Chehalis	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery	Total
1991-92	798	371	1,294	254	2,284	2,339	7,652	1,152	11,105	5,039	16,144
1992-93	288	245	425	558	1,463	1,439	5,904	720	7,900	3,142	11,042
1993-94	642	412	337	135	1,140	999	8,391	474	10,585	1,945	12,530
1994-95	290	311	386	42	542	1,712	8,713	747	9,856	2,887	12,743
1995-96	328	212	459	112	763	3,340	7,585	2,139	8,888	6,050	14,938
1996-97	226	350	558	157	155	2,778	6,714	2,702	7,445	6,195	13,640
1997-98	148	61	140	19	126	1,835	5,964	1,898	6,299	3,892	10,191
1998-99	113	78	124	72	225	1,299	10,720	1,124	11,136	2,619	13,755
1999-00	66	52	49	48	209	3,965	11,679	740	12,006	4,802	16,808
2000-01	628	189	617	175	263	3,547	9,802	788	10,882	5,127	16,009
2001-02	499	228	1,019	157	214	7,872	10,440	2,568	11,381	11,616	22,997
2002-03	1,156	181	1,026	175	207	5,954	8,424	1,685	9,968	8,840	18,808
2003-04	2,807	145	3,595	126	274	7,958	15,825	1,471	19,051	13,150	32,201
2004-05	1,474	301	3,221	875	148	5,155	9,059	1,524	10,982	10,775	21,757
2005-06	885	449	1,596	225	126	6,977	10,418	1,590	11,878	10,388	22,266
2006-07	720	271	2,633	214	107	5,111	7,602	1,890	8,700	9,848	18,548
2007-08	488	476	695	410	79	3,782	6,193	1,178	7,236	6,065	13,301
2008-09	45	357	318	350	79	1,764	6,956	654	7,437	3,086	10,523
2009-10	31	213	331	332	75	3,570	6,764	1,144	7,083	5,377	12,460
2010-11	551	329	2,366	326	75	3,848	6,089	1,182	7,044	7,722	14,766
2011-12	770	434	1,290	800	100	9,502	7,592	1,277	8,896	12,869	21,765
2012-13	530	203	758	200	113	7,325	9,776	1,593	10,622	9,876	20,498
2013-14	333	496	551	722	86	5,225	6,944	1,435	7,958	7,933	15,891
2014-15	1,256	272	2,807	210	130	8,057	10,568	3,156	12,350	14,230	26,580
2015-16	2,165	531	4,179	689	124	9,018	8,824	2,972	11,734	16,858	28,592
2016-17	274	597	493	975	60	5,051	4,618	2,255	5,622	8,774	14,396
2017-18	383	380	1,023	991	82	5,770	6,840	2,567	7,742	10,350	18,092
2018-19	348	89	453	119	70	2,661	6,130	1,064	6,682	4,297	10,979
2019-20	66	202	183	772	72	2,117	6,283	2,433	6,699	5,505	12,204
2020-21	19	3	127	2	61	1,293	5,634	2,178	5,793	3,601	9,394

Hatchery

For the purpose of this analysis, impacts are defined as the percentage reduction in natural productivity due to the effects of hatchery fish on natural population diversity, productivity, and fitness, as well as effects on fish health and complex ecological interactions. Estimates of hatchery impacts are not available for Chehalis salmon and steelhead. Therefore, estimates were inferred from information on hatchery effects in other areas based on the percentage of hatchery-origin spawners in Chehalis salmon and steelhead populations. Values are presented as a range reflecting uncertainties in the related science.[3] This definition of hatchery impacts refers only to the negative effects on natural production which is the focus of the analysis from a conservation perspective. Net effects of hatchery fish on total abundance are more complicated involving both negative and positive contributions that depend on the status of the natural populations and characteristics of the hatchery fish.

Background

Six main hatcheries and a variety of related facilities currently produce salmon and/or steelhead in this region (Figure 30, Table 24). The current production goal is 5.2 million juveniles per year (Figure 31). Coho account for over half of this total, followed by Fall Chinook, Winter Steelhead and Chum. Hatchery programs for Coho, Fall Chinook and Winter Steelhead are long-standing but have varied over the years (Figure 32). Summer Steelhead and Chum Salmon releases have consistently occurred since 2020.

Figure 30. Salmon and steelhead hatcheries and related facilities in Grays Harbor systems.

[3] Percentage of hatchery-origin spawners in natural populations was also the basis for Washington hatchery program reforms identified by the Hatchery Scientific Review Group (HSRG 2004).

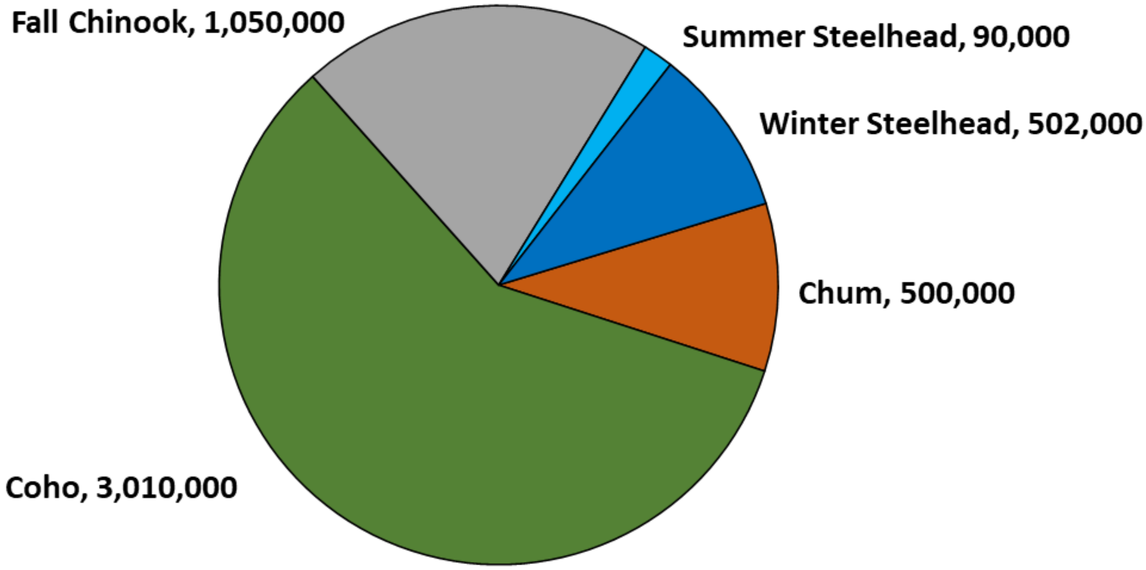

Figure 31. **Current hatchery production goals by species in Grays Harbor systems (WDFW 2022b).**

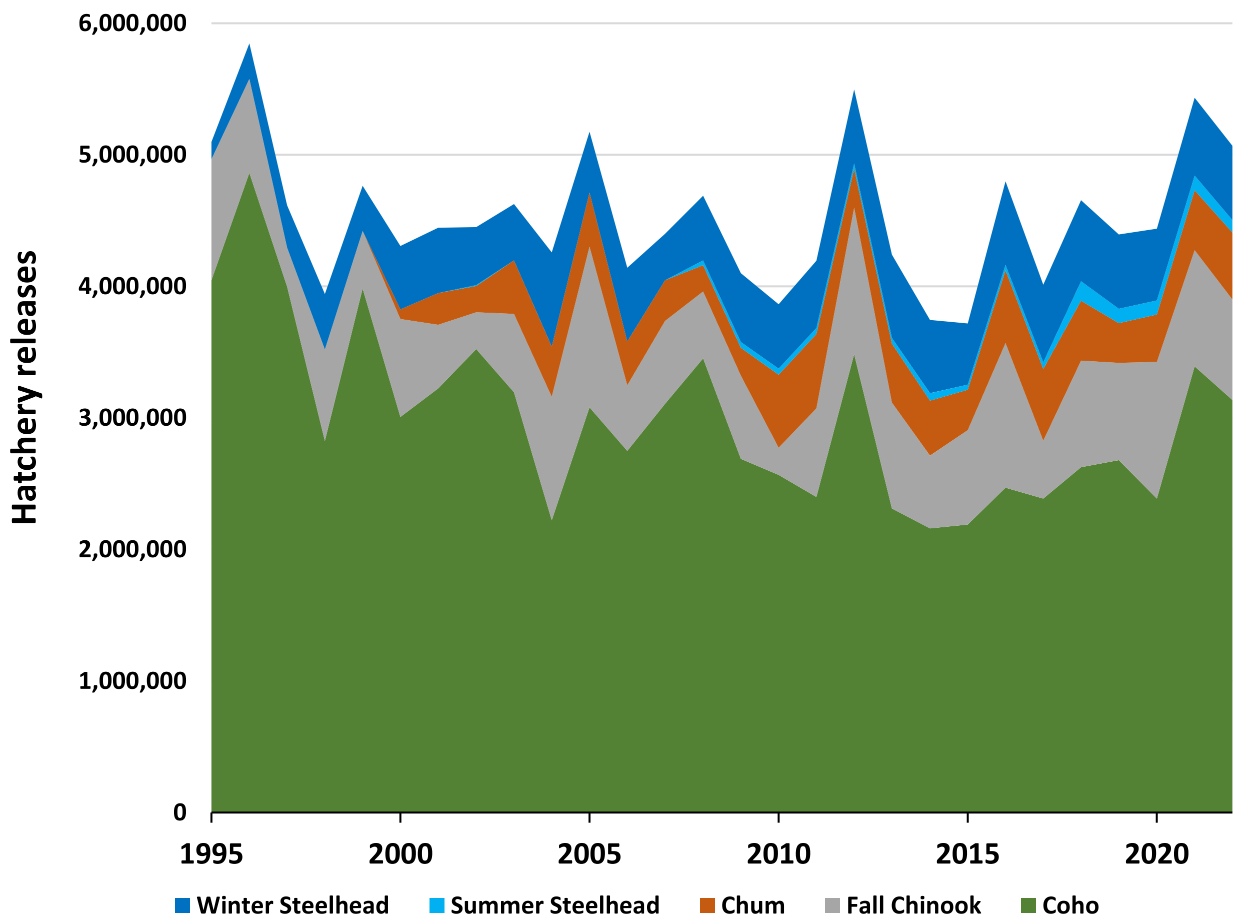

Figure 32. **Annual hatchery releases by species in Grays Harbor systems (WDFW unpublished data https://data.wa.gov/dataset/WDFW-Fish-Plants/6fex-3r7d).**

Table 24. Current hatchery production goals for Grays Harbor systems (WDFW 2022).

Species/Run	Hatchery	Stock	Stage	Origin	Goal	Acclimation site	Release site	Subbasin
Chum	Bingham Creek	Satsop R	Fry	Mixed	200,000	Bingham Creek Hatchery	Satsop EF	Satsop
	Bingham Creek	Satsop R	Fry	Mixed	200,000	Satsop Springs Ponds	Satsop R	Satsop
	Mayr Brothers	Wishkah R	Fry	Mixed	100,000	Mayr Brothers Ponds	Wishkah R	Wishkah
Coho	Humptulips	Humptulips R	Yearling	Mixed	900,000	Humptulips Hatchery	Stevens Creek	Humptulips
	Bingham Creek	Satsop R	Yearling	Mixed	25,000	Friends Landing Net Pens	Quigg Lake (Gray)	Wynoochee
	Bingham Creek	Satsop R	Yearling	Mixed	450,000	Bingham Creek Hatchery	Satsop EF	Satsop
	Bingham Creek	Satsop R	Yearling	Mixed	450,000	Satsop Springs Ponds	Satsop R	Satsop
	Bingham Creek	Satsop R	Yearling	Mixed	100,000	Westport Net Pens	Westport Boat Basin	Estuary
	Skookumchuck	Skookumchuck	Yearling	Mixed	50,000	Carlisle Lake Project	Gheer Creek	Newaukum
	Skookumchuck	Skookumchuck	Yearling	Mixed	50,000	Skookumchuck Hatchery	Skookumchuck R	Skookumchuck
	Deep Creek	Skookumchuck	Fry	Mixed	45,000	na	Gable Creek	Skookumchuck
	Deep Creek	Skookumchuck	Fry	Mixed	45,000	na	Tapp Creek	Skookumchuck
	Pedersen Project	Skookumchuck	Fry	Mixed	45,000	na	Newaukum R-NF	Newaukum
	Heimbigner Project	Skookumchuck	Fry	Mixed	45,000	na	Stearns Creek	Newaukum
	Mayr Brothers	Wishkah R	Yearling	Mixed	300,000	Mayr Brothers Ponds	Wishkah R	Wishkah
	Lake Aberdeen	Wynoochee R	Yearling	Mixed	30,000	Lake Aberdeen Hatchery	Van Winkle Creek	Wynoochee
Coho (late)	Humptulips	Humptulips R	Yearling	Mixed	100,000	Humptulips Hatchery	Stevens Creek	Humptulips
	Bingham Creek	Satsop R	Yearling	Mixed	150,000	Bingham Creek Hatchery	Satsop EF	Satsop
	Skookumchuck	Skookumchuck	Yearling	Mixed	100,000	Eight Creek/Upr Chehalis	Eight Creek	Boistfort
	Skookumchuck	Skookumchuck	Yearling	Mixed	50,000	Carlisle Lake Project	Gheer Creek	Newaukum
	Skookumchuck	Skookumchuck	Yearling	Mixed	25,000	Noel Cole Pond	Newaukum R-NF	Newaukum
	Skookumchuck	Skookumchuck	Yearling	Mixed	50,000	Skookumchuck Hatchery	Skookumchuck R	Skookumchuck
Fall Chinook	Humptulips	Humptulips R	Subyearling	Mixed	500,000	Humptulips Hatchery	Stevens Creek	Humptulips
	Bingham Creek	Satsop R	Subyearling	Mixed	200,000	Bingham Creek Hatchery	Satsop EF	Satsop
	Bingham Creek	Satsop R	Subyearling	Mixed	300,000	Satsop Springs Ponds	Satsop EF	Satsop
	Lake Aberdeen	Wynoochee R	Subyearling	Mixed	50,000	Lake Aberdeen Hatchery	Van Winkle Creek	Wynoochee
Summer	Humptulips	Humptulips	Smolt	Hatchery	30,000	Humptulips Hatchery	Stevens Creek	Humptulips
Steelhead	Lake Aberdeen	LK Aberdeen	Smolt	Hatchery	60,000	Lake Aberdeen Hatchery	Van Winkle Creek	Wynoochee
Winter Steelhead	Humptulips	Humptulips	Smolt	Hatchery	125,000	Humptulips Hatchery	Stevens Creek	Humptulips
(early)	Humptulips	Humptulips	Smolt	Hatchery	15,000	Mayr Brothers Ponds	Wishkah R	Wishkah
Winter Steelhead	Bingham Creek	Satsop R	Smolt	Mixed	55,000	Bingham Creek Hatchery	Satsop EF	Satsop
(late)	Skookumchuck	Skookumchuck	Smolt	Mixed	32,000	Eight Creek/Upr Chehalis	Eight Creek	Boistfort
	Skookumchuck	Skookumchuck	Smolt	Mixed	75,000	Skookumchuck Dam	Skookumchuck R	Skookumchuck
	Skookumchuck	Skookumchuck	Smolt	Mixed	30,000	Carlisle Lake Project	Gheer Creek	Newaukum
	Lake Aberdeen	Wynoochee R	Smolt	Mixed	170,000	Lake Aberdeen Hatchery	Van Winkle Creek	Wynoochee

Spring Chinook – Hatchery Spring Chinook are not currently released in Grays Harbor rivers. Spring Chinook from the Cowlitz Hatchery were introduced in the Wynoochee River in the 1970s but returns were minimal and hybridization with the local stock was unlikely (WDFW & WWTIT 1992, 2002).

Summer Chinook - Hatchery Summer Chinook are not currently released in the Satsop River or in any other Grays Harbor rivers. A large number of hatchery plants have historically been made in the Satsop and other area rivers from a variety of imported Chinook stocks. While the Satsop Summer population has an earlier timing than most of these imported stocks, some hybridization was assumed to have historically occurred (WDFW & WWTIT 1992, 2002).

Fall Chinook – Hatchery Fall Chinook have been released into the basin since at least the 1950s and historically included a variety of non-local stocks from Willapa Bay, Puget Sound, Columbia River and the Oregon coast (WDFW & WWTIT 1992, 2002; ASEPTC 2014). Hatchery Fall Chinook are currently released by the Humptulips, Bingham Creek and Lake Aberdeen programs into the Humptulips, Satsop and Wynochee rivers, respectively. These hatcheries are now operated as integrated programs where broodstock include a mixture of hatchery-origin and natural origin Fall Chinook in an attempt to maintain native population characteristics. Fall Chinook were also historically released from the Mayr Brothers Facility into the Wishkah River but this production was shifted to the Lake Aberdeen Hatchery after 2018.

Chum – Hatchery Chum Salmon are released into the Satsop River from Bingham Creek and Satsop Springs facilities and the Wishkah River from the Mayr Brother facility. Annual releases of hatchery Chum have occurred since the late 1990s although not from each facility in every year. Current programs utilize local-origin broodstock consisting of a mixture of natural-origin and hatchery Chum. Historical releases included non-native chum, mostly from Willapa Bay and Hood Canal. These introductions, primarily into the Satsop River, were generally unsuccessful, and it is unlikely that significant impact to the genetic makeup of the native stock has occurred (ASEPTC 2014).

Chum broodstock for the Satsop Springs and Bingham Creek programs are collected at the Satsop Springs spawning channel or by hook and line from the EF Satsop River (Edwards & Zimmerman 2018). Spawning and rearing occurs at Bingham Creek. Fry are split between hatcheries and released. Broodstock for the Mayr Brother Hatchery program are collected by dip-netting and seining in the mainstem Wishkah River above and below the hatchery (HSRG 2004). Hatchery Chum fry are not marked to distinguish from wild Chum as their small size at release is not suitable for external marking. Thermal marking of otoliths does not occur. Hatchery-origin Chum are reported to comprise 3% of the total run, on average (ASEPTC 2014).

Coho – Hatchery Coho have been released into the basin since at least the 1950s and historically included a mixture of local and non-local stocks (WDFW & WWTIT 1992, 2002). Out-of-basin hatchery stocks included Soos Creek, Samish, Dungeness, Minter Creek, and Sol Duc. Hatchery Coho are currently released by all five major programs in the basin (Table 24). These hatcheries are now operated as integrated programs where broodstock include a mixture of hatchery-origin and natural origin Coho in an attempt to maintain native population characteristics. Releases are primarily yearlings but also include fry.

Summer Steelhead –Summer Steelhead are released from the Humptulips Hatchery into Stevens Creek (Humptulips tributary) and from the Lake Aberdeen Hatchery into the Wynoochee River. Programs are considered to be largely segregated from the endemic winter run of steelhead due to large differences in run and spawn timing (Marston & Huff 2022). The Humptulips program was initiated in 1981 with summer steelhead from Skamania Hatchery, with the on-station program established in 1995 using summer steelhead from Lake Aberdeen Hatchery (Marston & Huff 2022). Production is now maintained with hatchery-origin broodstock returning to the hatchery with a trapping efficiency of 70 to 80%. The Lake

Aberdeen program is derived from Skamania stock and is currently self-sustaining with returns to Lake Aberdeen Hatchery and the trap at Wynoochee Dam on River Mile 51. Trapping efficiency of this program was assumed to be 20% to 30% which means that a large portion of the run spawns naturally. The productivity of hatchery summer steelhead spawning in the wild is uncertain (WDFW & WWTIT 1992, 2002). Marston & Huff (2022) have identified the Chehalis population of Summer Steelhead as a candidate for a wild steelhead management zone based on a low incidence of hatchery-origin fish.

Winter Steelhead - The WDFW has stocked the Chehalis River system with winter steelhead smolts since the early 1960's (QINDF & WDFW 2021). Originally, early timed South Puget Sound (Chambers Creek) stock was used. Use of the early timed hatchery in combination with later timed native winter stocks in the Chehalis system historically provided an extended period of fishery opportunity from November into April.

Significant reforms to historical Chehalis Basin Winter Steelhead programs have been implemented out of concern for potential impacts of the non-native early-run hatchery stock on the later-timed endemic populations. Production has largely shifted from the early-timed Chambers Creek stock to local broodstock with a late run timing is currently similar to the wild stock. This change has accordingly truncated the period of fishery opportunity. Bingham Creek, Lake Aberdeen and Skookumchuck hatcheries are now currently operated as integrated programs for local-origin late run Winter Steelhead (Marston & Huff 2022). Broodstock in these integrated programs include a mixture of hatchery-origin and natural origin fish in an attempt to maintain native population characteristics.

The Bingham Creek late program was founded in 1998 with natural origin steelhead collected from February to early April via hook and line in the Satsop River and at the Bingham Creek trap, which is a full rack across the stream (Marston & Huff 2022). The Lake Aberdeen late program was established in 1978 with natural origin fish collected in the Wynoochee River (Marston & Huff 2022). Broodstock are collected at the Wynochee Dam trap at River mile 51 and with some fish that recruit back to the trap at Lake Aberdeen Hatchery but overall trapping efficiency is low (20-30%), so substantial numbers of hatchery-origin steelhead are spawning in the wild (Marston & Huff 2022).

The Skookumchuck late program was established in 1973 with natural origin steelhead collected at the trap at Skookumchuck Dam. Skookumchuck Hatchery releases fish into the Skookumchuck River to mitigate for lost harvest opportunity caused by Skookumchuck Dam and also provides fish released into the Newaukum River (Lake Carlisle, Gheer Creek). Net pens in Lake Carlisle are operated by Onalaska High School. Skookumchuck Hatchery provided fry-sized fish for these programs. Fish reared in these net pens are released into Gheer Creek. There is also on-site rearing at the high school for steelhead.

Segregated programs using an early-run hatchery Winter Steelhead stock continue to be operated at the Humptulips Hatchery and the Mayr Brothers Hatchery on the Wishkah River. The Humptulips early winter steelhead was established with early returning naturally spawning steelhead in the 1980s and are believed to be the result of outplants from Lake Quinault and Bogachiel hatcheries, which is thought to be a mix of coastal and Chambers Creek stocks (Marston & Huff 2022). The Wishkah River early winter steelhead program was initiated in release year 2021 with juveniles originating from Humptulips Hatchery (Marston & Huff 2022).

Marston & Huff (2022) have identified Hoquiam, Wishkah, and Chehalis populations of Winter Steelhead as candidates for wild steelhead management zones based on a low incidence of hatchery-origin fish.

Table 25. Annual releases of juvenile salmon and steelhead into Grays Harbor systems (WDFW unpublished data https://data.wa.gov/dataset/WDFW-Fish-Plants/6fex-3r7d).

Year	Fall Chinook	Coho	Chum	Summer Steelhead	Winter Steelhead	Total
1995	921,100	4,046,010	0	0	131,488	5,098,598
1996	714,400	4,862,522	0	0	270,026	5,846,948
1997	296,353	3,998,959	0	0	321,520	4,616,832
1998	696,707	2,823,895	0	0	422,292	3,942,894
1999	437,000	3,984,380	0	0	343,880	4,765,260
2000	744,100	3,007,560	73,000	0	482,059	4,306,719
2001	484,425	3,222,859	242,000	0	496,385	4,445,669
2002	280,685	3,522,156	200,000	6,000	441,550	4,450,391
2003	596,750	3,194,495	406,000	0	429,122	4,626,367
2004	939,153	2,222,080	381,911	0	715,740	4,258,884
2005	1,220,275	3,080,746	411,500	0	463,945	5,176,466
2006	499,210	2,748,250	334,500	0	558,234	4,140,194
2007	630,700	3,106,800	307,974	0	353,170	4,398,644
2008	509,300	3,453,025	197,800	37,200	490,710	4,688,035
2009	631,500	2,689,292	211,082	45,191	522,489	4,099,554
2010	207,600	2,566,000	553,800	47,200	488,700	3,863,300
2011	676,314	2,397,596	563,100	45,638	461,778	4,144,426
2012	1,113,767	3,484,367	298,100	38,271	172,951	5,107,456
2013	804,030	2,311,923	448,480	42,949	152,271	3,759,653
2014	553,600	2,159,847	417,700	57,011	174,599	3,362,757
2015	718,855	2,188,723	307,550	37,374	146,426	3,398,928
2016	1,099,800	2,469,453	553,500	41,750	133,105	4,297,608
2017	440,918	2,386,587	544,900	50,700	138,300	3,561,405
2018	811,380	2,624,988	455,300	148,656	153,500	4,193,824
2019	740,300	2,678,172	301,920	109,450	132,700	3,962,542
2020	1,038,943	2,386,161	360,000	108,900	137,500	4,031,504
2021	883,024	3,392,400	454,600	113,221	153,400	4,996,645
2022	762,700	3,136,618	510,100	94,952	146,500	4,650,870

Estimation Method

This analysis follows estimation methods adapted from an approach applied previously in NOAA's Columbia Basin Partnership Project (CBPTF 2020). The following descriptions are excerpted from the report for that project.

The scale and significance of interactions of hatchery and natural fish remains a source of substantial uncertainty and no small amount of controversy. Net effects include a complex of both negative and positive contributions that depend on the status of the natural populations and characteristics of the hatchery fish. Hatchery conservation and supplementation programs have proven to be successful strategies for increasing the number of naturally spawning, natural-origin fish, at least in the short term NMFS (2014). Benefits may outweigh risks under circumstances where demographic or short-term extinction risk to the population is greater than risks to population diversity and productivity (NMFS 2019). Conversely, the long-term use of artificial propagation may pose risks to natural productivity and diversity (NMFS 2019). Demographic benefits are sustainable only if they exceed the predicted reductions in genetic viability and reproductive fitness of natural-origin fish in subsequent generations (HSRG 2009). The long-term success in recovering a self-sustaining, naturally spawning population is yet to be demonstrated and may be difficult without commensurate improvements in the condition of natural habitat (NMFS 2014).

The scientific literature has documented a number of hatchery-related risks to natural production (Waples 1991; Busack & Currens 1995; NRC 1996; Brannon et al. 2004; Lichatowich et al. 2006; McClure et al. 2008; Naish et al. 2008; Kostow 2009; HSRG 2014; Anderson et al. 2020). Traditional salmon hatchery strategies have contributed to a variety of biological problems, including demographic risks; genetic and evolutionary risks; problems due to behavior, health status, or physiology of hatchery fish; and ecological problems (NRC 1996). Hatchery programs can negatively affect naturally produced populationsthrough competition (for spawning sites and food), predation effects, disease effects, genetic effects (outbreeding depression), broodstock collection and facility effects (hatchery influenced selection) (NMFS 2019). The magnitude and type of the risk depends on the status of affected populations and on specific practices in the hatchery program (NMFS 2019).

The magntude of hatchery impact has proven difficult to quantify and various approaches have produced of broad range of related estimates. Comparisons of the relative reproductive success (RRS) of hatchery- and natural-origin salmon and steelhead have provided some of the earliest and most direct evidence for negative impacts of hatchery production. Relative reproductive success has been widely reported to be less for hatchery-origin fish than for natural-origin fish variously ranging from 6% to 100% (Araki et al. 2007; Berejikian & Ford 2004; Berntson et al. 2011; Buhle et al. 2009; Chilcote et al. 1986; Christie et al. 2014; Fleming & Gross 1993; Ford et al. 2008, 2016; Hulett et al. 1996; Janowitz-Koch et al. 2019; Kostow et al. 2003; McLean et al. 2003, 2004; Reisenbichler & McIntyre 1977, 1999; Ruben et al. 2003; Thériault et al. 2011; Williamson et al. 2010).

Ford (2002) developed a theoretical basis for assessing relative hatchery fitness of a wild and captive population using a phenotypic model based on a suite of fitness-correlated traits (such as time of spawning, length, etc.). A Hatchery Scientific Review Group (HSRG) evaluated regional hatchery program effects on the viability of natural populations based on population fitness using a similar quantitative genetic framework implemented in the "All-H Analyzer (AHA)" model (Mobrand et al. 2005; HSRG 2004, 2014).[4] Chilcote et al. (2011, 2013) examined hatchery impacts with a correlative model comparing productivity of natural populations with percentage of hatchery-origin spawners. The Idaho Supplementation Studies (ISS) measured the population effects of dedicated, intentional hatchery supplementation on the abundance and productivity of Chinook Salmon during and after supplementation (Venditti et al. 2015; ISRP 2016). Finally, Courter et al. (2019) evaluated the response of hatchery elimination on abundance and productivity of a natural population steelhead population.

Box 1. **Definition of terms related to hatchery effects on natural production (HSRG 2014).**

Natural-origin spawners (NOS): Natural-origin fish spawning naturally. Natural-origin fish are offspring of parents that spawned in the natural environment rather than the hatchery environment. Parent can include both natural and hatchery-origin fish.

Hatchery-origin spawners (HOS): Hatchery-origin fish spawning naturally. The percentage of hatchery-origin spawners is often referred to as pHOS.

Relative reproductive success (RRS): The breeding success or survival of the hatchery-origin fish spawning naturally (HOS) relative to that of natural-origin fish spawning naturally (NOS) (i.e., ratio of hatchery recruits per spawner to natural recruits per spawner). The relative RRS of first-generation hatchery-origin adults in the wild is affected by both genetic and environmental factors. For example, domestication selection and choice of hatchery broodstock may affect spawn timing, growth and maturation of hatchery fish, while release location and size/age at release may affect the choice of spawning location.

Natural-origin broodstock NOB: Natural-origin fish used in a hatchery program. The percentage of natural-origin fish in the hatchery broodstock is referred to as pNOB.

Proportionate natural influence (PNI): PNI is a metric used as an indicator of the genetic influence through interbreeding of the hatchery-origin component of a population with the natural-origin component of a population. Computationally it is a function of both the proportion of naturally spawning salmon or steelhead that are hatchery-origin fish (pHOS) and the proportion of a hatchery program's broodstock that is made up of natural-origin fish (pNOB). [pNOB/(pNOB+pHOS)].

Integrated hatchery program: A hatchery program that aims to be genetically identical to an associated natural population though intentional natural spawning of hatchery-origin fish and hatchery spawning of natural-origin fish.

Segregated hatchery program: A hatchery program intended to be genetically distinct from natural populations by minimizing both the number of hatchery-origin fish that spawn naturally and the number natural-origin fish used as hatchery broodstock.

For the purposes of this analysis, a broad range of potential hatchery impact was identified for each stock to reflect uncertainties identified in scientific literature for the potential magnitude of fitness-related and ecological effects. Impacts were assumed to be directly related to the percentage of hatchery-origin spawners (pHOS) in the naturally-spawning population (Figure 33). Estimates of pHOS are generally available for most populations based on spawning ground survey data. Hatchery fish are typically distinguished by adipose fin clips or code-wire tags.

[4] *Marston & Huff (2022) have recently applied this same approach to analysis of Chehalis steelhead hatchery programs.*

Low range values assume relatively small hatchery impacts consistent with consistent with empirical results of the Idaho Supplementation Study (Venditti et al. 2015; ISRP 2016) and Courter et al.'s (2019) hatchery elimination response. These values were based on the product of an assumed 90% RRS for the stock [10% reduction in productivity). These values reflect a RRS for hatchery fish that might be expected in a fully-integrated hatchery program. Low range values primarily reflect fitness effects but might also underestimate the influence of ecological effects.

High range values assume relatively high hatchery impacts consistent with relationships between pHOS and productivity reported by Chilcote et al. (2011, 2013). High range estimates are generally greater than pHOS and comparable to what might be expected from a RRS of zero. High range values reflect both fitness and some level of fish health or ecological impact but might also be inflated by choice of spawning location by hatchery fish due to their release location and size/age at release. Point estimates of hatchery impact for each stock were based on the midpoint between a range of values reflecting uncertainties in the magnitude of fitness-related and ecological effects.

These impact estimates generally assume that equilibrium conditions have been reached for the hatchery fraction in the wild and for relative fitness of hatchery and wild fish. This simplifying assumption was necessary because more detailed information is lacking on how far the current situation is from equilibrium. In practice, actual differences in fitness of hatchery and natural fish at any given time depend on inherent differences in fitness and the degree and period of interaction (Lynch and O'Hely 2001). The index may thus over or underestimate the true current impact of hatchery spawners on wild fitness depending on past history.

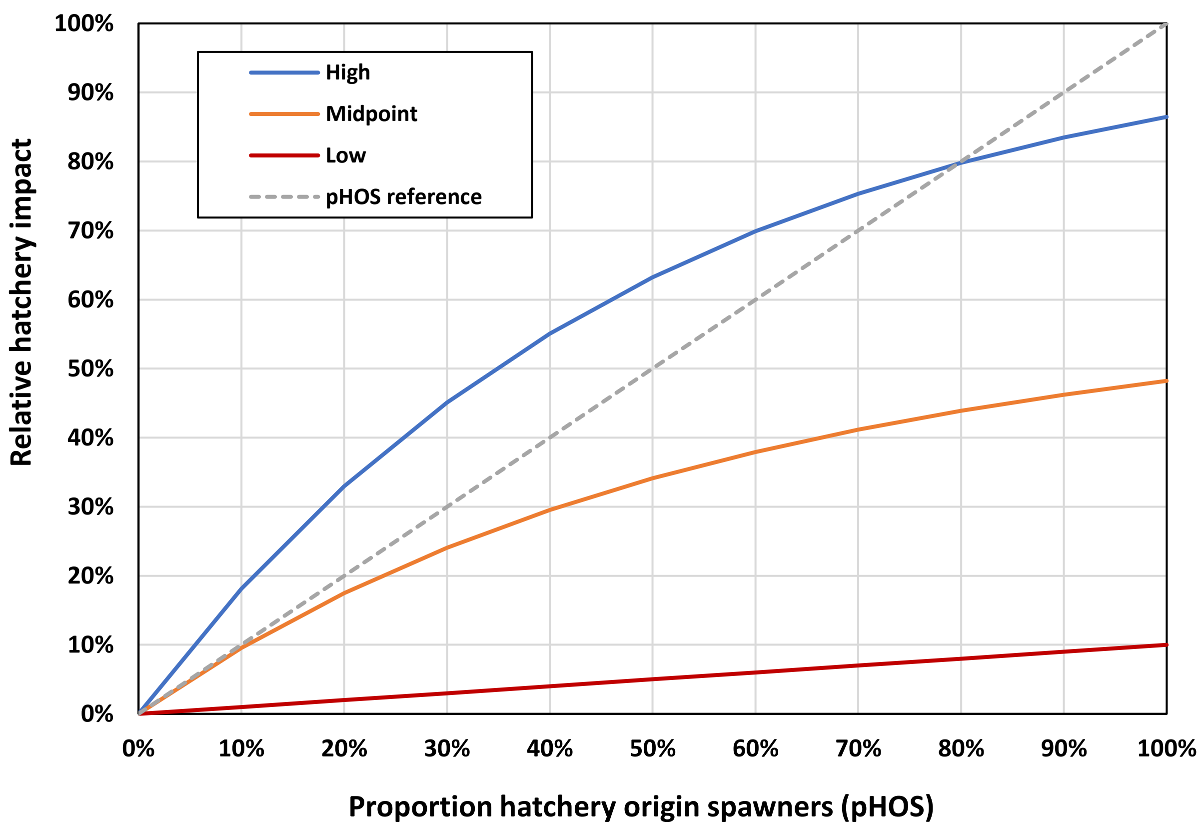

Figure 33. Functional relationships between relative hatchery impacts on natural production and proportion hatchery spawners based on a range of assumptions.

Hatchery Impact Estimates

Observed numbers of hatchery-origin spawners in natural production areas create a potential for low to moderate negative impacts when considered in aggregate of populations for Grays Harbor salmon and steelhead stocks (Figure 34). Wide ranges around point estimates reflect uncertainties regarding the potential magnitude of hatchery effects. Point estimates of impacts for most stocks are typically 15% or less although high range values are close to double the point estimates. Spring and Summer Chinook are not subject to significant hatchery influence. No information is available for Summer Steelhead due to a lack of information on spawner numbers. However, hatchery-origin Summer Steelhead spawners are likely to comprise a substantial percentage of natural spawners due to apparent low numbers of natural spawners and low collection efficiencies of hatchery adults. Impacts vary considerably among populations with substantially greater values in areas where hatchery releases are concentrated (Figure 35, Table 26).

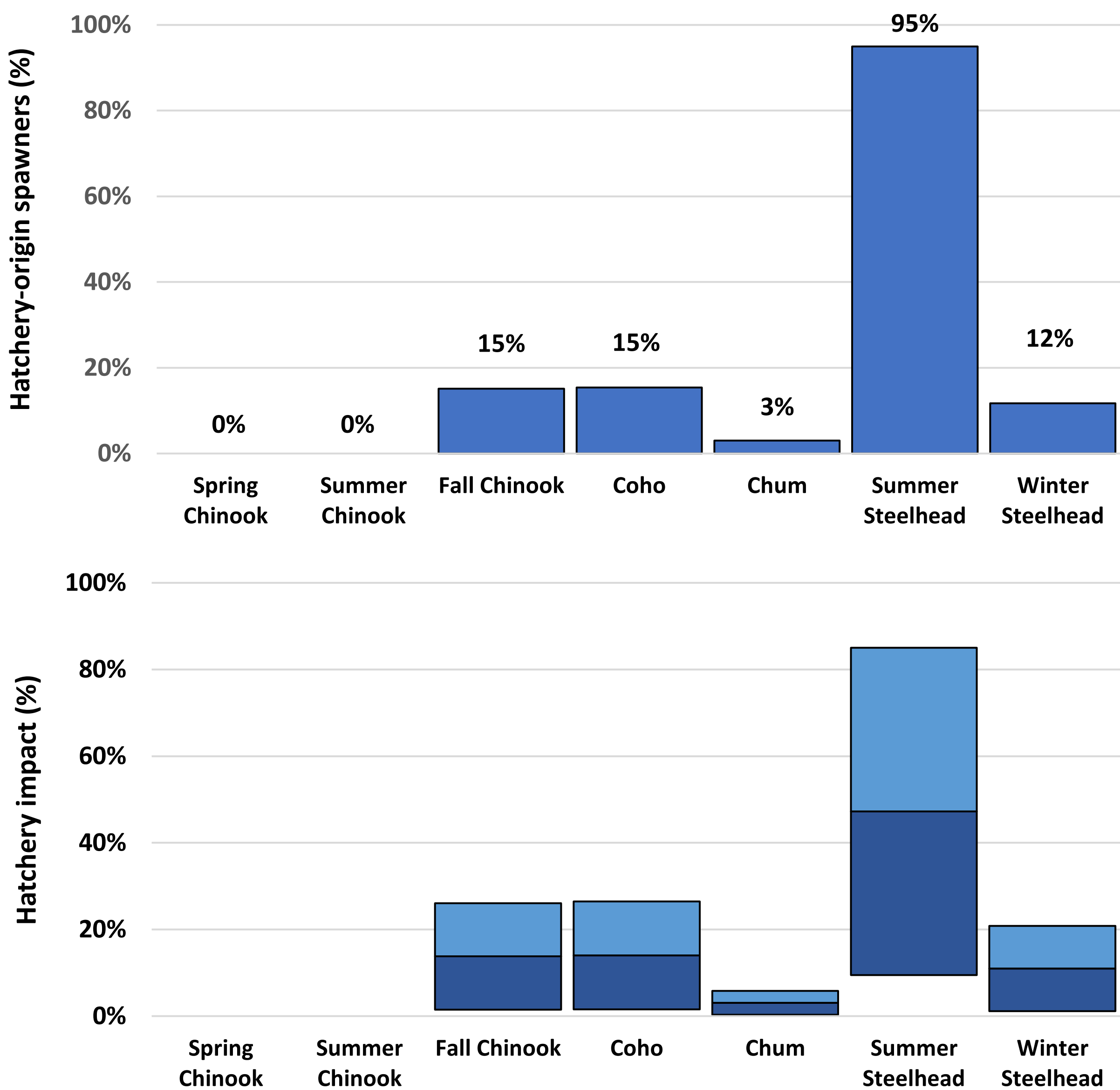

Figure 34. Hatchery-origin spawners by species and run with corresponding hatchery impacts presented as a range reflecting parameter uncertainty.

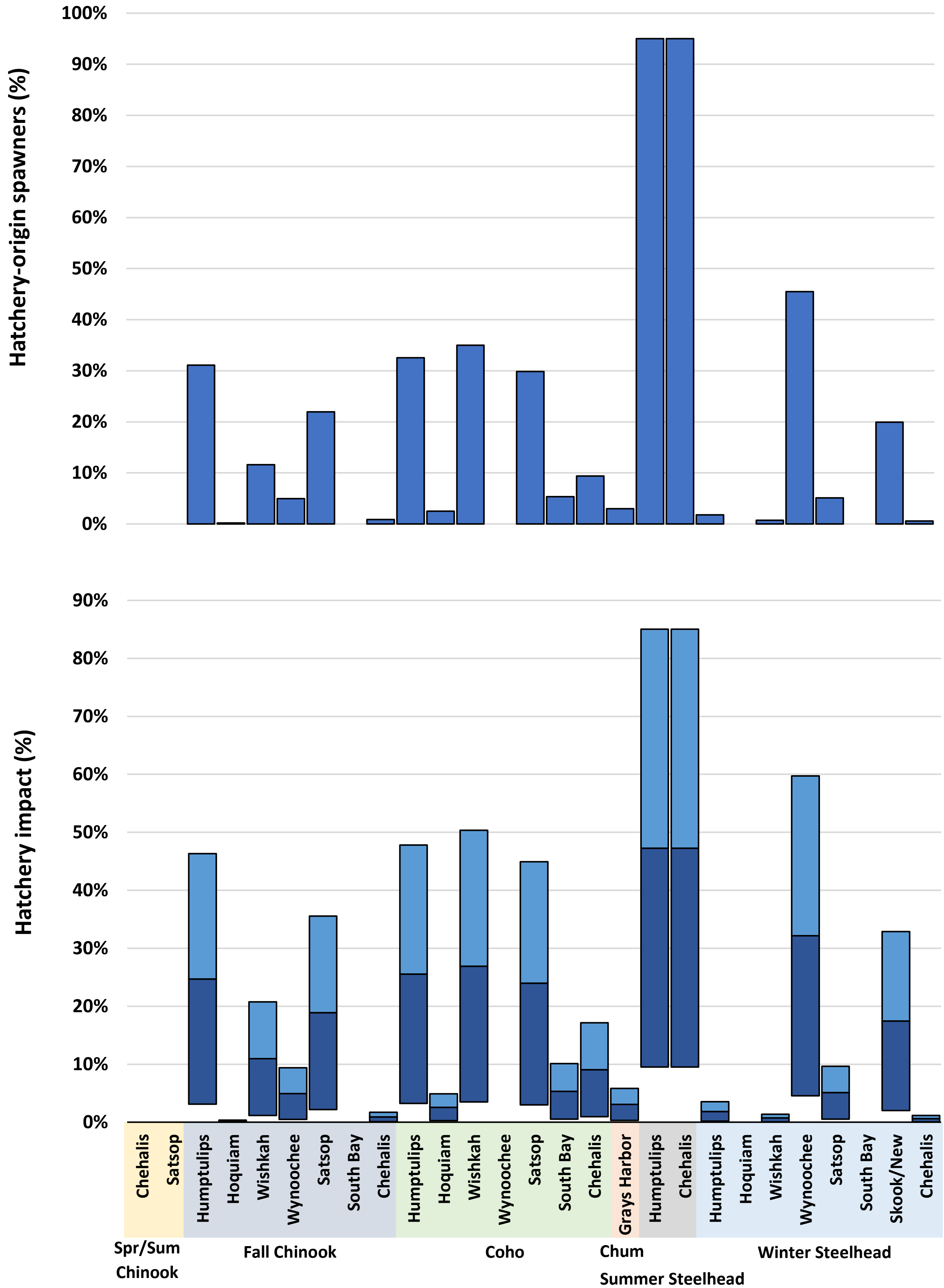

Figure 35. Hatchery-origin spawners and corresponding hatchery impacts presented as range reflecting parameter uncertainty.

Table 26. Hatchery-origin spawners and corresponding hatchery impacts presented as range reflecting parameter uncertainty.

Species/run	Population	% Hat.	Hatchery impact		
			Low[a]	Midpoint	High[b]
Spring Chinook	Chehalis	0%	0%	0%	0%
Summer Chinook	Satsop	0%	0%	0%	0%
Fall Chinook	Humptulips	31%	3%	25%	46%
	Hoquiam	0%	0%	0%	0%
	Wishkah	12%	1%	11%	21%
	Wynoochee	5%	0%	5%	9%
	Satsop	22%	2%	19%	36%
	South Bay				
	Chehalis	1%	0%	1%	2%
	Total	*15%*	*2%*	*14%*	*26%*
Coho	Humptulips	33%	3%	26%	48%
	Hoquiam	3%	0%	3%	5%
	Wishkah	35%	3%	27%	50%
	Wynoochee	0%	0%	0%	0%
	Satsop	30%	3%	24%	45%
	South Bay	5%	1%	5%	10%
	Chehalis	9%	1%	9%	17%
	Total	15%	2%	14%	26%
Chum	Grays Harbor	3%	0%	3%	6%
Summer Steelhead	Humptulips	95%	47%	10%	85%
	Chehalis	95%	47%	10%	85%
Winter Steelhead	Humptulips	2%	0%	2%	4%
	Hoquiam				
	Wishkah	1%	0%	1%	1%
	Wynoochee	45%	5%	32%	60%
	Satsop	5%	1%	5%	10%
	South Bay				
	Skook/New	20%	2%	17%	33%
	Chehalis	1%	0%	1%	1%
	Total	*12%*	*1%*	*11%*	*21%*

[a] *Product of % hatchery-origin spawners and a relative reproductive success of 90% [pHOS * (1-0.9)].*

[b] *Calculated as 1 – exp[-2 (% hatchery-origin spawners)]*

Predation

Impacts are defined as the percentage mortality due to potentially manageable predators including birds, pinnipeds, and introduced fish species. Quantitative information is lacking for predation impacts on Chehalis salmon and steelhead. Therefore, this analysis identified values as a starting point for potential contributions to salmonid restoration. Interpretation should be qualified accordingly.

Background

Although predation is a natural source of mortality on both juvenile and adult salmonids, it has been exacerbated by human activities. This analysis focuses on the portion of predation which might reasonably be quantified or inferred.

Birds – A variety of piscivorous waterbirds including Double-crested Cormorants, Caspian Terns, Hooded Mergansers, and Gulls are common in the Chehalis Basin and Grays Harbor estuary. However, information is lacking on the magnitude of salmonid predation by waterbirds in this system.

Predation rates by piscivorous colonial waterbirds, including terns, cormorants, and gulls, have been quantified in the Columbia River (ISAB 2019; NMFS 2019). Caspian terns eat 1-2% of juvenile Chinook and 9-10% of juvenile steelhead migrating through the Columbia River estuary. Cormorants were estimated to eat an additional 1-5% of Chinook and 5-9% of steelhead migrating through the estuary (NMFS 2019). The degree to which avian mortality in the Columbia River is additive (affecting net survival) or compensatory (offset by other sources of mortality) is a subject of continuing debate (ISRP 2021).

Pinnipeds – Abundance of seals and sea lions has increased considerably along the Pacific northwest coast since the Marine Mammal Protection Act (MMPA) was enacted in 1972 (Carretta et al. 2014); WSAS 2022). Pinnipeds are typically opportunistic predators, feeding on seasonally and locally abundant species of fish and squid, including juvenile and adult salmonids (ISAB 2019). Pinnipeds appear to be effective and significant predators of salmon in all habitats of the state (WSAS 2022). Pinnipeds that use river mouths, estuaries, and upriver habitats are more likely to be specialists in predating on salmon than those that forage in open-ocean habitats. Thomas et al. (2017) reported that harbor seal predation was substantial on both adult and juvenile salmonids in marine waters of the Strait of Georgia, Canada.

Information is limited on the magnitude of pinniped predation in and around Grays Harbor. Within Grays Harbor, harbor seals are numerous with haul-outs located on intertidal mudflats and sandbars (WDE 2020). Smaller numbers of California sea lions may occur within Grays Harbor and their numbers have increased in recent years just outside of Grays Harbor at Westport (WDE 2020).

The WSAS (2022) found that the available evidence is consistent with the hypothesis that pinniped predation is a plausible explanation for reduced abundance of salmon in Washington State waters and lack of salmon recovery following efforts to protect them. However, this evidence does not support a definitive conclusion that pinnipeds are a primary cause of the lack of salmonid population recovery in these ecosystems (WSAS 2022).

One of the few quantitative estimates of pinniped predation rates on salmonids comes from the Columbia River. The weight of scientific evidence indicates that the survival of salmon and steelhead is potentially impacted by pinniped predators in the Columbia River (ISAB 2019). Sorel et al. (2020) estimated that approximately 10-20% of adult upriver Spring Chinook were eaten by seasonal concentrations of California and Steller Sea Lions in the lower Columbia River.

Fish –Predaceous fishes can be a significant source of mortality of juvenile salmonids in Pacific Northwest rivers (ISAB 2019; NMFS 2019). These include a variety of non-native fish species which have been introduced to the Chehalis River and other habitats within the Chehalis Basin (WDE 2020). Introduced species are most common in the warmer reaches and slow-moving off-channel habitat of the lower and middle Chehalis River (Henning et al. 2007; Hayes et al. 2015, 2016, 2019). Predators including largemouth bass, smallmouth bass, and yellow perch are found in at least 40% of the mainstem Chehalis River (Hughes and Herlihy 2012). In the mainstem Chehalis River, the non-native bass and sunfish distribution extends as far upstream as Rainbow Falls (Winkowski et al. 2018).

Northern pikeminnow is a predaceous native species which is also widely distributed in the lower and middle Chehalis mainstem. Northern pikeminnow were estimated to consume about seven percent of hatchery smolts and less than one percent of wild smolts in the Chehalis River (Schroder and Fresh 1992). This observation is consistent with a review of pikeminnow predation by Brown & Moyle (1981) who found that this species does not appear to be significant predators of salmon and trout ins streams except under highly localized, seasonal or unusual circumstances such as hatchery release sites and highly-altered habitats. In the mainstem of the Columbia and Snake Rivers, the altered habitats in project reservoirs reduce smolt migration rates, create more favorable habitat conditions for fish predators, and enhance conditions for predation in reservoirs and tailraces. Research during the 1980s and early 1990s estimated that pikeminnow eat about 8% juvenile salmonids migrating downstream of which half occurred in the 140 miles between the estuary and Bonneville Dam (Beamesderfer et al. 1996).

The magnitude of predation on salmonids by largemouth and smallmouth bass in the Chehalis basin is unclear. In Columbia River studies, salmonids comprised just 20% of the diet of smallmouth bass (Poe et al. 1991) and accounted for 9% of the total loss to piscivorous fish (Rieman et al. 1991). However, predation rates can be greater areas of smallmouth bass concentration like the lower Yakima River (Fritts and Pearsons 2008). Predation by bass on salmonids appears to be exacerbated by warm temperatures which favor nonnative species (Hughes & Herlihy 2012). As a result, bass predation may be best addressed by habitat protection and restoration activities which favor colder water temperatures (ISAB 2019).

Estimation

Estimates of predation rates on Chehalis salmon and steelhead are lacking. One of the few available attempts to quantify predation comes from the Columbia where the combined impact of Pikeminnow, predaceous waterbirds and Sea Lions in the Columbia River to range from approximately 2% to 50% for different salmon and steelhead species CBPTF (2020). The lowest estimates were for Chum Salmon and the highest for Steelhead. The Columbia River is obviously a much different system than the Chehalis and so it is difficult to make inferences among the respective systems.

For the purposes of the Chehalis analysis, we identified a 20% predation mortality for all salmon and steelhead species as a potential scope for improvement based on a review of information in other systems. Predation impacts are likely to vary among salmon and steelhead species based on life history. For instance, anecdotal observations indicate that smallmouth bass predation on subyearling Chinook are higher during the outmigration period (April through June) than on other species like steelhead. However, spring migrants, particularly including steelhead, are also subject to high rates of predation by pinnipeds and birds in the Columbia River estuary. Lacking a clear basis for distinguishing species differences, this analysis simply applied the same rate assumption to all salmon and steelhead species.

This value was identified to facilitate consideration of the potential benefits of predator management. While this value is scaled to reflect our limited understanding of an order-of-magnitude of the potential for managing predation, it should not be considered an estimate of the net impact of avian, pinniped and fish predation on abundance of Chehalis salmon and steelhead.

Future Conditions

For the purposes of this analysis, impacts of assumed future conditions are defined as the percentage reduction in productivity due to declines in freshwater productivity resulting from assumptions for climate change and future development. Effects of climate change on ocean survival were not included in our analysis due to their uncertain nature.

Background

Future conditions in the Chehalis Basin will likely be affected by a range of factors, including climate change, human population growth, land use, and resource needs—all of which will exacerbate current problems and continue to contribute to an uncertain future for aquatic species (ASRPSC 2019). Future climate change is projected to affect temperature, precipitation, and other factors that will further degrade habitat conditions and reduce the abundance of native aquatic species (ASRPSC 2019). Future development driven by human population growth and future land use changes is projected to reduce forested land cover, increase fine sediment, increase streambed scour, and reduce riparian cover, thereby affecting stream temperature and other relevant habitat attributes (ASRPSC 2019).

Estimation Methods

Impacts of potential future conditions are based on values reported in ASRPSC (2019). Climate change parameters were integrated into the models used for the ASRP to project well-informed future baseline conditions. These models also anticipated habitat degradation resulting from changes in land cover as a result of future development. Projected habitat changes were used in the EDT model to represent the degree to which habitat changes could be expected to degrade habitat potential for salmon and steelhead (ASRPSC 2019). These projected changes as a result of future climate conditions and future land use were incorporated into the No Action scenario in the EDT model to project future changes to salmonid populations.

Impact Estimates

Impacts vary among species depending on habitat usage and requirements (Figure 36).

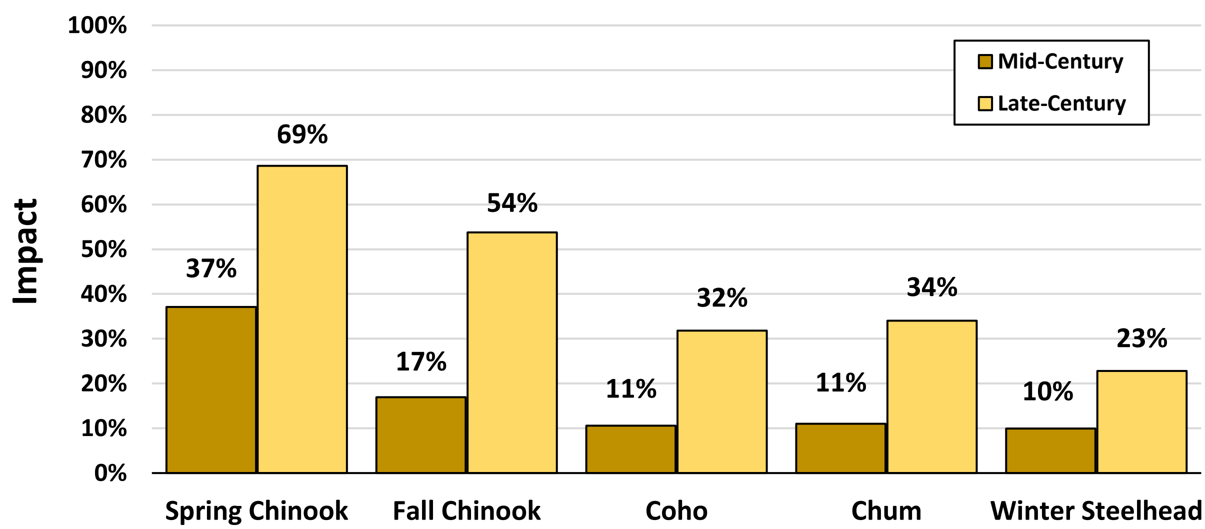

Figure 36. Projected changes in salmon and steelhead populations as a result of future climate conditions and future land use were incorporated into a No Action scenario in the EDT model (ASRPSC 2019). Values are based on the latest EDT results as reflected in WDE (2020) and may differ insignificantly from numbers reported in ASRPSC (2019).

Impacts Summary

Estimates of impacts are summarized for each stock in Figure 37 and Table 27. Freshwater habitat impacts are substantial for all species. Impacts of other factors are generally less than freshwater habitat impacts but are generally comparable when considered in aggregate (Figure 38).

Population	Freshwater Habitat	Estuary Habitat	Dams	Fishery	Hatchery	Predation
Spring Chinook	82%	24%	26%	13%	0%	20%
Summer Chinook	64%	24%	0%	na	0%	20%
Fall Chinook	64%	17%	2%	59%	14%	20%
Coho	79%	17%	9%	35%	14%	20%
Chum	35%	17%	0%	32%	3%	20%
Summer Steelhead	58%	17%	0%	8%	47%	20%
Winter Steelhead	58%	17%	16%	11%	11%	20%

<5%	5-20%	21-30%	31-50%	>50%

Figure 37. Heat map of impacts of limiting factors for Chehalis salmon and steelhead.

Table 27. Estimates of impacts for limiting factors by stock and population including ranges reflecting uncertainties, where appropriate. Units are percentage reductions in equilibrium abundance (generally equivalent to mortality rates).

Stock	Population	Freshwtr Habitat	Estuary Habitat	Dams	Pre-dation	Fishery	Hatchery
Chinook (spring)	Aggregate	82	24	26	20	13	0
	Chehalis	82	24	26	20	13	0
Chinook (summer)	Aggregate	64	24	0	20	59	0
	Satsop	na	24	0	20	59	0
Chinook (fall)	Aggregate	64	17	2	20	59	14
	Chehalis	80	24	6	20	59	1
	Hoquiam	66	40	0	20	59	0
	Humptulips	66	0	0	20	59	25
	Satsop	73	24	0	20	59	19
	South Bay	64	9	0	20	59	
	Wishkah	66	18	0	20	59	11
	Wynoochee	73	24	0	20	59	5
Coho	Aggregate	79	17	9	20	35	14
	Chehalis	60	24	18	20	35	9
	Hoquiam	69	40	0	20	35	3
	Humptulips	69	0	0	20	35	26
	Satsop	73	24	0	20	35	24
	South Bay	79	9	0	20	35	5
	Wishkah	69	18	0	20	35	27
	Wynoochee	73	24	17	20	35	0
Chum	Aggregate	35	17	0	20	32	3
	Grays Harbor	35	17	0	20	32	3
Steelhead (summer)	Aggregate	58	17	0	20	8	47
	Chehalis	75	24	0	20	8	47
	Humptulips	na	0	0	20	8	47
Steelhead (winter)	Aggregate	58	17	16	20	11	11
	Chehalis	75	24	0	20	11	1
	Hoquiam	64	40	0	20	11	
	Humptulips	64	0	0	20	11	2
	Satsop	68	24	0	20	11	5
	Skookumchuck/Newaukum	77	24	21	20	11	17
	South Bay	58	9	0	20	11	
	Wishkah	64	18	0	20	11	1
	Wynoochee	68	24	53	20	11	32

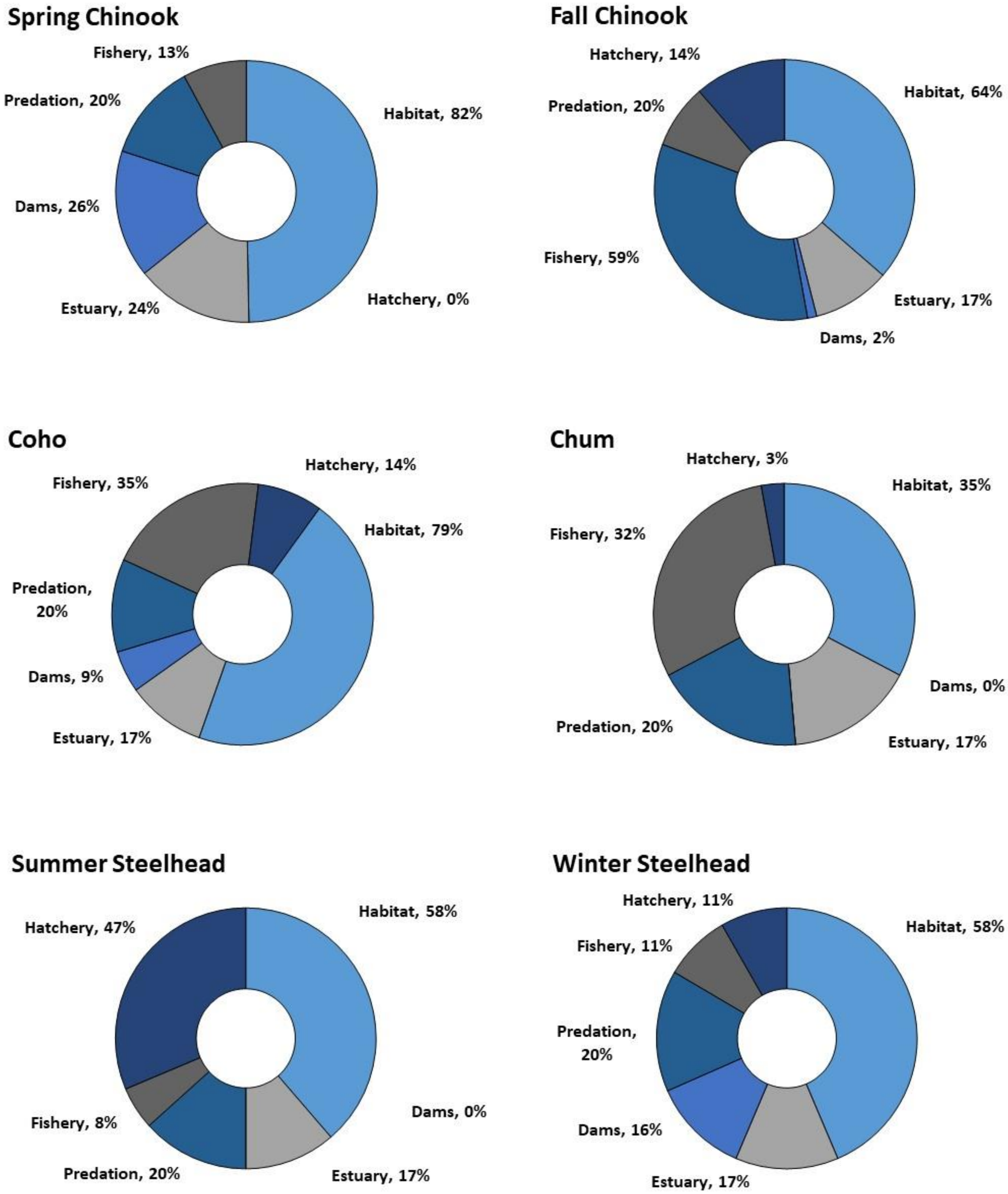

Figure 38. Estimates of impacts for limiting factors by stock. Impacts are displayed in pay charts to illustrate the relative magnitude in relation to each other. Percentages are independent estimates of the reductions associated with each impact. Percentages are not calculated relative to the total impact, thus, do not add up to 100%.

LIFE CYCLE ANALYSES

Life cycle analyses examine the effects of changes in limiting factors on adult abundance. Sensitivity analyses generally examine the effects of changes in individual factors. Scenario analyses generally examine the effects of combinations of changes in factors.

Salmon Analyzer Model Description

The Salmon Analyzer is a simple life-cycle model adapted to facilitate exploration of broad hypotheses and coarse-scale strategies for increasing salmon and steelhead abundance. The model relates fish numbers to factors that impact productivity or survival at various stages in the salmon life cycle. Quantifying these relationships allows us to calculate likely changes in fish abundance in response to increases or decreases in any given impact or combinations of changes in impacts.

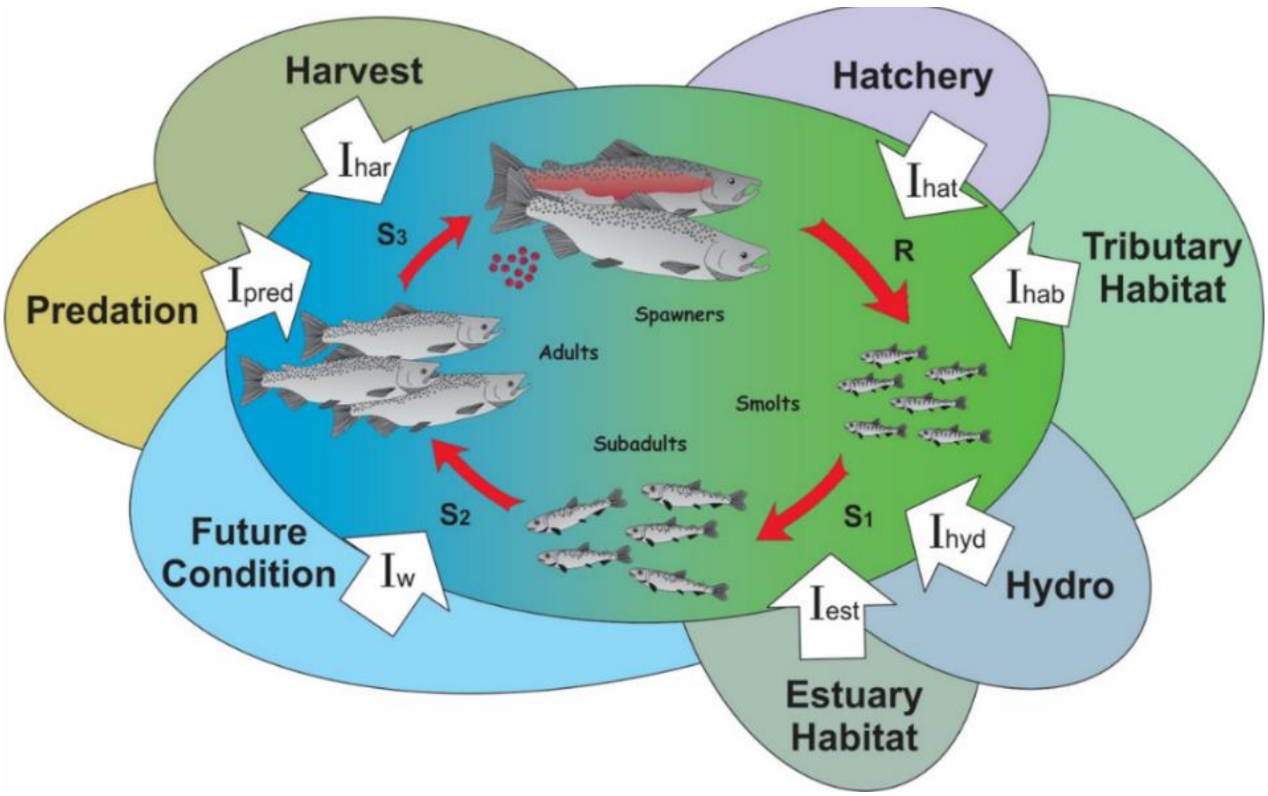

Figure 39. Conceptual depiction of Salmon Analyzer formulation in relation to impacts (I) of factors affecting productivity or survival at stages in the salmon life cycle.

The Salmon Analyzer is a heuristic model, meaning that its appropriate and intended application is as a tool for interactive learning and hypothesis exploration. The Salmon Analyzer is not designed to evaluate specific actions, management decisions, or resource allocations but rather to suggest general approaches (strategies) that then need finer-scale analyses to transition into management actions. This model is robust in this application by virtue of its simplicity and transparency. The model captures a large portion of the dynamics of interest and can be broadly applied across many species and stocks where a lack of empirical life history data does not permit finer-scale analysis.

The Salmon Analyzer is an equilibrium modeling approach that generally identifies "average" conditions corresponding to the net effect of a combination of inputs. This approach is adapted from a model originally developed for the lower Columbia River salmon and steelhead ESA recovery plan. The core concept of this modeling approach is that equilibrium or average salmon abundance measured on the spawning grounds can be directly and proportionally related to changes in limiting factors. For example, doubling the quantity or quality of fish habitat, all other things being equal, can be expected to double average adult abundance. Increasing fishing mortality rates by 10 percent, decreases average adult abundance on average by 10 percent.

The basic model formulation is:

$$\bar{A} = \bar{A}' \, [(1 - I_1)\,(1 - I_2) \ldots \; (1 - I_x)]$$

Where, $\bar{A}$ = current average (equilibrium) abundance.

$\bar{A}'$ = historical average (equilibrium) abundance that would have occurred in the absence of human-related or potentially-manageable impacts.

I_x = potentially-manageable impacts for factor x.

The model is algebraically derived from the conventional stage-specific stock-recruitment function in wide use for life-cycle modeling of salmon (Figure 40).

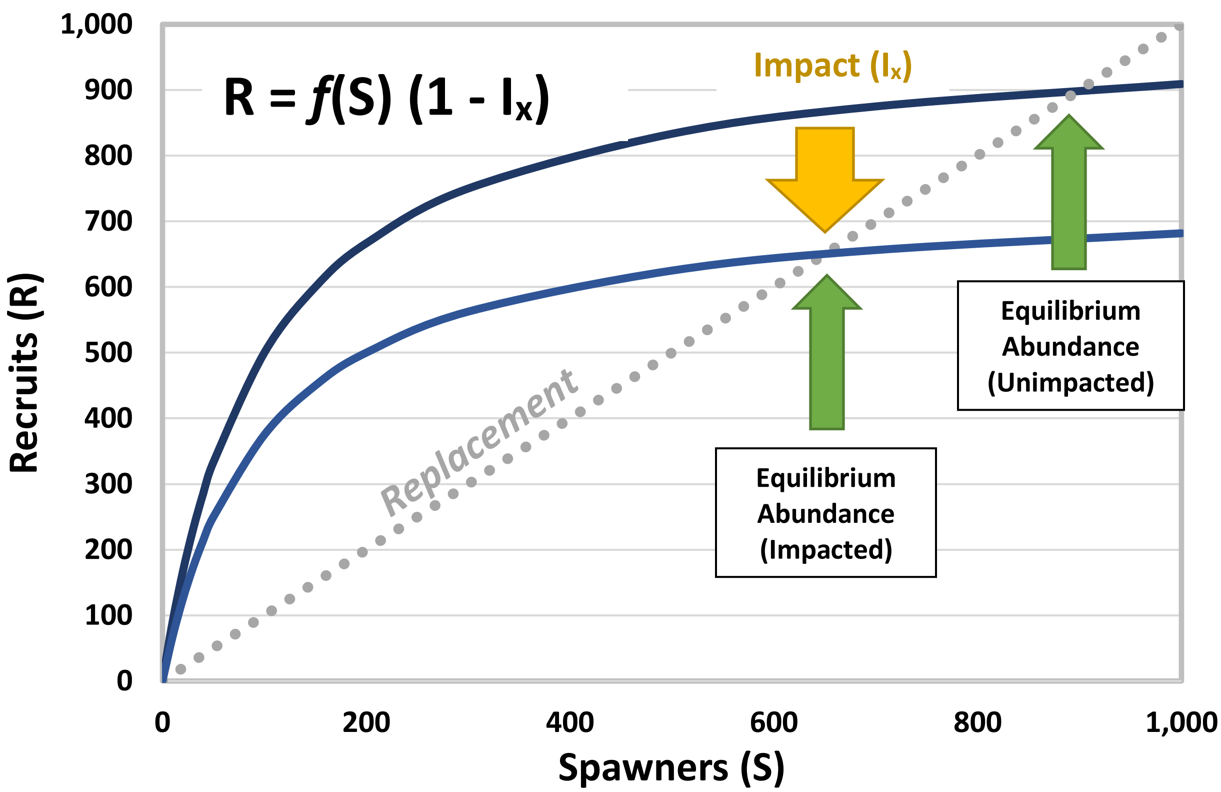

Figure 40. Graphical depiction of stage-specific salmon stock-recruitment function employed in the life-cycle analysis.

Analysis inputs include:

1. Estimates of current average abundance of natural origin spawners for salmon and steelhead stocks and/or populations.
2. Current impact estimates of potentially-manageable factors. These are the same impacts described above for the limiting factors analysis (tributary habitat, estuary habitat, dams, predation, fishery, hatchery, assumed future conditions).

3. Changes in impacts of potentially manageable factors (user option).
4. Low, medium and high range escapement goals for natural-origin spawners of a stock, which are input for reference purposes.
5. Percentage of hatchery-origin spawners, which is also input for reference purposes so that the analysis can calculate both natural-origin and hatchery-origin abundance. Contributions of hatchery programs are reflected in the change in total number of spawners on the spawning grounds.

Analysis outputs include:

1. Equilibrium abundance of natural-origin spawners produced by changes in impacts of potentially-manageable factors.
2. Number of hatchery-origin spawners and percentage of total spawners comprised of hatchery-origin spawners (pHOS) resulting from changes in impacts of potentially-manageable factors.[5]

The model is operated through an interface designed to facilitate analysis. The Salmon Analyzer is constructed in MS Excel with macros constructed in Visual Basic to automate certain applications. Impact assumptions may be increased or decreased relative to current reference values to examine incremental and aggregate effects on abundance.

All life-cycle models are necessarily abstractions of complex natural systems. The Salmon Analyzer employs a number of features or assumptions to provide broad and consistent applicability to all salmon and steelhead stocks throughout the region. These include:

- Impacts are assumed to act independently at various stages of the life cycle and produce additive rather than compensatory effects. This assumption is generally robust because density-dependent processes are typically concentrated in the freshwater rearing stage of the salmon life cycle. If out-of-subbasin impacts are strongly density-dependent, the model would underestimate the net benefits of interacting factors.
- Impacts are included where values can be reasonably quantified or assumed based on scientific information. Where impacts are uncertain, a range of values are identified reflecting those uncertainties. Quantitative information is lacking for a number of factors such as toxic contaminants and marine-derived nutrients.
- Analyses include no determination regarding the feasibility and cost of any given impact reduction.
- Statistical confidence intervals are not quantified directly based on explicit estimates of parameter uncertainty. Where impacts are particularly uncertain, estimates are presented as ranges.
- The analysis does not explicitly incorporate a time component. Results are intended to represent equilibrium values produced by combinations of changes in impacts.

Additional details on model derivation and validation may be found in Appendix C of CBPTF (2020).[6]

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[5] *Percentages of hatchery-origin spawners decrease in response to reductions in tributary habitat impacts which increase numbers of naturally-produced fish. Reductions in hatchery impacts reduce both numbers and percentage of hatchery-origin adults*

[6] *https://s3.amazonaws.com/media.fisheries.noaa.gov/2020-10/MAFAC_CBP_Phase2_Appendix-C_BiologicalAnalysis_Final_20200829_508.pdf?null*

Salmon Analyzer User Guide

The Salmon Analyzer is constructed in MS Excel with macros constructed in Visual Basic to automate certain applications. The model will run in Excel when macros are enabled. Search help for instructions to enable macros in your version of excel. For instance, <File><Options><Trust Center><Trust Center Setting><Enable all macros>.

The model is operated through an interface designed to facilitate analysis. Model inputs and work are also contained in spreadsheet tabs which are accessible to users interested in the underlying structure and calculations. The model also includes macros in VisualBasic code which automate a number of functions for user convenience. Elements of the user interface are numbered in Figure 41 to match descriptions in the list below.

1. Species and populations may be selected from drop-down lists. Populations may be individual or treated in aggregate for all populations of a species.
2. Projected abundance under a scenario is shown in both graphical and tabular form relative to low, medium-, and high-range benchmarks. Low range benchmarks are based on spawning escapement goals identified by fishery managers. Medium and high range goals were arbitrarily selected for the purposes of this exercise as 150% and 200% of low range values, respectively. Values in this table are automated and should not be overtyped.
3. Numbers of hatchery-origin fish contributing to natural production. Inferred from current hatchery percentages and projected effects of future changes in natural and hatchery fish based on changes in impacts. Numbers of hatchery fish are also shown on the bar graph. Values in this table are automated and should not be overtyped.

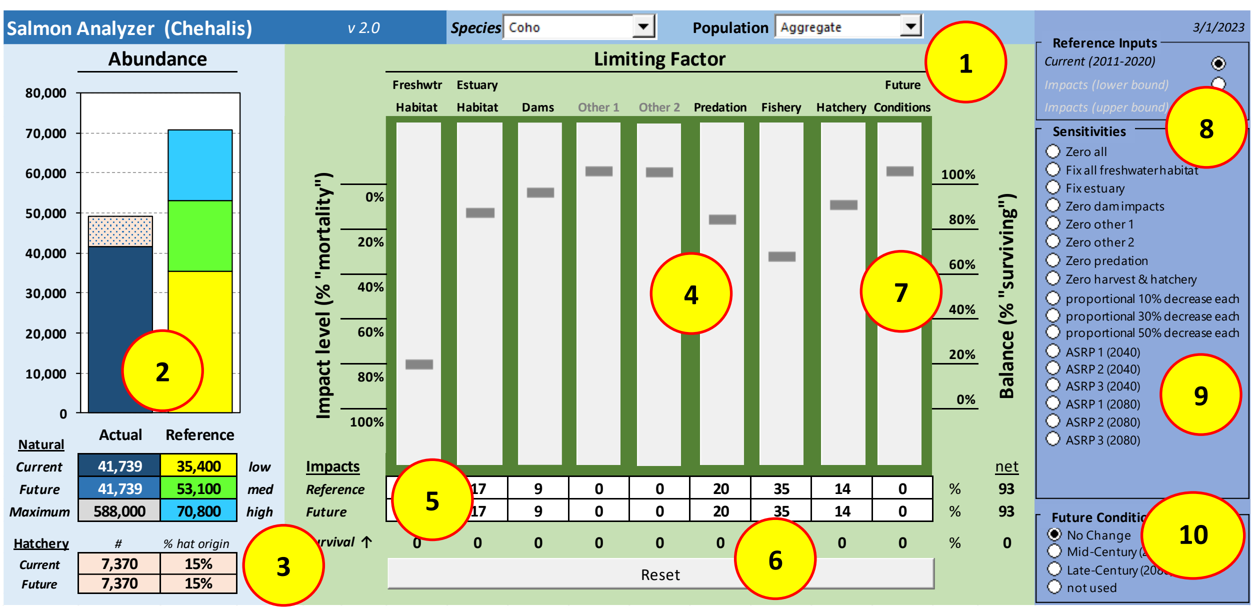

Figure 41. Salmon Analyzer Model Interface.

4. Slider bars are parameterized for each stock with preliminary values meant to depict current conditions. Users may manipulate slider bars to decrease (move slider up) or increase (move slider down) impacts relative to current values. Each bar corresponds to one factor. This version of the model includes two slider (other 1 and other 2) which are not assigned to a factor for the Chehalis version of the model. The sliders work so this provides a user option to explicitly consider other factors if desired.
5. Numerical values (in terms of percent impact) for current and future impacts are depicted in a table below the slider bars. The top row displays the current impact (or reference value) for the subject – these are automatically set when the species/population is selected. The second row shows new values relative to the reference values – users can change these by moving the slider bars or by overtyping the numerical values. Note that the current reference values may also be changed by overtyping if one wishes to explore alternative assumptions for reference conditions. The third row shows the change in terms of percentage improvement as opposed to reduction in impact – one is just the flip side of the other.
6. The reset button restores current and future impact values to the defaults identified for each stock.
7. Scales to the left and right of the slider bars show impact levels (left) and corresponding balances surviving (right). The model is parameterized with impacts but the balance is also displayed for context. They are directly related as balance is simply (1 – impact).
8. Pre-set alternatives may be selected by clicking option buttons to the right. This is a handy option for quicky running model sensitivity or scenario analyses. Options contained in a box are mutually exclusive. That is to say, only one option within a box can be selected. If combinations of changes are desired, they can be modeled by selecting different values in different boxes, changing slider bars or changing values in the white cells of tables under the slider bars.
9. Zero options show the sensitivity of changes in one or more impacts to zero (this effectively represents restoration of pre-development conditions). Proportional reductions are examples of scenarios where reductions in impacts are shared across factors in proportion to the relative magnitude of each impact (x% of a big number is larger than X% of a small number). ASRP options are reflect scenarios for habitat restoration identified in the 2019 Aquatic Species Restoration Plan.
10. “Future conditions” automates an aggregate level of potential impact due to climate, future population growth or other long-term threats. Corresponding low, medium, and high values are based on values identified in the 2019 Aquatic Species Restoration Plan.

Sensitivity Analysis

Sensitivity analyses were used to explore system dynamics and the potential range of response to various changes in quantitative impacts to one or more limiting factors. Analyses examined isolated effects of:

1) reducing impacts of each individual factor to zero;
2) reducing impacts of all individual factors to zero;
3) reducing habitat impacts proportional to incremental improvements identified in ASRPSC (2019);
4) increasing climate change impacts identified in ASRPSC (2019); and
5) proportional reductions in impacts of all factors (e.g., 10 percent, 30 percent, 50 percent).

Reducing any impact to zero is unrealistic in most cases but does identify the scope for potential improvement that might be gained by addressing any given limiting factor. For instance, reducing habitat impacts to zero would involve restoring pristine, pre-development conditions. These sensitivity analyses illustrate the limits of potential improvements which might be gained from any given factor. The actual scope for improvement will depend on the feasibility, costs and willingness to produce any given level of impact reduction within the scope of the potential range.

Reducing all impacts to zero is similarly unrealistic but does provide a test of consistency between impact estimates and estimates of historical abundance. This result places a theoretical upper bound on the production potential of a stock or population. If all impacts could be estimated accurately, this value might represent a pre-development historical abundance.

Incremental improvements associated with freshwater habitat improvement scenarios identified in the Aquatic Species Restoration Plan (ASRPSC 2019) are also included in this analysis as a point of reference. These include mid-century (~2040) and late century (~2080) under three restoration scenarios representing incrementally greater levels of ambition. These improvements are taken directly from the ASRP except they are presented in our sensitivity analysis independent of the effects of climate change which are treated separately. In integrated scenario analyses with the Salmon Slider documented later in this report, habitat and climate change effects are mixed and matched in combination with changes in other factors to explore a more comprehensive range of potential changes.

Proportional reductions illustrate the sensitivity in response to reducing multiple impacts by a given amount. These examples reduce impacts in proportion to their relative magnitude. Thus, a 50% reduction in a 50% impact produces an impact of 25%. A 50% reduction in a 10% impact produces an impact of 5%. These are an illustration of the effects of sharing impact reductions "evenly" across impacts but are provided merely as examples and are not meant to imply any type of judgement on the relative values or implications of reductions in any given impact.

Results of sensitivity analyses are summarized for each stock in Figure 42 through Figure 46. Substantial declines in abundance of all species are associated with climate change assumptions included in ASRP scenarios. Improvements resulting from zeroing impacts of individual factors are proportional to the scale of each impact. Thus, the greatest scope for improvement is generally associated with zeroing habitat impacts. Other factors produce smaller incremental improvements. ASRP habitat scenarios are associated with substantial improvements in fish abundance up to approximately half of the historical production potential. Proportional reduction in impacts across multiple factors appear to have the potential of achieving substantial improvements in fish abundance.

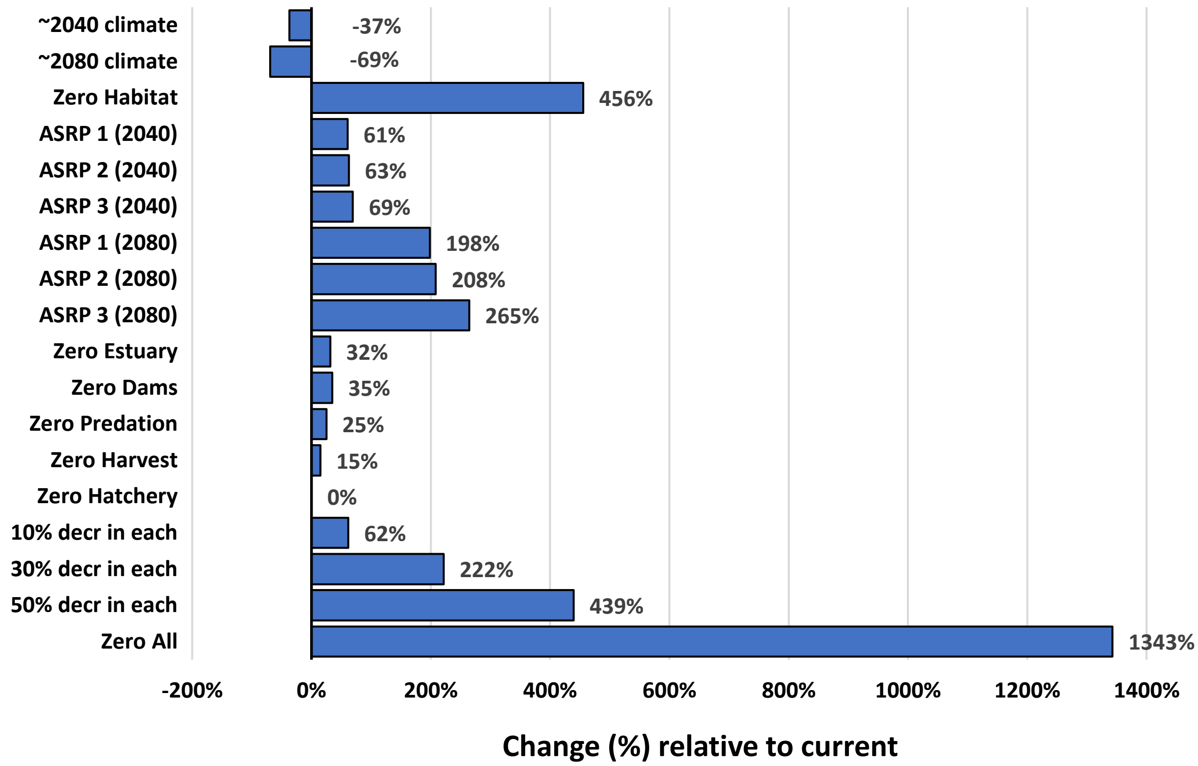

Figure 42. **Sensitivity of Spring Chinook abundance to changes in various factor impacts relative to current average levels.**

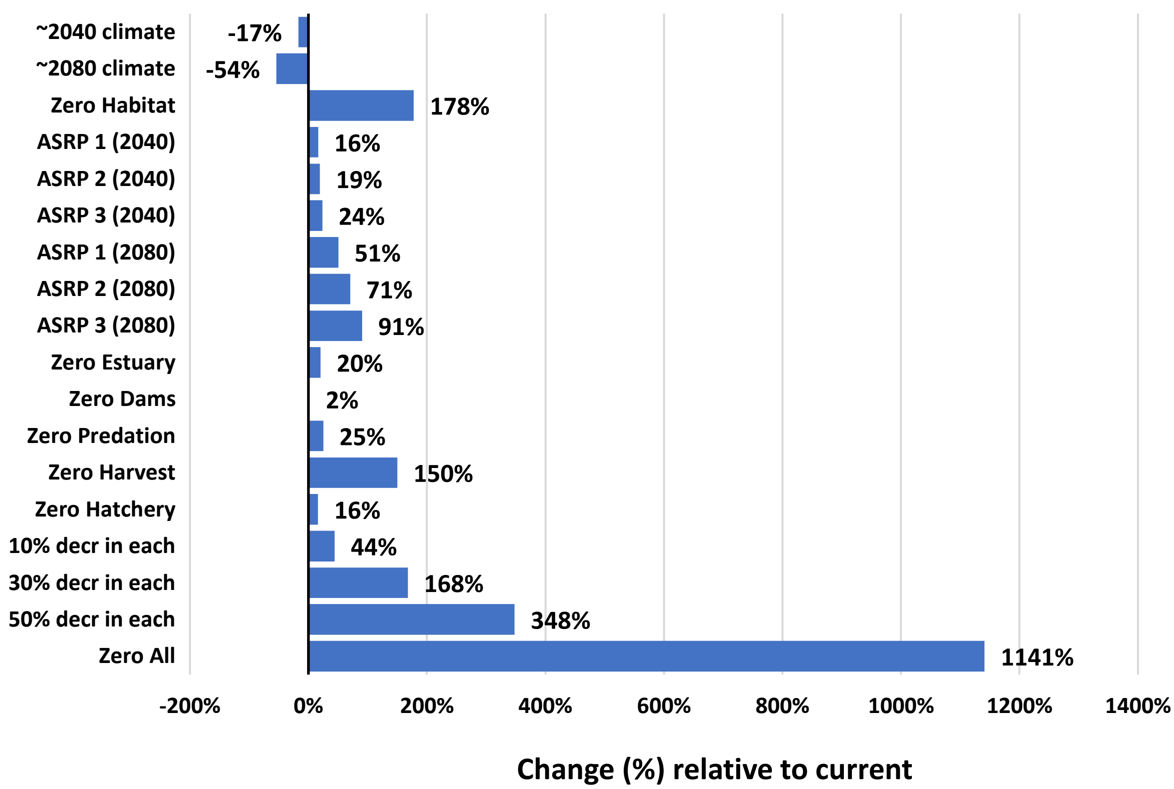

Figure 43. **Sensitivity of Fall Chinook abundance to changes in various factor impacts relative to current average levels.**

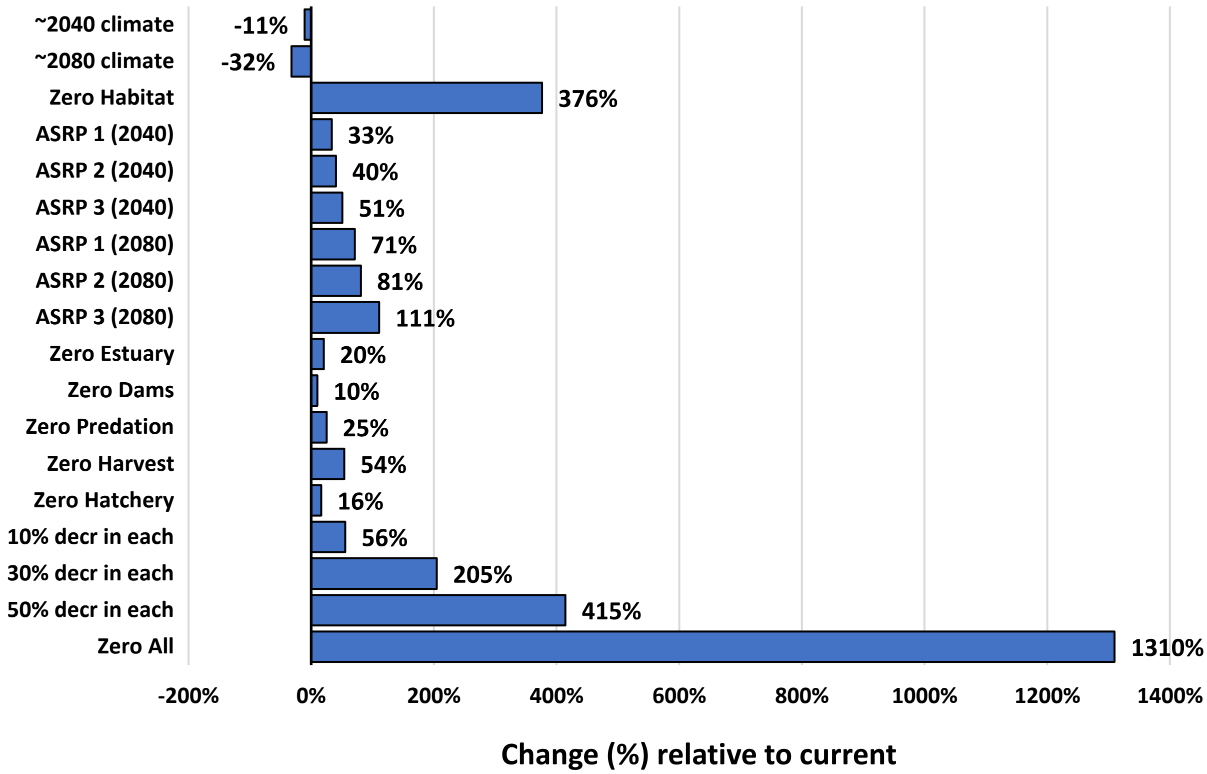

Figure 44. Sensitivity of Coho abundance to changes in various factor impacts relative to current average levels.

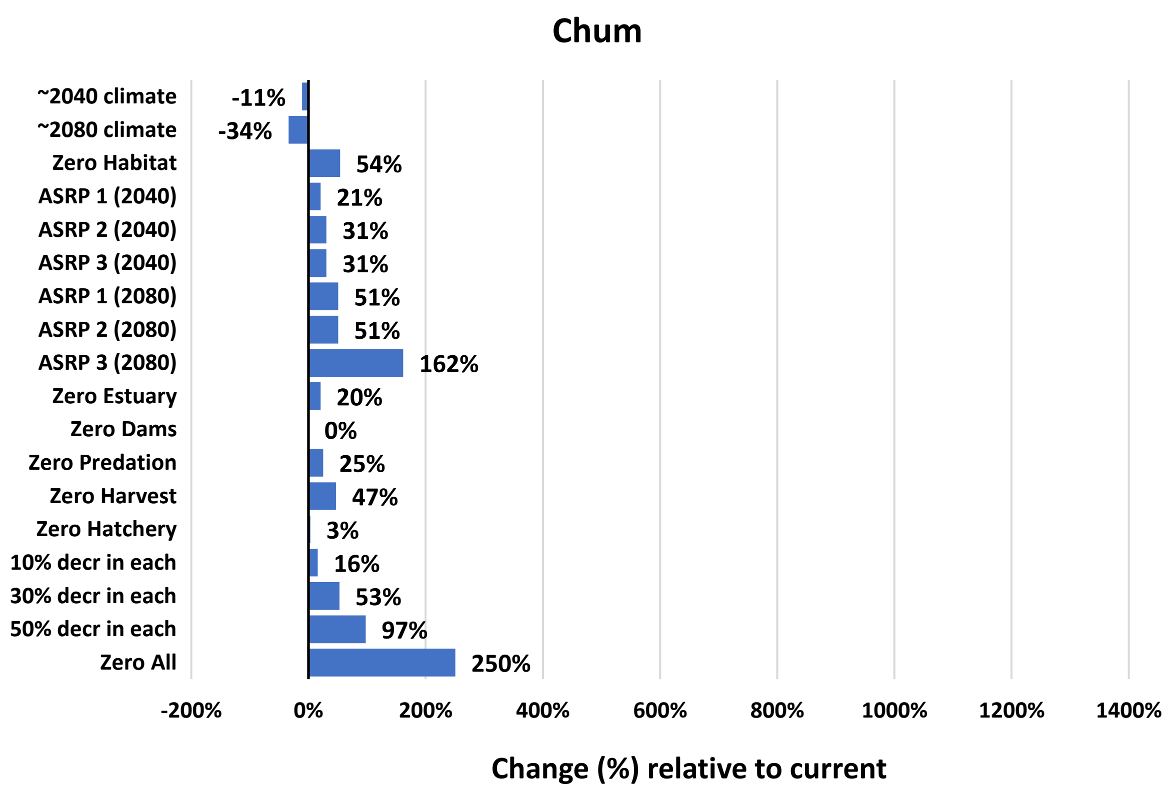

Figure 45. Sensitivity of Chum abundance to changes in various factor impacts relative to current average levels.

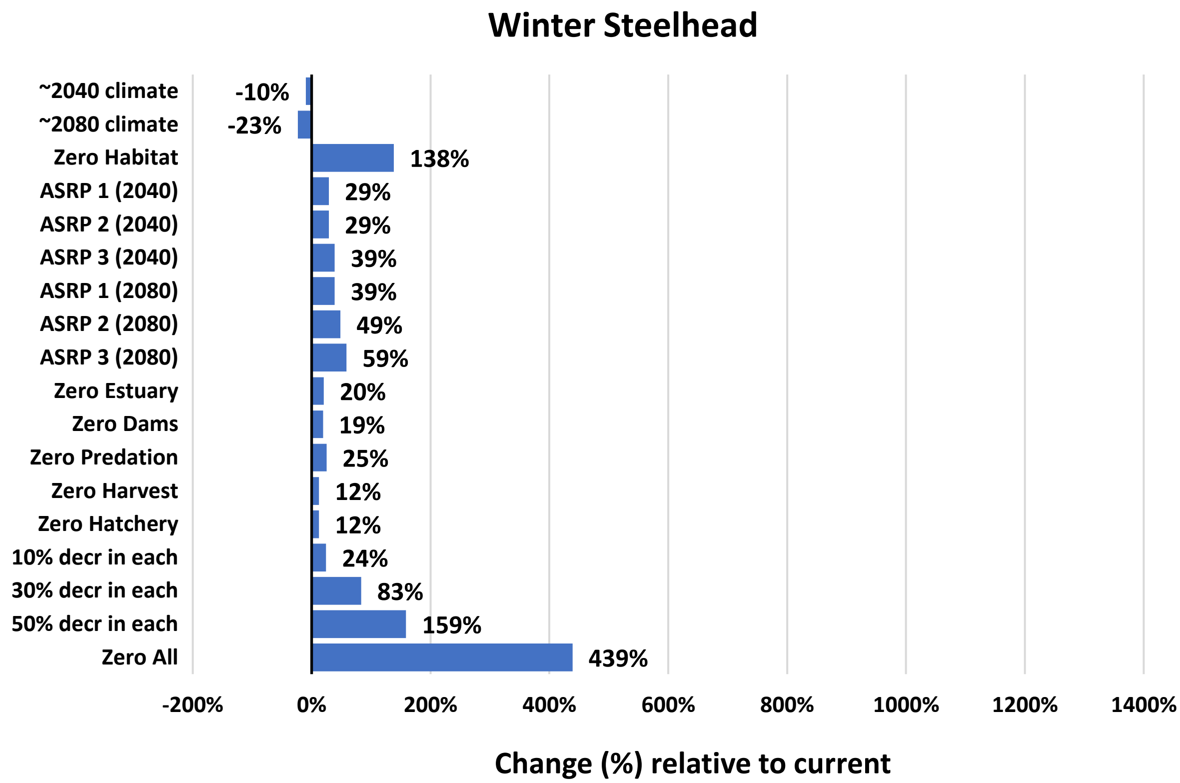

Figure 46. Sensitivity of Winter Steelhead abundance to changes in various factor impacts relative to current average levels.

Scenario Analysis

Scenarios examined the effects of combinations of changes in factor impacts on modeled abundance of Chehalis salmon and steelhead (Table 28). Analyses were completed for each species and run. These scenarios are presented for illustration purposes and make no assumptions regarding the feasibility of any given level of impact reduction and corresponding improvement.

Scenarios in the integrated analysis build on habitat restoration scenarios identified in the Aquatic Species Restoration Plan (ASRPSC 2019). The ASRP identified three habitat scenarios involving progressively greater levels of improvement (identified in the model as a reduction in impact relative to the current condition). The ASRP scenarios included projections to mid-century (~2040) and late-century (~2080) as well as assumptions for the negative impact of climate change on freshwater productivity. The ASRP scenarios were recreated in the integrated analysis as a point of reference for additional scenarios involving other factors. In Table 28, the ASRP scenarios are labeled as 1a, 2a, and 3a for the mid-century projection and 1c, 2c and 3c for the late-century projection. The scale of habitat improvement and climate decline in these scenarios correspond to values identified in the ASRP.

Scenarios also modeled the combined effects of ASRP habitat improvements and reductions in other impacts. Small, medium and large reductions were identified to correspond to small, medium and large habitat improvements described by ASRP habitat scenarios (Table 28). In Table 28, the combined scenarios are labeled as 1b, 2b, and 3b for the mid-century ASRP projection and 1d, 2d and 3d for the late-century ASRP projection. The combined scenarios use the same climate change assumptions identified in the ASRP. In general, small, medium and large reductions in other impacts were assumed to be relative 10%, 25% and 50% reduction in current impact levels. For instance, a 10% reduction in a 30% impact would result in a 27% impact which would correspond to a net 4% improvement.

Combined scenarios have to potential to produce substantially greater improvements in fish numbers than corresponding habitat restoration scenarios alone (Figure 47). This pattern is consistent across fish stocks but numbers vary depending on the specific limitations of each stock. Scenarios generally suggest that modest improvements in fish numbers in the range of 20-50% would require significant reductions in impacts across multiple factors. Scenarios also suggest that doubling fish numbers would require relatively large reductions in impacts across multiple factors.

Scenarios showing declines in fish numbers relative to the current state are the result of climate change assumptions which exceed the net improvements in the corresponding scenarios. Improvements will be required to avoid further declines due to climate effects. Substantial climate impacts will also erode the net benefits of costly improvements in other factors.

Table 28. Parameter inputs for scenario analyses based on impact reductions in limiting factors. Downward arrows represent reduced impacts (which produce fish status improvements). Upward arrows represent increased impacts (which produce fish status decrements).

	Scenario	Change in impact						
		Habitat	Estuary	Dams	Fishery	Hatchery	Predation	Climate
1a	ASRP 1 (2040)	small ↓	--	--	--	--	--	med↑
2a	ASRP 2 (2040)	med ↓	--	--	--	--	--	med↑
3a	ASRP 3 (2040)	large ↓	--	--	--	--	--	med↑
1b	ASRP 1 plus (2040)	small ↓	--	small ↓	small ↓	small ↓	small ↓	large↑
2b	ASRP 2 plus (2040)	med ↓	small ↓	med ↓	med ↓	med ↓	med ↓	large↑
3b	ASRP 3 plus (2040)	large ↓	med ↓	large ↓	large ↓	large ↓	large ↓	large↑
1c	ASRP 1 (2080)	small ↓	--	--	--	--	--	med↑
2c	ASRP 2 (2080)	med ↓	--	--	--	--	--	med↑
3c	ASRP 3 (2080)	large ↓	--	--	--	--	--	med↑
1d	ASRP 1 plus (2080)	small ↓	--	small ↓	small ↓	small ↓	small ↓	large↑
2d	ASRP 2 plus (2080)	med ↓	small ↓	med ↓	med ↓	med ↓	med ↓	large↑
3d	ASRP 3 plus (2080)	large ↓	med ↓	large ↓	large ↓	large ↓	large ↓	large↑

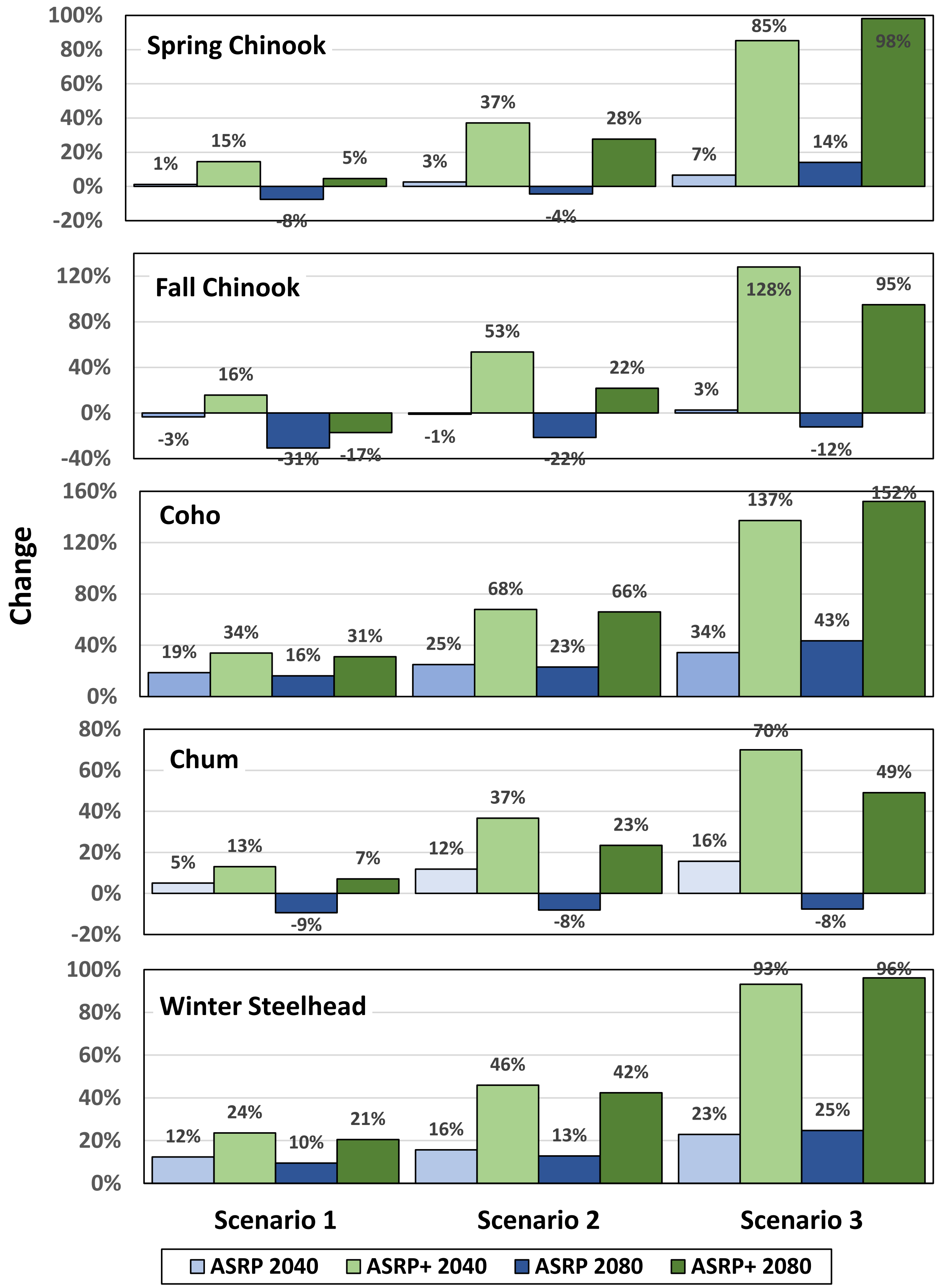

Figure 47. Scenarios for changes in fish abundance associated with reductions in factor impacts and corresponding habitat improvements identified in the Aquatic Species Restoration Plan (ASRPSC 2019).

DISCUSSION

The integrated analysis was designed to improve our understanding of the magnitude and interactions of all factors responsible for the decline of Chehalis salmon and steelhead, and evaluate the potential for increasing fish numbers. This project identified the relative significance of human-related and/or potentially-manageable limiting factors based on a review and high-level analysis of the large volume of technical information available for Chehalis salmon and steelhead. This analysis demonstrated that the relative magnitude of factor-specific impacts can generally be identified, albeit with varying levels of certainty.

The integrated analysis estimated the scale of factor impacts on Grays Harbor salmon and steelhead based on the best available data for each factor. The available information ranges widely in quality from factor to factor. For instance, detailed quantitative estimates are available from the management agencies for fishery impact rates. Estimates of freshwater habitat and dam effects are deduced from detailed of habitat and life cycle models developed to project the effects of restoration activities and flood control measures in Grays Harbor systems. Specific information on predation and hatchery impacts in these systems is generally lacking but related research and information from other areas provides some basis for inference at a course level. Finally, impacts of future climate change remain are to be seen but a range of potential values has been identified for Grays Harbor systems for contingency planning purposes. All estimates and inferences are subject to some level of interpretation, assumption and expert judgement. The integrated analysis was a concerted attempt to describe the scientific information available on each category of limiting factor and characterize the uncertainties in each.

The integrated analysis suggests that freshwater habitat degradation accounts for by far the largest factor impact across all species and stocks over the long term. Impacts of other individual factors are less than habitat impacts but comparable when considered in aggregate. Therefore, significant improvements in the status of Chehalis salmon and steelhead will require substantial improvements in freshwater habitat conditions. At the same time, sensitivity analyses suggest that it will be difficult to achieve high levels of restoration from improvements in any single factor alone. This is particularly true where substantial improvements will also be required to offset continuing to decline as a result potential future climate impact.

The life-cycle analysis indicates that broad-based restoration strategies addressing multiple factors have to potential to make substantial improvements which likely could not be achieved by addressing any single factor by itself. Pervasive impacts of multiple factors have depleted numbers of salmon and steelhead. Improvements in multiple factors produce compounding benefits which can result in large improvements. Complementary improvements create synergies which far surpass the contributions of the individual factors alone. For instance, improving habitat quantity and quality will increase productivity measured in terms of juveniles produced per adult spawner, but numbers will still be limited by out-of-basin factors that affect smolt-to-adult return rates. Conversely, improving smolt-to-adult return rates by addressing out-of-basin limitations will return greater numbers of spawners, but production will still ultimately depend on the habitat conditions they find. However, improving both habitat productivity and smolt-to-adult survivals multiplies the value of each. More, better habitat allows larger numbers of fish surviving out-of-basin factors to realize much higher numbers than they would otherwise have produced by returning to less productive areas. Higher out-of-basin survival returns more fish that are better able to use the habitats available.

This integrated analysis does not assess the feasibility or identify actions necessary to reduce impacts of specific factors. The Salmon Analyzer is broadly applicable across species and stocks to inform the development of complementary strategies which consider all factors. The tradeoff for this general applicability is that the model does not provide for mechanistic assessments of the effects of specific conditions or actions. Specific action plans for each factor will require more detailed assessments and finer-scale models. Detailed analyses and action plans have been developed for freshwater habitat restoration in the Chehalis Basin in the form of the Aquatic Species Restoration Plan. Plans to address other limiting factors are generally less well-developed.

The integrated analysis recognizes that our knowledge base is not perfect, and that critical uncertainties remain. Our analysis broadly synthesized the results of the many assessments, research results and modeling evaluations available for Chehalis salmon and steelhead over the years. Analyses are intended to complement, but not substitute for, the wide array of analyses and models currently employed for salmon assessments throughout the region.

A comprehensive understanding of the magnitude and interactions of all factors is essential to implementation of effective and coordinated management efforts of salmon and steelhead. Decisions will be made on where and how much to invest in a wide range of potential conservation and restoration actions with the information available even when it is not perfect. The integrated analysis provides a structured way to consider factors impacting salmon and steelhead based on the best information we have on hand. The analysis captures and organizes what we think we know regarding each of the factors. The analysis qualifies related uncertainties and highlights where information is limited. Results effectively place all factors in context relative to each other and provide a systematic means of evaluating the potential for improvements.

This analysis is most robust as a hypothesis-testing and learning exercise to examine the likely response of fish numbers to alternative restoration strategies. Where concerns or disagreements on inputs exist, the modeling framework encourages users to articulate alternative assumptions, and it allows for exploration of the related implications in a systematic fashion. Ultimately, effective long-term salmon and steelhead restoration will test the response to substantive actions on the ground and adapt strategies accordingly.

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