2024 Wild Coho Forecasts for Puget Sound, Washington Coast, and Lower Columbia

Washington Department of Fish & Wildlife

Science Division, Fish Program

by

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Introduction

Run size forecasts for wild coho stocks are an important part of the pre-season planning process for Washington State salmon fisheries. Accurate forecasts are needed at the scale of management units to ensure adequate spawning escapements, realize harvest benefits, and achieve harvest allocation goals.

Wild coho run sizes (adult ocean recruits) have been predicted using various approaches across Washington's coho producing systems. Methods that rely on the relationship between adult escapement and resulting run sizes are problematic due to inaccurate escapement estimates and difficulty allocating catch in mixed stock fisheries. In addition, escapement-based coho forecasts often have no predictive value because watersheds become fully seeded at low spawner abundances (Bradford et al. 2000). Furthermore, different variables in the freshwater (Lawson et al. 2004; Sharma and Hilborn 2001) and marine environments (Logerwell et al. 2003; Nickelson 1986; Rupp et al. 2012; Ryding and Skalski 1999) influence coho survival and recruitment to the next life stage. Therefore, the accuracy of coho run size forecasts can be improved by partitioning recruitment into freshwater production and marine survival. In this forecast, wild coho run sizes (adult ocean recruits) are the product of smolt abundance and marine survival and are expressed in a matrix that combines these two components. This approach is like that used to predict hatchery returns where the starting population (number of smolts released) is known.

Freshwater production, or smolt abundance, is measured as the number of coho smolts leaving freshwater at the conclusion of the freshwater life stage. The Washington Department of Fish and Wildlife (WDFW) and tribal natural resource departments have made substantial investments to monitor smolt abundance in order to assess watershed capacity and escapement goals and to improve run size forecasts. Long-term studies on wild coho populations have been used to identify environmental variables contributing to freshwater production (e.g., low summer flows, pink salmon escapement, watershed gradient). For stocks where smolt abundance is not measured, smolt abundance is estimated by using the identified correlates and extrapolating information from neighboring or comparable watersheds.

Marine survival is defined as survival after passing the smolt trap through the ocean rearing phase to the point that harvest begins. Marine survival of a given cohort is measured by summing coho harvest and escapement and dividing by smolt production. Harvest of wild coho is measured by releasing a known number of coded-wire tagged wild coho smolts and compiling their recoveries in coastwide fisheries. Coastwide recoveries are compiled from the Regional Mark Processing Center database (www.rpmc.org). Tags detected in returning spawners are enumerated at upstream trapping structures. Results from these monitoring stations are correlated with ecological variables from the marine environment to describe patterns in survival among years and watersheds. The identified correlations are used to predict or forecast marine survival of wild coho cohort for a given year.

The WDFW Fish Program Science Division has developed forecasts of wild coho run size since 1996 when a wild coho forecast was developed for all primary and most secondary management units in Puget Sound and the Washington coast (Seiler 1996). A forecast methodology for Lower Columbia natural coho was added in 2000 (Seiler 2000) and has continued to evolve in response to listing of Lower Columbia coho under the Endangered Species Act in 2005 (Volkhardt et al. 2007). The methodology used in these forecasts continues to be updated; the most notable update in recent years has been in the methods used to predict marine survival.

Table 1 summarizes the 2024 run-size forecasts for wild coho for Puget Sound, Washington Coast, and Lower Columbia River systems. Forecasts of three-year old ocean recruits were adjusted to January age-3 recruits and compared to recent (10-year average) January recruits in order to provide appropriate inputs for coho management models (expansion factor = 1.23, expansion provides for natural mortality). The following sections describe the approach used to derive smolt production and predict marine survival.

Table 1. 2024 wild coho run forecast summary for Puget Sound, Coastal Washington, and Lower Columbia.

	Production X	Marine Survival	= Recruits		10-yr avg
Production Unit	**Estimated Smolts Spring 2023**	**Predicted Marine Survival**	**Adults (Age 3)**	**Jan. (Age 3)**	**Jan. (Age 3)**
Puget Sound					
Primary Units					
Skagit River	826,000	11.4%	94,164	115,981	72,097
Stillaguamish River	498,000	4.6%	22,908	28,216	38,543
Snohomish River	1,557,000	4.6%	71,622	88,216	92,850
Hood Canal	340,000	3.7%	12,580	15,495	54,892
Strait of Juan de Fuca	339,000	6.8%	23,052	28,393	10,132
Secondary Units					
Nooksack River	468,000	1.7%	7,956	9,799	14,550
Strait of Georgia	16,000	1.7%	272	335	1,907
Samish River	114,000	11.4%	12,996	16,007	13,015
Lake Washington	114,000	5.4%	6,156	7,582	1,652
Green River	322,000	5.4%	17,388	21,417	8,567
East Kitsap	87,000	5.4%	4,698	5,786	2,192
Puyallup River	210,000	5.4%	11,340	13,967	32,133
Nisqually River	142,000	4.3%	6,106	7,521	11,126
Deschutes River	17,000	4.3%	731	900	910
South Sound	152,000	4.3%	6,536	8,050	9,133
Puget Sound Total	5,202,000		298,505	367,666	363,699
Coast					
Quillayute River	192,000	2.6%	4,992	6,149	13,682
Hoh River	167,000	2.6%	4,342	5,348	7,113
Queets River	288,000	2.6%	7,488	9,223	7,835
Quinault River	294,000	2.6%	7,644	9,415	38,218
Independent Tributaries	203,000	2.6%	5,278	6,501	--
Grays Harbor					
Chehalis River	2,419,000	2.6%	62,894	77,466	70,957
Humptulips River	263,000	2.6%	6,838	8,422	6,347
Willapa Bay	680,000	2.6%	17,680	21,776	39,163
Coastal Systems Total	4,506,000		117,156	144,300	183,315
Lower Columbia Total	804,000	7.7%	61,908	76,252	45,587
GRAND TOTAL	10,512,000		477,569	588,218	592,601

Puget Sound Smolt Production

Approach

Wild coho production estimates for each of the primary and secondary management units in Puget Sound were derived from results of juvenile trapping studies. Over the past 40 years, WDFW has measured wild coho production in the Skagit, Stillaguamish, Snohomish, Green, Nisqually, and Deschutes rivers as well as in tributaries to Lake Washington and Hood Canal. Analyses of these long-term data sets demonstrated that wild coho smolt production is limited by a combination of factors including seeding levels (i.e., escapement), environmental conditions (flows, marine derived nutrients), and habitat degradation. In several systems, census adult coho data are available to pair with the juvenile abundance estimates. In these systems, freshwater productivity (juveniles/female) is a decreasing function of spawner abundance (Figure 1), demonstrating density dependence in juvenile survival. In most watersheds, overall production of juvenile coho (juveniles/female * number females) is rarely limited by spawner abundance, and the majority of variation in juvenile production is the result of environmental conditions (Bradford et al. 2000). Summer rearing flows are a key environmental variable affecting the freshwater survival and production of Puget Sound coho (Mathews and Olson 1980; Smoker 1955), although extreme flow events in the overwinter rearing period (Kinsel et al. 2009) and local habitat condition influenced by wood cover and channel complexity, fish passage, road densities, and water quality are also likely to influence smolt production (Quinn and Peterson 1996; Sharma and Hilborn 2001). In addition, increases in odd-year pink salmon returns to Puget Sound beginning in 2001 have dramatically increased the marine derived nutrients and food resources available for coho salmon cohorts resulting from even-year spawners because these cohorts rear in freshwater in odd years when pink salmon carcasses, eggs, and fry are present in the river systems.

In some watersheds, habitat degradation and depressed run sizes have been a chronic issue. Smaller watersheds, which provide important spawning habitat for coho, are particularly sensitive to both habitat degradation and low escapements. Density-dependent compensation may not be observed when habitat degradation is severe or when escapements fall below critical thresholds. For example, chronically low coho returns to the Deschutes River (South Sound), beginning in the mid-1990s, have resulted in much lower freshwater survival (juveniles/female) than would be predicted from years when coho salmon returns to the Deschutes River were substantially higher (Figure 2a) or from other watersheds where spawner escapement has not been chronically depressed (Figure 1).

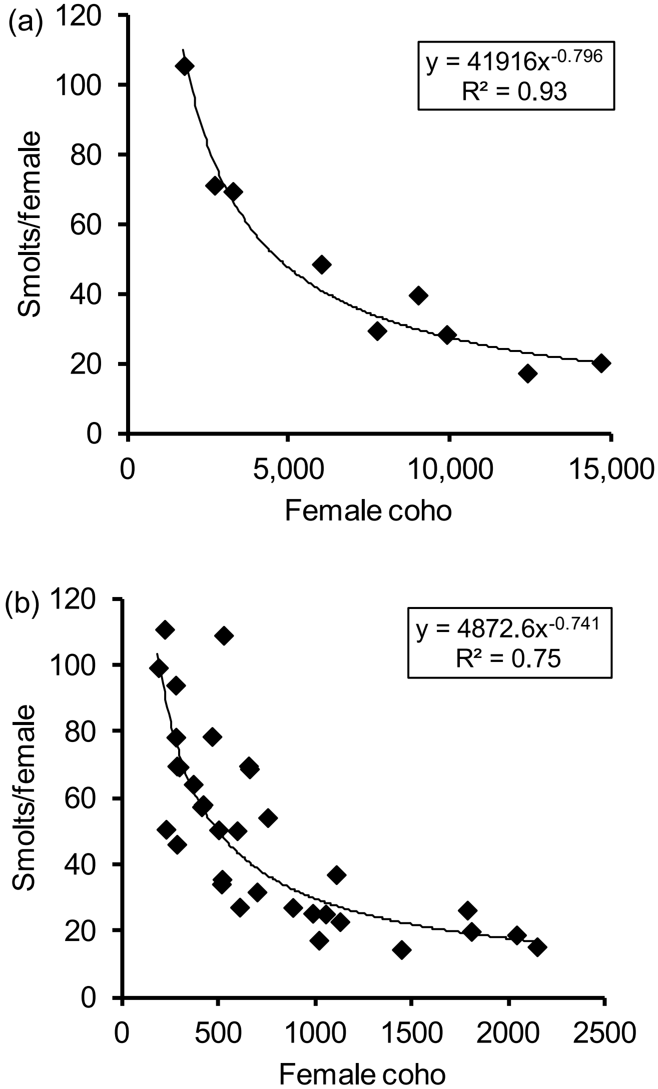

Figure 1. Freshwater productivity (juveniles/female) as a decreasing function of female coho escapement in the South Fork Skykomish (*a*, Sunset Falls, brood year 1976-1984) and Big Beef Creek (*b*, brood year 1978-2009) watersheds.

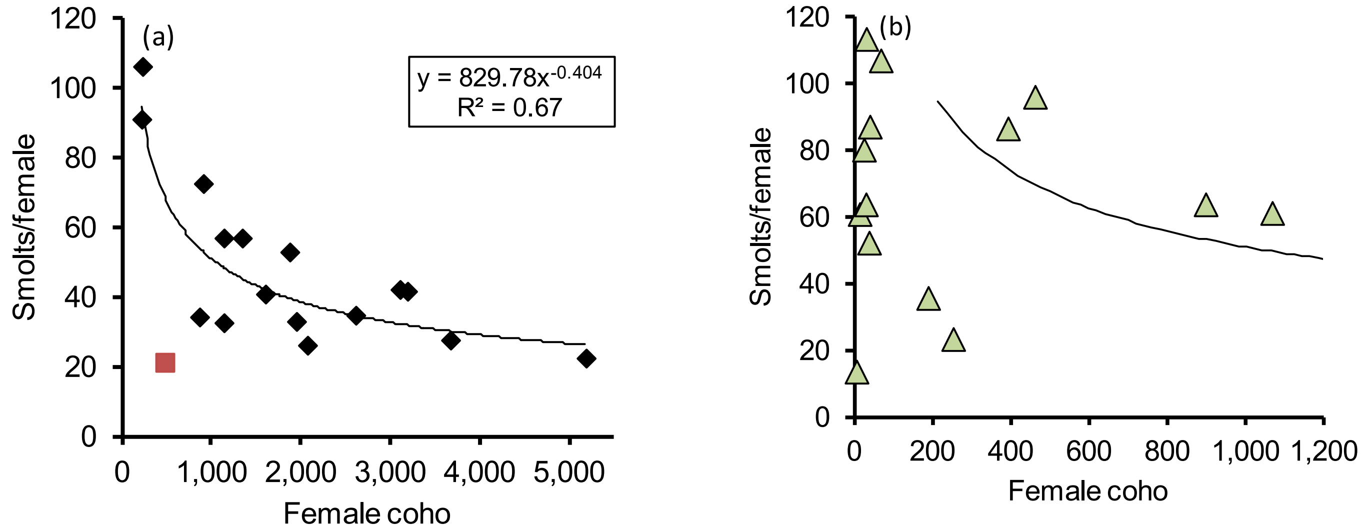

Figure 2. Freshwater productivity (juveniles/female) as a function of female coho spawners in the Deschutes River. For brood year 1978-1994 (*a*), coho productivity was a decreasing function of escapement (black square), with the exception of brood year 1989 (red square). The 1989 brood year corresponded with a landslide during egg incubation. For brood year 1995 to 2009 (*b*), spawner escapements have been chronically depressed and coho productivity has been far below the levels predicted (black line) under higher escapements (1978-1994).

In 2023, WDFW measured coho smolt abundance in six of the Puget Sound management units (Skagit, Hood Canal, Lake Washington, Green, Nisqually, Deschutes). Smolt production data from seven additional management units (Nooksack, Juan de Fuca, Stillaguamish, Snohomish, Puyallup, East Kitsap, South Sound) were available due to juvenile monitoring studies conducted by the Lummi, Jamestown, Elwha, Makah, Stillaguamish, Tulalip, Puyallup, Suquamish, and Squaxin tribes. For watersheds where trapping data were not available in 2023 (e.g., Samish), coho smolt abundance was indirectly estimated using several approaches.

The most commonly used approach to measure coho smolt abundance is based on the smolt potential predicted for each watershed by Zillges (1977). Rearing habitat is estimated for each stream segment by the length of available habitat defined in the Washington stream catalog (Williams et al. 1975) and summer stream width estimated by Zillges (1977). Coho densities applied to the summer stream area of each segment is based on smolt densities measured in small (Chapman 1965) and large (Lister and Walker 1966) watersheds. Average production estimates for Puget Sound watersheds range between 6.4% and 90.7% of the predicted potential production (Table 2). This approach was used to indirectly estimate production from an entire watershed or management unit when smolt production was known from at least some portion of that watershed or management unit or when a similar production level (percentage of potential production) was assumed from a neighboring watershed.

Zillges (1977) approach was based on the observation that summer flows are an important predictor of freshwater survival in Puget Sound watersheds (Mathews and Olson 1980; Smoker 1955). Summer flows in Puget Sound rivers can be described by the Puget Sound Summer Low Flow Index (PSSLFI,

Appendix A). The PSSLFI is calculated from a representative series of eight USGS stream flow gages in Puget Sound and is based on the general observation that summer low flows are correlated among Puget Sound watersheds. Summer low flows in 2022 (corresponding to the 2023 outmigration and 2024 returning adults) were the third lowest in 59 years and had an index value of 5.3 or 66% of the average for the time series (Figure 3). In past years, this index has been used to estimate smolts in watersheds where historical estimates were available but current year estimates are not. In this year's forecast, the information is provided as context for the observed smolt production.

Table 2. Wild coho smolt production from WDFW smolt evaluation studies in Puget Sound watersheds. Table includes the measured production compared to the potential production predicted by Zillges (1977) above the smolt trap location in each watershed. Average values in this table are the arithmetic means and those of the smolt production time series are geometric means.

		Smolt production above trap			Zillges (1977) potential above trap		
Stream	No. Years	Geomean	Min	Max	Average	Min	Max
Hood Canal							
Big Beef	46	23,839	3,066	58,136	61.8%	7.9%	150.7%
Little Anderson	30	327	24	1,969	6.4%	0.5%	38.6%
Seabeck	30	1,117	315	2,725	10.6%	3.0%	26.0%
Stavis	30	4,427	1,549	9,667	88.1%	30.8%	192.3%
Skagit River	34	1,022,334	426,963	1,884,668	74.6%	31.1%	137.5%
SF Skykomish River	9*	249,331**	212,039	353,981	82.0%**	69.7%	116.4%
Stillaguamish River	3	284,142**	211,671	383,756	42.9%**	31.9%	57.9%
Lake Washington							
Cedar River***	25	61,283	13,322	179,915	50.7%	11.0%	148.8%
Bear Creek	25	21,470	2,294	62,970	42.9%	4.6%	125.7%
Green River****	19	70,498	22,671	287,745	31.3%	10.1%	127.6%
Nisqually	15	104,755	33,562	254,456	90.7%	29.0%	220.2%
Deschutes*****	43	18,089	1,187	133,198	8.2%	0.5%	60.7%

* Data does not include the three years when smolt production was limited by experimental escapement reduction.

** Arithmetic average, not geometric mean.

*** Cedar River production potential does not include new habitat available to coho above Landsburg Dam beginning in 2003.

****Green River production does not include 2004-2005, 2008, or 2020-2021 estimates. Recent estimates include unmarked hatchery smolts.

***** Deschutes smolt production in this table includes yearling and subyearling smolts. Both age classes are known to contribute to adult returns. There were no trapping operations in 2019 or 2020.

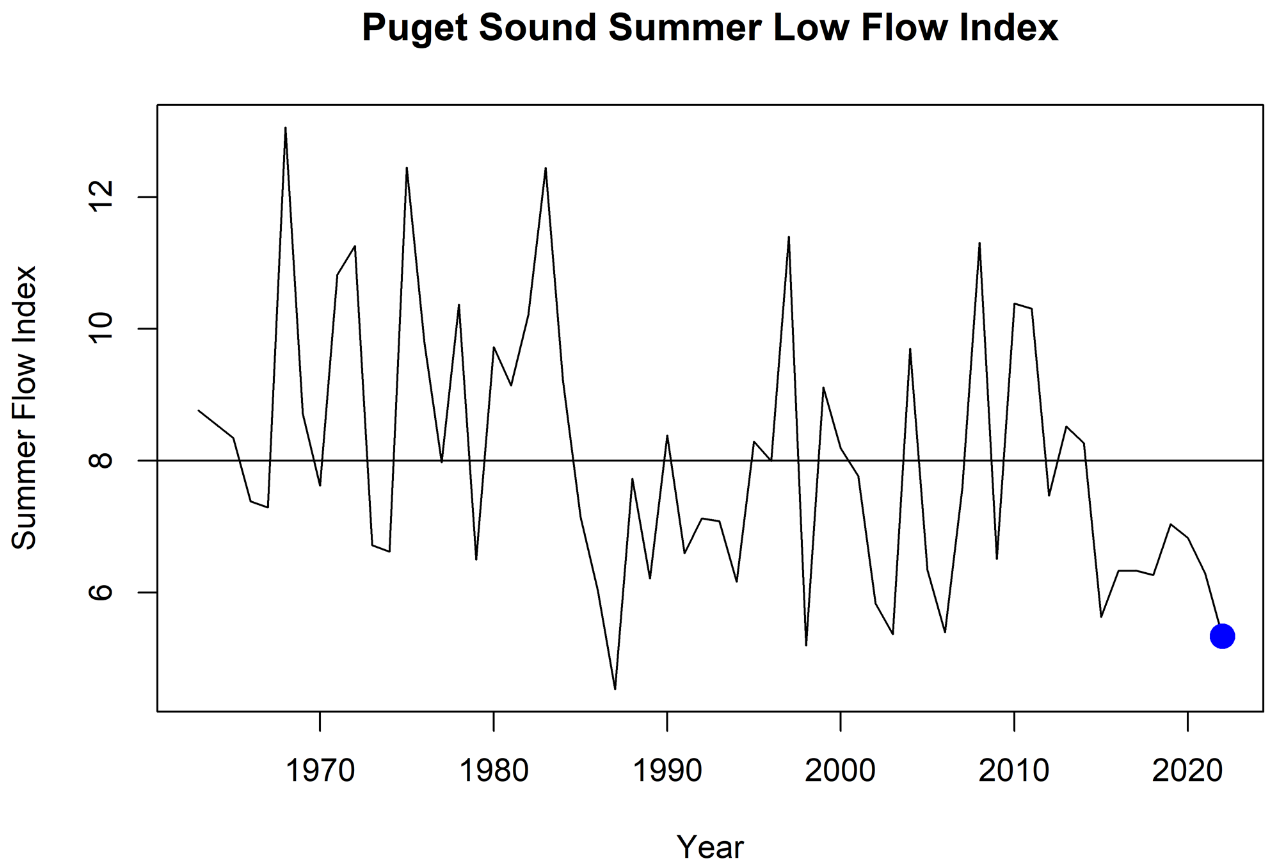

Figure 3. Puget Sound Summer Low Flow Index (PSSLFI) by summer rearing year (return year – 2). PSSLFI is based on 60-day minimum flow averages at eight stream gages in Puget Sound (see Appendix A). The minimum 60-day average flow at each gage is compared to the time series average (1963 to present) and then summed across all eight gages. Flow index corresponding to the 2024 wild coho return (5.3) shown as blue point on graph.

Puget Sound Primary Units

Skagit River

A total of 826,000 wild coho smolts (rounded from 825,505) are estimated to have emigrated from the Skagit River in 2023 (Table 1). This estimate is based on catch of wild coho in a juvenile trap operated on the lower main stem Skagit River (river mile 17.0 near Mount Vernon, Washington). The juvenile trap was calibrated using recaptures of wild yearling coho marked and released from an upstream tributary (Mannser Creek) and smolt abundance was calculated using a Petersen estimator with Chapman modification (Seber 1973; Volkhardt et al. 2007). Coho smolt production from the Skagit River in 2023 was 825,505 (±158,294 95% C.I.), which represents a 19% decrease from the average (geometric mean) of 1,022,334 smolts between the 1990 and 2023 ocean entry years (Table 2, Figure 4).

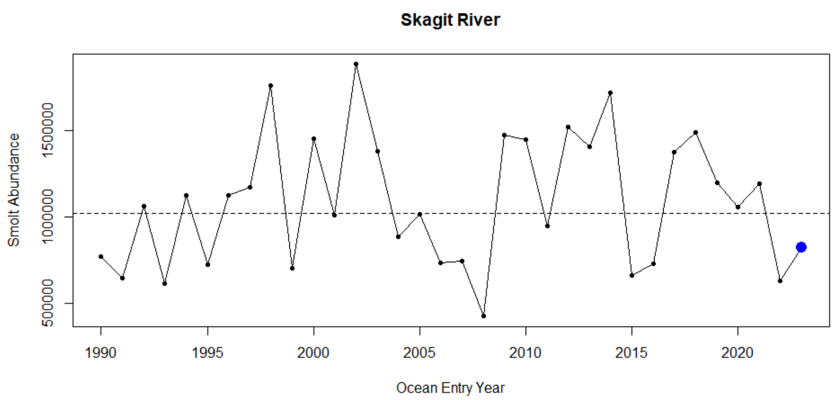

Figure 4. Time series of wild coho smolt outmigration from the Skagit River, ocean entry years 1990 to 2023. Blue point represents outmigration of the cohort included in this forecast. Horizontal line is the geometric mean of the time series.

Stillaguamish River

A total of 498,000 coho smolts (rounded from 498,199) are estimated to have emigrated from the Stillaguamish River in 2023 (Table 1). This estimate was based on a CPUE index of abundance for the 2023 outmigration and a relationship between a time series of CPUEs versus back-calculated smolt abundances for the Stillaguamish River.

There have been two different trapping operations conducted on the Stillaguamish River since 1981. Between 1981 and 1983, smolt abundance estimates resulted from a juvenile trap study operated by WDFW upstream of river mile (R.M.) 16. Basin-wide smolt abundance during these years was estimated above the trap and expanded to the entire watershed above and below trap. The average smolt abundance during these years was 360,000 smolts using methods described in previous forecast documents (Seiler 1996; Zimmerman 2013). From 2001 to present, smolt catch-per-unit-effort (CPUE) have been obtained from a juvenile trap study conducted by the Stillaguamish Tribe near R.M. 6 (A. Voloshin, Stillaguamish Natural Resources, personal communication). The more recent monitoring effort has not included trap efficiency trials needed to directly expand CPUE to watershed abundance. However, CPUE provides an index of abundance to the extent that trap efficiency is relatively constant among years. Between 2003 and 2023, CPUE has averaged 4.0 fish/hour (range 0.4 to 8.5). The first two years of trap operation (2001, 2002) were shorter in length and CPUE data from these years are not directly comparable to the remainder of the time series.

An indirect estimate of smolt abundance for the Stillaguamish River was back-calculated from ocean age-3 abundance and an estimated marine survival rate. Ocean age-3 abundance is the summed estimates of coho spawner escapement and harvest (terminal and pre-terminal) and is calculated annually by the Coho Technical Committee of the Pacific Salmon Commission. Marine survival is not directly available for the Stillaguamish River; however, a marine survival time series from the neighboring SF Skykomish River was used to generate the back-calculated smolt time series for the Stillaguamish River. Back calculated smolt estimates between 2003 and 2020 outmigration have a geometric mean of 437,659 smolts (range 164,896 to 1,195,420), values that bracket the watershed smolt estimates calculated in 1981-1983.

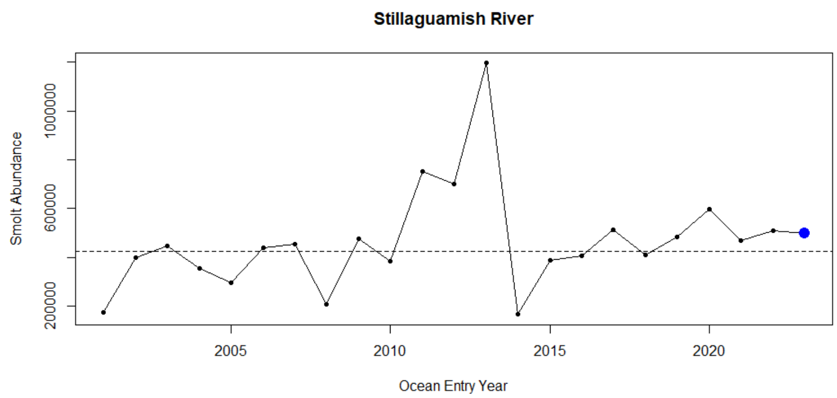

Figure 5. Time series of wild coho smolt outmigration from the Stillaguamish River, ocean entry years 2001 to 2023. Blue point represents outmigration of the cohort included in this forecast. Horizontal line is the geometric mean of the time series. Data provided by A. Voloshin (Stillaguamish Natural Resources).

A positive correlation exists between the smolt trap CPUE and the back-calculated estimates of coho smolts. Data were log transformed for analysis. This relationship was applied to the CPUE obtained during the 2023 outmigration (4.2 fish/hour) resulting in an estimated outmigration of 498,199 smolts (Figure 5). Data from 2015 were not used in the predictive model because this data point had large influence on the fit of the regression. For the purpose of comparison, the predictive model that included the 2015 data resulted in an estimated outmigration of 455,294 smolts.

Snohomish River

A total of 1,557,000 coho smolts are estimated to have emigrated from the Snohomish River in 2023 (Table 1). Coho smolt production in the Snohomish River is based on a mark-recapture estimate of smolt abundance from two smolt traps, one operated on the Skykomish River (river mile 26.5) and the second on the Snoqualmie River (R.M. 12.2). Traps are operated and results provided by the Tulalip Tribes (D. Holmgren, personal communication). Abundance at each trap in 2023 was determined using Bayesian p-splines and hierarchical modeling of trap efficiencies (Bonner and Schwarz (2011; 2014). A total of 876,537 (95% C.I. = 446,146 to 1,696,272) smolts are estimated to have emigrated past the Skykomish trap and 242,667 (95% C.I. = 95,429 to 684,991) smolts are estimated to have emigrated past the Snoqualmie trap. Smolt trap estimates for the Skykomish and Snoqualmie rivers are summed and further expanded for rearing downstream of the trap locations in the Snohomish River (per Zillges 1977). Coho smolt production from the Snohomish in 2023 was a 19% increase from the average (geometric mean) of 1,307,428 smolts between 2001 and 2023 ocean entry years (Figure 6).

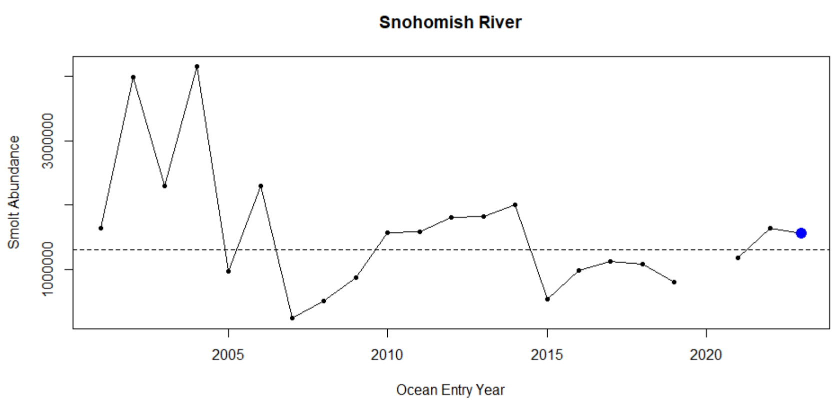

Figure 6. Time series of wild coho smolt outmigration from the Snohomish River, ocean entry years 2001 to 2023. No estimate available for 2020. Blue point represents outmigration of the cohort included in this forecast. The horizontal line is the geometric mean of the time series. Data provided by D. Holmgren (Tulalip Tribes).

Hood Canal

A total of 340,000 coho smolts (rounded from 339,724) are estimated to have emigrated from Hood Canal tributaries in 2023 (Table 1). This estimate is based on measured smolt abundance in select tributaries expanded to the entire management unit.

In 2023, wild coho smolt abundance was measured in Big Beef Creek (BBC; *n* = 17,301), Little Anderson Creek (*n* = 24), Seabeck Creek (*n* = 1,088), and Stavis Creek (*n* = 7,406). Coho smolts in these watersheds were captured in fan traps (BBC) and fence weirs. Catch was extrapolated for early and late spring migrants using historical migration timing data.

The 2023 abundance of coho smolts from BBC was a decrease of 27% from the average (geometric mean) of 23,839 between the 1978 and 2023 ocean entry years (Table 2, Figure 7). Coho smolt abundances in neighboring Little Anderson and Seabeck creeks were decreases of 93% and 3% respectively, while Stavis Creek was an increase of 67%, based on time series averages (geometric mean) in these watersheds (Table 2). Smolt production in Little Anderson in 2023 was the lowest of the time series.

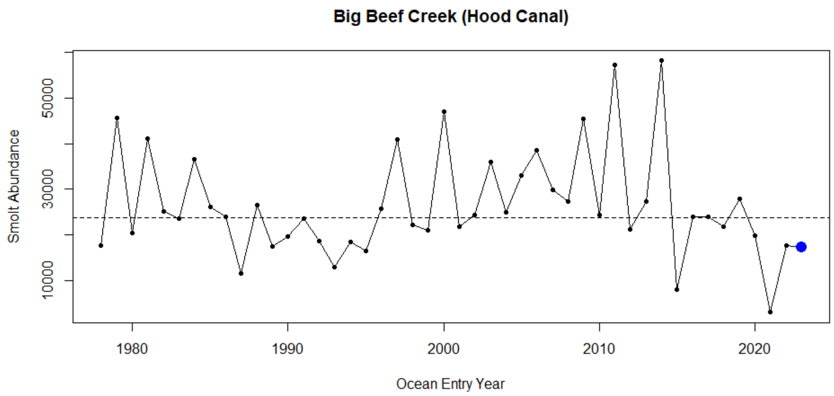

Figure 7. Time series of wild coho smolts from Big Beef Creek, ocean entry years 1978 to 2023. Blue point represents outmigration of the cohort included in this forecast. Horizontal line is the geometric mean of the time series.

Three approaches have been used to expand measured smolt abundance in these tributaries to the entire the Hood Canal management unit. The first approach assumes that coho abundance from all four tributaries (Little Anderson, Big Beef, Seabeck, and Stavis creeks) is 5.9% of the entire Hood Canal (Zillges 1977). A subsequent review by the Hood Canal Joint Technical Committee (HCJTC) revised this estimate to 7.6% of Hood Canal (HCJTC 1994). A third approach (Volkhardt and Seiler 2001), based on the HCJTC forecast review in summer of 2001, estimated that coho smolt abundance from Big Beef Creek is 4.56% of Hood Canal.

As described, the three approaches estimated that the 2023 wild coho production in Hood Canal ranged between 340,000 and 438,000 smolts. Using the Zillges approach, the total of 25,819 smolts from the four tributaries were expanded to an estimated 437,610 Hood Canal smolts. Using the second approach (HCJTC 1994 revision), the total smolts were expanded to 339,724. The third approach expanded the 17,301 smolts from Big Beef Creek to a total of 379,408 Hood Canal smolts. This forecast is based on the most conservative result, provided by the second approach.

Juan de Fuca

A total of 339,000 coho smolts (rounded from 338,984) are estimated to have emigrated from Juan de Fuca tributaries in 2023 (Table 1). This estimate is based on measured smolt abundance in select tributaries expanded to the entire management unit. In most years, up to eleven tributaries are monitored in the Strait of Juan de Fuca through a collaborative effort by WDFW, Jamestown S'Klallam Tribe, Elwha Tribe, and the Makah Tribe. Monitored tributaries in 2023 were Jimmy Come Lately, Siebert, Bell, McDonald, and Snow creeks in the eastern part of the Strait and Salt, East Twin, West Twin, Deep, Little Hoko, and Johnson creeks in the western part of the Strait. Measured smolt abundance was extrapolated to all tributaries in the Juan de Fuca management unit based on the proportion of summer rearing habitat represented in the monitored tributaries (calculations provided by Hap Leon, Makah Tribe). The Elwha and Dungeness rivers are managed separately from the Juan de Fuca management unit and are not included in this forecast. Coho smolt production from the Juan de Fuca tributaries in 2023 was a 22% increase from the average (geometric mean) of 277,829 smolts between the 1998 and 2023 ocean entry years (Figure 8).

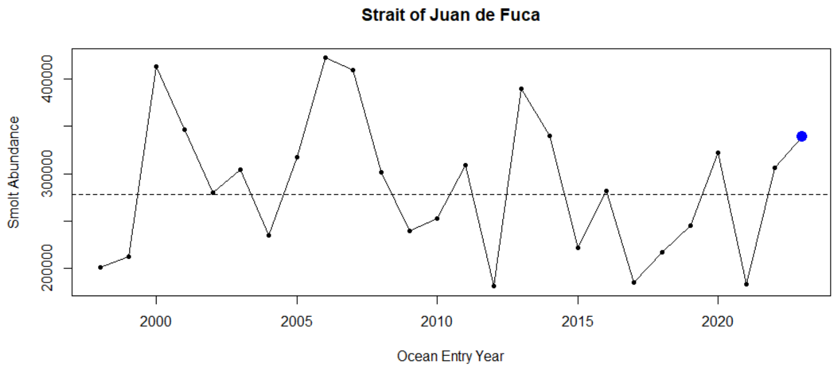

Figure 8. Time series of wild coho smolts from Strait of Juan de Fuca tributaries, ocean entry years 1998 to 2023. Blue point represents the cohort contributing to this forecast. The horizontal line is the geometric mean of the time series. Data provided by Hap Leon (Makah Tribe).

Puget Sound Secondary Units

Nooksack River

A total of 468,000 coho smolts (rounded from 467,791) are estimated to have emigrated from the Nooksack River in 2023 (Table 1). The 2023 estimate is based on a mark-recapture estimate of smolt abundance from a smolt trap operated by the Lummi Tribe. In 2021, a new version of the catch efficiency model was developed to estimate juvenile abundance that resulted in updated coho smolt production estimates. Results provided by the Lummi Tribe (D. Flawd, Lummi Nation, personal communication).

Between the 2005 and 2023 ocean entry years coho smolt production in the Nooksack River averaged (geometric mean) 301,482 smolts (Figure 9, range 97,615 to 928,633, estimates from 2018-2020 updated in 2021 by D. Flawd and T. Taylor, Lummi Nation). An additional number of coho (0% to 5% of the total yearling smolts) are estimated to emigrate as fry. Fry estimates are not included in the forecast calculations because they represent a small proportion of the outmigration and their survival likely to be substantially lower than that of the yearling smolts. The coho smolt production estimate from the Nooksack River in 2023 was a 55% increase from the average (geometric mean) for the time series.

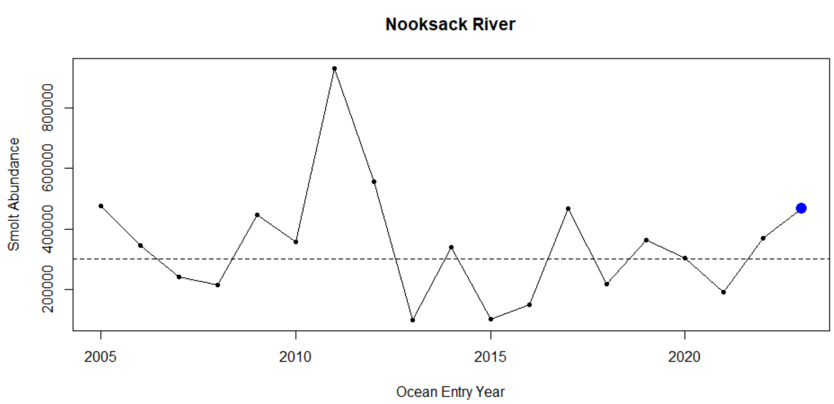

Figure 9. Time series of wild coho smolts from the Nooksack River, ocean entry years 2005 to 2023. Estimates from 2018-2020 updated in 2021. Blue point represents the cohort contributing to this forecast. The horizontal line is the geometric mean of the time series. Data provided by D. Flawd (Lummi Nation).

Strait of Georgia

A total of 16,000 coho smolts (rounded from 15,546) are estimated to have emigrated from Strait of Georgia watersheds in 2023 (Table 1). Coho smolt abundance has not been measured in any of the tributaries in this region and was estimated based on the potential predicted by Zillges (1977) and the assumptions that this management unit experienced similar levels of smolt production that were observed in multiple Puget Sound management units. The Strait of Georgia management unit is comprised of small independent tributaries that drain into the Strait of Georgia near the U.S. – Canadian border. There is no direct measure of coho smolt production in these tributaries. Previous forecasts for the Strait of Georgia estimated that wild coho production was 20% to 50% of its potential. Measured smolt production for watersheds in geographic proximity to the Strait of Georgia tributaries (i.e., Skagit) were 19% lower than the long-term average in 2023. Therefore, the 2023 coho production was estimated to be 15,546 smolts, 30% of the total production potential for these watersheds (51,821 smolts per Zillges 1977).

Samish River

A total of 114,000 coho smolts (rounded from 114,286) are estimated to have emigrated from the Samish River in 2023 (Table 1). Coho smolt abundance has not been measured in the Samish River and was approximated using recent adult escapement and an assumed marine survival rate.

In the last decade, marine survival of wild coho in Puget Sound has averaged 7.5% with an average of 7.0% in the Baker River, which is the measure of wild coho marine survival in closest geographic proximity to the Samish River. During this time, natural coho returns to the Samish River averaged ~8,000 adults. Assuming a marine survival rate of 7.0%, an average of 114,286 smolts will result in a return of 8,000 adult spawners. This estimate corresponds to 29 smolts/female (assume 1:1 male:female) and 67% of the potential production predicted by Zillges (1977), both reasonable values when compared to other watersheds. The Zillges (1977) calculation includes a potential of 57,923 below the hatchery rack and 111,566 above the hatchery rack (57,923 + 111,566 = 169,489).

Lake Washington

A total of 114,000 coho smolts (rounded from 113,866) were estimated to have entered Puget Sound from the Lake Washington basin in 2023 (Table 1). This estimate is based on measured smolt estimates for two major tributaries to Lake Washington (Cedar River and Bear Creek), historical production data for Issaquah Creek (2000 migration year), and an estimate of survival through Lake Washington. Juvenile traps operated in each watershed were calibrated using recaptures of marked coho released above the trap and abundance estimated using Bayesian p-splines and hierarchical modeling of trap efficiencies at weekly intervals (Bonner and Schwarz (2011; 2014).

The potential coho production for the Lake Washington basin (768,740 smolts) predicted by Zillges (1977) is unrealistically high for an urbanized watershed. In addition, this potential includes the lake as a substantial portion of rearing habitat, an assumption that has not been supported by field surveys (Seiler 1998). Therefore, basin-wide smolt abundance was estimated based on the three sub-basins –

Cedar River, Bear Creek, and Issaquah Creek – that represent the majority of coho spawning and rearing habitat.

In 2023, coho smolt abundance from the Cedar River was estimated to be 118,119 (±48,441 95% C.I.) smolts. This production was an increase of 93% from the geometric mean of 61,283 smolts between the 1999 and 2023 ocean entry years (Figure 10). Coho smolts from Bear Creek were estimated to be 16,309 (±6,576 95% C.I.), a 24% decrease from the geometric mean of 21,470 smolts between the 1999 and 2023 ocean entry years (Figure 10). Between 1999 and present, the trend in the number of coho smolts produced by the Cedar River has increased and Bear Creek has decreased. Among the potential reasons for the observed pattern is the use of newly colonized habitat on the Cedar River. A fish passage facility at Landsburg Dam was completed in 2003 and provides coho with access to at least 12.5 miles of quality spawning and rearing habitat between Landsburg and Cedar Falls. Adult coho returns to this portion of the watershed have increased over time (J. Unrein, SPU, unpubl. data), and natural productivity appears to be contributing substantially to this trend (Anderson 2011).

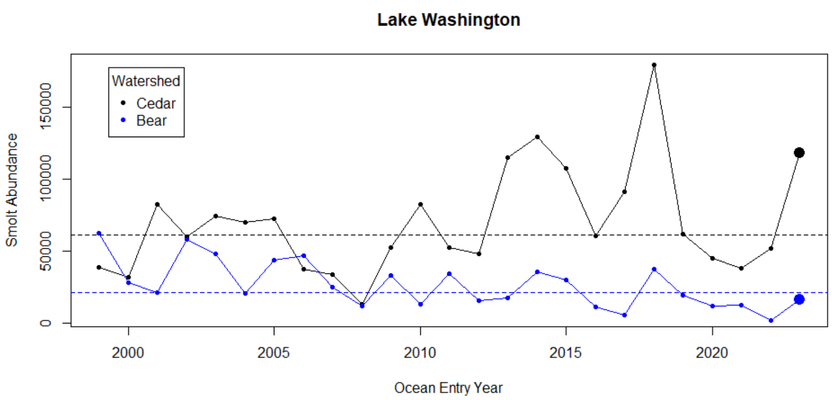

Figure 10. Time series of natural-origin coho smolts from Cedar River (black) and Bear Creek (blue), ocean entry years 1999 to 2023. Larger symbol represents outmigration of cohort contributing to this forecast. Horizontal lines are the geometric mean for the time series in each watershed.

Issaquah Creek in the Sammamish sub-basin is the other major coho producing watershed in the Lake Washington management unit. Coho smolt production from Issaquah Creek is based on monitoring data from the neighboring Bear Creek. Both watersheds flow into the northern extent of the lake and are assumed to be influenced by returns of natural and hatchery coho and summer low flows. The 2023 coho production from Issaquah Creek was estimated by scaling the 2000 estimate for this creek (19,812 smolts; Seiler et al. 2002a) based on the 2023:2000 smolt ratio in Bear Creek. In 2023, coho smolt production in Bear Creek was 58% of that measured in 2000 (16,309 / 28,142 = 0.580). Therefore, 2023 coho production from Issaquah Creek was estimated to be 11,482 smolts (19,812 * 0.580).

The total coho production of 113,866 assumed 78% survival through Lake Washington. A total of 145,982 coho smolts were estimated to enter Lake Washington (118,191 Cedar + 16,309 Bear + 11,482 Issaquah). The 78% survival rate was estimated from detections of Passive Integrated Transponder (PIT) tags applied to coho smolts caught in the traps and redetected at the Ballard Locks from 2001 – 2011 (e.g., Kiyohara and Zimmerman 2011; 2012) and new information based on PIT tag detections for outmigrating smolts from 2021 – 2022 (P. Lisi, WDFW, unpubl. data).

Green River

A total of 322,000 (rounded from 322,469) coho smolts are estimated to have emigrated from the Green River in 2023 (Table 1). This estimate is the sum of 287,745 smolts upstream of the juvenile trap (river mile 34), 34,724 smolts below the juvenile trap, and no smolts from Big Soos Creek.

In 2023, coho smolts emigrating from above river mile 34 were estimated with a rotary screw trap. The juvenile trap was calibrated based on recapture rates of marked wild coho and abundance estimated using a time-stratified Petersen estimator (Carlson et al. 1998; Volkhardt et al. 2007). Production above the trap was estimated to be 287,745 smolts and was the highest value since trapping began in 2000. However, efficiency at the trap was based on the low 2022 estimate of 1.02% and the total includes both natural and unmarked hatchery production. This production was an increase of 308% from the geometric mean of 70,498 smolts (Figure 11).

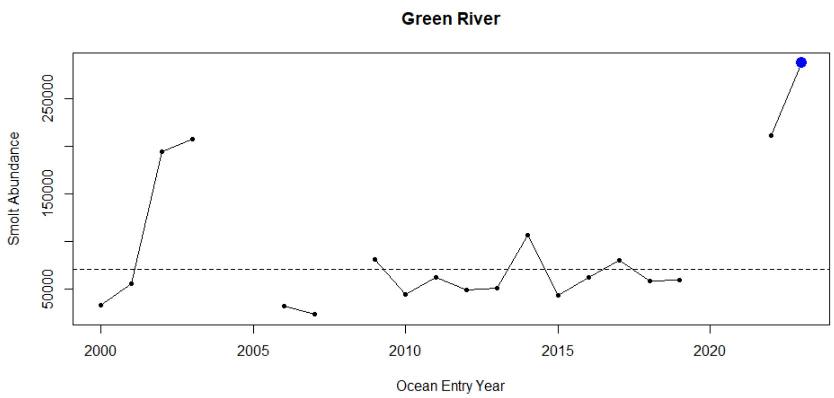

Figure 11. Time series of natural-origin coho smolts above the Green River smolt trap (river mile 34), ocean entry years 2000 to 2023. No estimate available for 2004-2005, 2008, or 2020-2021 ocean entry years. Blue point represents cohort contributing to this forecast. Horizontal line is the geometric mean for the time series.

Coho smolt production above the juvenile trap was 129.0% of the 223,106 smolt potential estimated for this portion of the watershed (Zillges 1977). Because this value seemed unnaturally high, the number of coho rearing in the main stem and tributaries (except Soos Creek) below the trap was estimated to be 34,724 smolts based on the recent (5-year average) of 27.0% of the potential production (128,630) predicted for this portion of the watershed.

Big Soos Creek is a low gradient tributary that enters the Green River downstream of the juvenile trap. A juvenile trap was operated in Big Soos Creek by WDFW in 2000 and natural-origin coho smolts were estimated to be 64,341 smolts in this year (Seiler et al. 2002b). However, the Big Soos Creek trap was not operated during 2018-2023 and, because there are no immediate plans to operate this trap in the future, Muckleshoot Indian Tribe developed a methodology to estimate smolt emigration based on the historically available smolt production, female abundance, summer minimum flow, and winter maximum flow data. For 2023, it is estimated that no natural-origin coho smolts emigrated from Big Soos Creek as no returning wild adults were planted above the Big Soos Creek trap in 2021.

East Kitsap

A total of 87,000 coho smolts (rounded from 86,890) are estimated to have emigrated from East Kitsap tributaries in 2023 (Table 1). In previous years, this estimate was based on an expansion of measured production in Steele Creek, an East Kitsap tributary which was trapped between 2001 and 2010 by the Steele Creek Organization for Resource Enhancement). During these years, smolt abundance from Steele Creek ranged between 1,040 and 2,958 wild coho smolts, representing 25% to 71% of the 4,140 smolt potential for this creek (Zillges 1977).

The Suquamish Tribe established a smolt monitoring study on Lost and Wildcat creeks in 2011 and continued this work in 2023 (J. Oleyar, Suquamish Tribe, personal communication). Based on an updated assessment of summer rearing habitat conducted by the Suquamish Tribe, the smolt potential above the trap locations is 2,809 smolts on Lost Creek, 6,875 smolts on Wildcat Creek, and 155,269 smolts for the entire management unit (J. Oleyar, Suquamish Tribe). This smolt potential was slightly higher than that estimated by Zillges based on an increased length of summer rearing habitat in Lost Creek (1.7 to 1.9 as determined by the Suquamish Tribe biologists).

The 2023 coho abundance of 5,419 smolts from Lost (n = 1,784) and Wildcat (n = 3,635) creeks was 56% of the calculated smolt potential. Total coho smolt abundance for the East Kitsap management unit was estimated to be 86,890 smolts based on 56% of the 155,269 smolt potential for all watersheds in this management unit.

Puyallup River

A total of 210,000 coho smolts (rounded from 210,272) are estimated to have emigrated from the Puyallup River in 2023 (Table 1). This estimate is based on measured production in the Puyallup River above the juvenile trap (75,176), estimated production from the White River (128,402), and an estimate from the Puyallup River below the Puyallup-White confluence (6,694).

In 2023, the Puyallup Tribe operated a juvenile fish trap on the Puyallup River just upstream of the confluence with the White River. A total of 75,176 coho smolts were estimated to have emigrated from the Puyallup River above the smolt trap, including production above Electron Dam (Berger 2023; A. Berger, Puyallup Tribe, personal communication). This production represented an increase of 27% from the average (geometric mean) of 59,353 smolts between the 2005 and 2023 ocean entry years (Figure 12). Coho smolt production above the juvenile trap represents 27.3% of the smolt potential for the watershed between the Puyallup-White confluence and Electron dam (Zillges 1977). However, the actual rate is lower than this percentage as the 2023 smolts had access to spawning and rearing habitat above Electron Dam which was not accounted for in Zillges estimations. Coho in the Puyallup River have had access to the upper Puyallup River since a fish ladder was installed at Electron Dam in 2000.

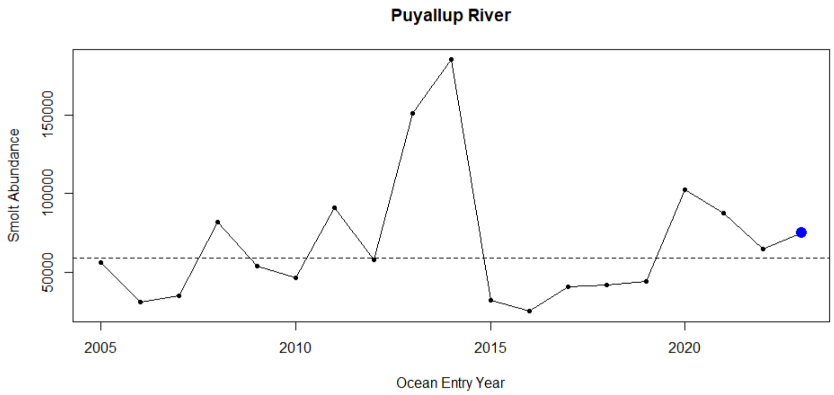

Figure 12. Time series of natural-origin coho smolts above the Puyallup River smolt trap (upstream of confluence with White River), ocean entry years 2005 to 2023. Blue point represents cohort included in this forecast. Horizontal line is the geometric mean of the time series. Data provided by A. Berger (Puyallup Tribe).

A total of 128,402 coho smolts are estimated to have emigrated from the White River, including production upstream of Mud Mountain Dam, in 2023. This estimate was the second smallest since trapping began in 2016 and was derived from catch in a rotary screw trap (*n* = 3,943) operated in the White River above the confluence with the Puyallup River with an assumed 3.1% trap efficiency for coho smolts (A. Berger, Puyallup Tribe, personal communication). Trap efficiency in 2023 came from hatchery-reared coho based on two experiments completed with 800 individuals per release. This was different from other years that relied on steelhead to estimate capture efficiency.

An additional 6,694 coho smolts were estimated to rear below the Puyallup and White confluence, based on a rate of 10% of potential production applied to the 66,943 potential production of the lower Puyallup (Zillges 1977). The total watershed production of 210,272 was the sum of coho smolt production from the Puyallup River (75,176 above White River confluence), White River (128,402) above confluence with Puyallup River), and Puyallup River (6,694 below White River confluence).

Nisqually River

A total of 142,000 coho smolts (rounded from 142,316) are estimated to have emigrated from the Nisqually River in 2023 (Table 1). Smolt abundance was estimated above a main-stem trap (river mile 12) and expanded for non-trapped portions of the watershed. The main-stem trap was calibrated using recaptures of marked wild coho that are released upstream of the trap; a smolt abundance estimate was based on a time-stratified Petersen estimator (Carlson et al. 1998; Volkhardt et al. 2007).

Smolt production above the trap (river mile 12) was estimated to be 111,722 (±16,679 95% C.I.) smolts. This production represented an 7% increase from the geometric mean of 104,755 smolts between the 2009 and 2023 ocean entry years (Figure 13). This estimate was 96.7% of the 115,554 smolt potential predicted by Zillges (1977). Total smolts above and below the trap were estimated to be 30,594 assuming that smolt production was also 96.7% of the 31,643 smolt potential predicted by Zillges (1977) below the trap (= 111,722 + (31,643 * 0.967).

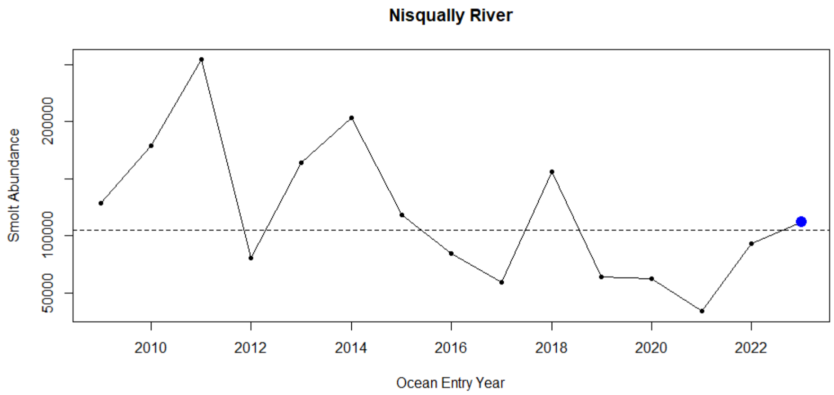

Figure 13. Time series of natural-origin coho smolts from the Nisqually River above the smolt trap (rm 12), ocean entry years 2009 to 2023. Blue point represents outmigration of the cohort included in this forecast. Horizontal line is the geometric mean for the time series.

Deschutes River

A total of 17,000 natural-origin coho smolts (rounded from 16,874) are estimated to have emigrated from the Deschutes River in 2023 (Table 1). The 2023 production estimate was based on smolts captured at a trap below Tumwater Falls. The estimate was calculated by expanding the total catch (4,168) by a historic capture efficiency estimate of 24.7% (4,168 / 0.247 = 16,874). The 2023 production estimate is the last to be produced from this location due difficulties producing natural-origin estimates in recent years on account of hatchery fry plants and recreational activities occurring near the trap.

The 2023 production represents a decrease of 7% from the geometric mean of 18,089 smolts between the 1979 and 2023 ocean entry years (Figure 14) and was just 7.7% (16,874 / 219,574) of the smolt potential estimated by Zillges (1977). Production of coho smolts in the Deschutes River is primarily limited by spawner escapement (Figure 15), which has been severely depressed over the past two decades. Two of the three brood lines have been virtually extinct during this time frame. Efforts to increase production in the Deschutes River watershed were initiated in 2013 by releasing hatchery adults upstream in the fall and hatchery fry in the spring. For the 2021 brood, 649 females (combination of natural-origin and hatchery-origin) were released upstream of Tumwater Falls to spawn. Freshwater productivity from this spawner escapement was 26 smolts-per-female, much lower than productivity expected from typical density-dependent freshwater relationships for coho salmon (Figure 2).

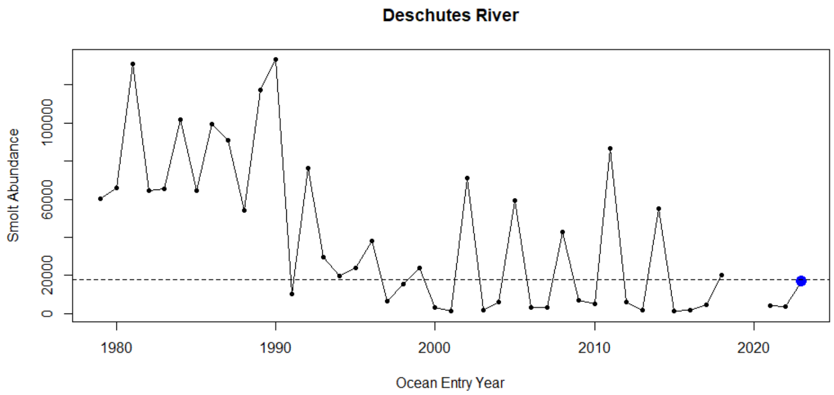

Figure 14. Time series of natural-origin coho smolts from the Deschutes River, ocean entry years 1979 to 2023. There was no trapping in 2019 and 2020. Blue point represents outmigration of cohort included in this forecast. Horizontal line is the geometric mean of the time series.

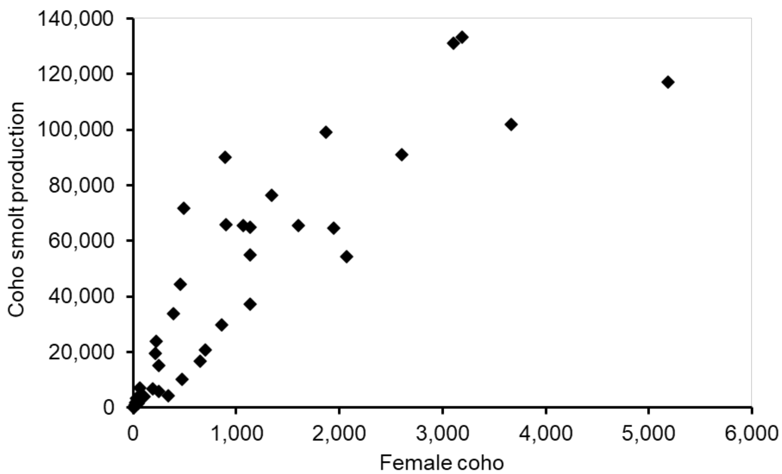

Figure 15. Coho smolt production as a function of female spawners in the Deschutes River, Washington, brood years 1978-2021.

South Sound

A total of 152,000 coho smolts (rounded from 152,290) are estimated to have emigrated from South Sound tributaries in 2023 (Table 1). This estimate was based on results of smolt monitoring in Mill, Skookum, and Goldsborough creeks conducted by the Squaxin Island Tribe (data provided by D. Kuntz, Natural Resources Department, Squaxin Island Tribe). The wild coho smolt estimate for Mill Creek was 3,922 smolts (7.0%). The smolt estimate for Skookum Creek was 2,265 (7.8%) and Goldsborough Creek was 115,634 smolts (161.4%). Numbers in parentheses show the variable proportion of the smolt potential observed in these tributaries (Zillges 1977). Gosnell Creek is the upper extent of Mill Creek above Lake Isabella and no production estimate was generated in 2023 for this portion of the Mill Creek watershed. Other tributaries that have been monitored in the past, but were not in 2023, include Cranberry, Johns, and Sherwood creeks. Localized conditions among small creeks can lead to among-watershed variability that is dampened in large river systems. This variability makes extrapolation monitoring results from a few small creeks to a management unit more uncertain, especially because the creeks are not selected randomly for monitoring.

In general, South Sound tributaries are influenced by a combination of factors including low spawner returns to South Sound (as observed in the Deschutes River) and degraded habitat conditions in this region. Throughout the time series of smolt data collected by the Squaxin Tribe, Goldsborough Creek has consistently produced a higher proportion of its production potential than the other six monitored tributaries and is unlikely to represent current conditions in many of the small creeks in this management unit. Therefore, the 2023 coho production for the South Sound management unit was estimated in two steps – smolt estimate for Goldsborough Creek (115,634) was added to an extrapolated estimate for all other tributaries in this management unit. The extrapolated estimate for other tributaries (not including Goldsborough Creek) was 36,656, which was 7.3% applied to the Zillges production potential of 502,142 smolts for these watersheds. The rate of 7.3% represents the 2023 proportion of the overall production potential observed in Mill Creek and Skookum Creek. Coho production for the entire South Sound management unit was estimated to be 152,290 smolts (= 36,656 + 115,634), which is 26.5% of the 573,770 smolt potential for all watersheds in this management unit (including production above Minter hatchery rack) predicted by Zillges (1977).

Coastal Systems Smolt Abundance

Approach

Major coho producing basins in Coastal Washington range in watershed characteristics and hydrology. On the north coast, the rivers drain westward from the Olympic Mountains and are higher gradient with a transitional hydrology influenced by both winter rains and spring snow melt. In the southwest coast, rivers are low gradient with rain-fed rivers that drain into Grays Harbor and Willapa Bay. Additional independent tributaries lack the complexity of the larger watersheds and have primarily rain-driven hydrology. Where juvenile trapping studies have been conducted, smolt production has averaged 417 to 1,021 smolts per unit (mi^2) of drainage area (Table 3). Smolt densities in low-gradient watersheds, such as the Chehalis (Grays Harbor) or Dickey (tributary to the Quillayute) rivers, are typically higher than high-gradient watersheds, such as the Clearwater (Queets tributary) or Bogachiel (Quillayute tributary) rivers.

In 2023, WDFW estimated wild coho smolt abundance in the Chehalis River using a predictive relationship between stream flows and smolts (Grays Harbor management unit). Smolt abundance in the Queets River management unit was available due to a juvenile monitoring program conducted by the Quinault Division of Natural Resources. Smolt abundance data was also available from the Dickey and Bogachiel rivers in the Quillayute watershed due to a juvenile monitoring program conducted by the Quileute Tribe. In coastal watersheds where smolt monitoring did not occur in 2023, wild coho smolt abundance was estimated by applying a smolt density (smolts/mi^2) from monitored watersheds to the non-monitored watersheds (drainage areas provided in Appendix B). Among the factors considered when applying a smolt density to each watershed were baseline data (historical smolt estimates), watershed geomorphology (i.e., gradient), harvest impacts, and habitat condition.

Table 3. Wild coho smolt production and production per unit drainage area (smolts/mi^2) measured for coastal Washington watersheds. Data from the Clearwater and Queets rivers were provided by the Quinault Nation (T. Jurasin). Average values are arithmetic means.

		Coho smolt production			Production/mi^2		
Watershed	Number of years	Average	Low	High	Average	Low	High
Dickey (Quillayute)	3	71,189	61,717	77,554	818	709	891
Bogachiel (Quillayute)	3	53,751	48,962	61,580	417	380	477
Clearwater (Queets)	42	67,964	27,314	134,052	485	195	958
Queets (no Clearwater)	40	190,425	53,473	352,694	614	172	1,138
Chehalis (Grays Harbor)[a]	40	2,158,198	502,918	3,769,789	1,021	238	1,783

[a]Data summary excludes 1993 return when tag recoveries were too few to provide a reliable estimate.

Queets River

A total of 288,000 (rounded from 288,225) wild coho smolts are estimated to have emigrated from the entire Queets River watershed in 2023 (Table 1). This estimate was based on coho smolt data collected and analyzed by the Quinault Tribe (T. Jurasin, Quinault Division of Natural Resources, personal communication) and includes smolts from the Clearwater River. Smolt abundance from the Clearwater River alone was estimated to be 78,349 wild coho smolts (560 smolts/mi^2). Smolt abundance from the Queets River (without the Clearwater) was estimated to be 209,876 wild coho smolts (677 smolts/mi^2).

Quillayute River

A total of 192,000 coho smolts (rounded from 192,068) are estimated to have emigrated from the Quillayute River system in 2023 (Table 1). This estimate is based on coho smolt data measured in the Quillayute watershed in 2023 by West Fork Environmental and the Quileute Nation (C. Wagemann, Quileute Natural Resources, personal communication). Smolt abundance from the Dickey River alone was estimated to be 27,432 wild coho smolts and applied to the 108 mi^2 watershed (254 smolts/mi^2). Smolt abundance from the Bogachiel, Calawah, and Sol Duc rivers was estimated to be 164,636 wild coho smolts and was determined from the average Bogachiel production value (316 smolts/mi^2) applied to the 521 mi^2 of the Quillayute watershed, excluding the Dickey River sub-basin. This was a 23% decrease over the 2021-2023 average (geomean) of 248,597 smolts and due to low Dickey River production. In the past, abundance was based on historic measurements in two sub-basins of the Quillayute River and a current year-to-historical smolt abundance ratio in the Clearwater River (Queets management unit). Both estimates are provided for comparison.

In the Quillayute watershed, smolt production was measured historically in the Bogachiel and Dickey rivers. Coho smolt abundance above the Dickey River trap (87 mi^2) averaged 71,189 coho (818 smolts/mi^2) between 1992 and 1994. Coho smolt abundance above the Bogachiel River trap (129 mi^2) averaged 53,751 smolts (417 smolts/mi^2) over three years (1987, 1988, and 1990). The difference in smolt densities between watersheds was hypothesized to result from additional rearing habitat in the lower gradient Dickey River when compared to the Bogachiel River (Seiler 1996). This interpretation is further supported by the relatively high smolt densities observed in other low-gradient systems such as the Chehalis River (Table 3). Lower gradient topography may increase access to and availability of summer and winter rearing habitats (Sharma and Hilborn 2001).

During the period of historical monitoring in the Dickey and Bogachiel rivers, average wild coho smolt abundance was estimated to be 306,000 smolts for the entire Quillayute watershed (Seiler 1996). The watershed average was based on estimated production above and below the Dickey River smolt trap summed with coho smolts in the remainder of the basin. Average production for the entire Dickey River sub-basin was estimated by applying smolt densities above the trap (818 smolts/mi^2) to the total drainage area (108 mi^2), resulting in 88,344 smolts. Average smolt abundance for the Quillayute system outside the Dickey River was estimated by applying the smolt densities above the Bogachiel trap (417 smolts/mi^2) to the 521 mi^2 of the Quillayute watershed (excluding the Dickey River sub-basin), resulting in 217,257 smolts. The sum of these estimates totaled 306,000 smolts (rounded from 305,601).

The 2023 Quillayute coho production estimate using the historic method was based on previously measured smolt abundance adjusted by the ratio of current year to previously measured smolt abundance in the Clearwater River. An expansion factor of 1.28 was the ratio of Clearwater River production in 2023 (78,349) to average Clearwater River production between 1992 and 1994 (78,349 / 61,000 = 1.28) for the Dickey River and an expansion factor of 1.24 was the ratio of Clearwater River production in 2023 (78,349) to average Clearwater production in 1987, 1988, and 1990 (78,349 / 63,333 = 1.24) for the Bogachiel River. Because historical smolt densities differed between the Dickey and Bogachiel rivers, separate estimates were developed for two portions of the Quillayute River watershed. The 2023 coho smolt abundance in the Dickey River was estimated to be 113,470 smolts (1.28 * 88,344 smolts). The 2023 coho smolt abundance in the Quillayute (excluding the Dickey) was estimated to be 268,766 smolts (1.24 * 217,257 smolts). The 2023 coho production of 382,000 smolts using the historic method was the rounded sum of these estimates (113,470 + 268,766 = 382,236) and was nearly double the smolt abundance measured using smolt traps in 2023.

Hoh River

A total of 167,000 wild coho smolts are estimated to have emigrated from the Hoh River in 2023 (Table 1). Smolt abundance was not directly measured in the Hoh River watershed; therefore, the estimate was based on smolt densities in the Clearwater River. The Hoh and Clearwater rivers have similar watershed characteristics as well as regional proximity. The smolt density of 560 smolts/mi^2 from the Clearwater River was applied to the 299-mi^2 of the Hoh watershed and resulted in an estimated 167,000 smolts (rounded from 167,331) from the Hoh River system.

Quinault River

A total of 294,000 wild coho smolts are estimated to have emigrated from the Quinault River in 2023 (Table 1). Smolt abundance was not directly measured in this watershed; therefore, the estimate was based on smolt densities in the Queets River system. For 2023, a production rate of 677 smolts/mi^2 was applied to the 434-mi^2 Quinault River system, resulting in an estimated 294,000 smolts (rounded from 293,826).

Independent Tributaries

A total of 203,000 wild coho smolts are estimated to have emigrated from the independent tributaries of Coastal Washington in 2023 (Table 1). Coho smolt production has not been directly measured in any of the coastal tributaries. For 2023, the five-year average production rate of 479 smolts/mi^2 from the Queets River system was applied to the total area of these watersheds (424 mi^2; Appendix B), resulting in an estimated 203,000 smolts (rounded from 203,096).

Grays Harbor

A total of 2,682,000 (rounded from 2,681,682) wild coho smolts are predicted to have emigrated from the Grays Harbor system in 2023 (Table 1). This estimate was derived in two steps. Wild coho production was first estimated for the Chehalis River (*n* = 2,223,167). Smolt abundance per unit watershed area of the Chehalis River system was then applied to the Grays Harbor tributaries (*n* = 195,605, Hoquaim, Johns, and Elk rivers) and the Humptulips River (*n* = 262,910).

Coho smolt abundance in the Chehalis River is estimated using a mark-recapture method. Smolts are coded-wire tagged and released from a juvenile trap on the Chehalis main stem (RM 52) and Bingham Creek (right bank tributary to the East Fork Satsop River at RM 17.4). These tag groups are expanded to a basin-wide smolt abundance based on the recaptures of tagged and untagged wild coho in the Grays Harbor terminal net fishery. Coded-wire tag recoveries in this fishery are processed and reported by the Quinault Tribe (T. Jurasin, Quinault Division of Natural Resources, personal communication). Smolt abundance is estimated after adults have passed through the fishery and returned to the river.

Smolt abundance estimates from the mark-recapture method are not available in the year that coho recruit into the fishery; therefore, the run size forecasts are based on a modeled smolt estimate. In previous forecasts, predictive models have been explored flow metrics associated with spawning, incubation, and rearing flows (Seiler 2005; Zimmerman 2015). These relationships are biologically relevant, but their stability has depended on the time period used for analysis. The current predictive model includes metrics of summer and overwinter rearing flows (Figure 16). Although incubation flows are also correlated with smolt production, including this variable does not improve model fit and therefore incubation flows were not used in the predictive model. For the 2022 ocean entry year (2023 return), this model predicted a smolt abundance of 2,468,076 (2,168,314 – 2,809,279) which was lower than the back-calculated mark-recapture estimate of 3,005,648 (1,766,828 – 4,244,468, 95% C.I.).

In the 2023 ocean entry year, coho smolts were associated with above average incubation flows, below average summer flows, and below average overwinter flows as measured at USGS gage #12027500, Grand Mound (Figure 16). The 2023 smolt production was predicted to be 2,223,167 (2,063,954 – 2,394,662, 95% C.I.) based on the multiple regression model including summer and overwinter flows. This prediction is 3.0% higher than the time series average of 2,158,198 wild coho smolts.

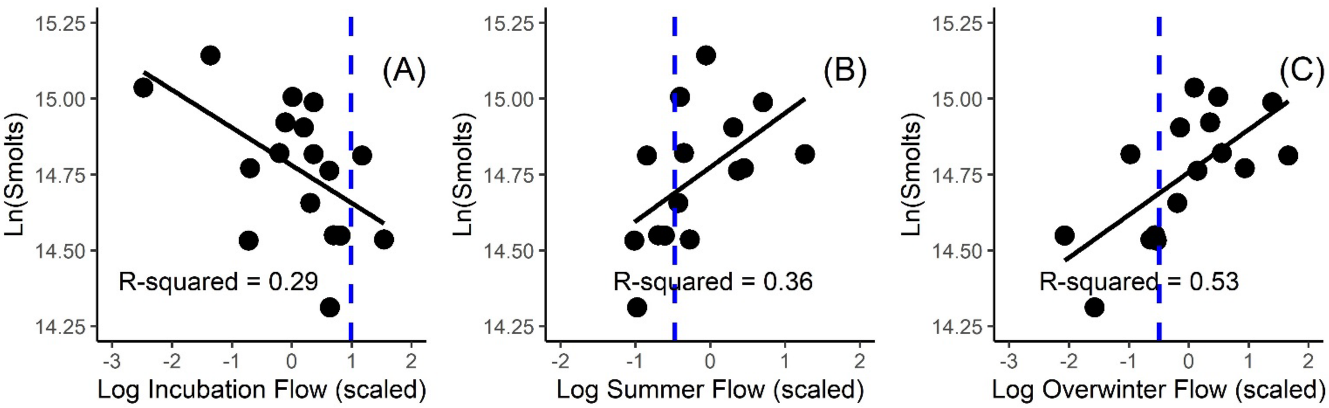

Figure 16. Chehalis River wild coho smolt production as a function of incubation flows (a), summer rearing flows (b), and overwinter rearing flows (c) for ocean entry year 2001-2023 as measured at USGS gage #12027500 in Grand Mound. Incubation flows are the cumulative daily mean flow between December 1 and March 1. Summer rearing flows are maximum daily flows in the month of August. Overwinter rearing flows are minimum daily flows between November 1 and February 28. Three data points were removed (OEY 2004, 2006, and 2015) because of high leverage on the regressions. Vertical blue dashed line indicates the conditions associated with the 2023 ocean entry year.

Coho smolt abundances in other portions of the Grays Harbor management unit were estimated from the smolt densities for the Chehalis River basin. Abundance per unit area for the Chehalis basin including the Wishkah River was 1,052 smolts/mi^2 (2,223,167 smolts per 2,114 mi^2). A total of 195,605 coho smolts are estimated for the tributaries of Grays Harbor (1,052 smolts/mi^2*186 mi^2, including the Hoquiam, Johns, and Elk Rivers and other south side tributaries downstream of the terminal treaty net fishery). Coho smolt abundance from the Humptulips River was estimated to be 262,910 smolts (1,052 smolts/mi^2*250 mi^2). After summing smolt abundance estimates for all watersheds in the Grays Harbor management unit, total wild coho production in 2023 was estimated to be 2,681,682 smolts (2,223,167 + 195,605 + 262,910 = 2,681,682).

Willapa Bay

A total of 680,000 coho smolts are estimated to have emigrated from the Willapa Bay basin in 2023 (Table 1). As smolt abundance was not directly measured, this estimate is based on smolt densities in the Chehalis Basin. The Willapa Basin consists of four main river systems and several smaller tributaries. Like Grays Harbor, rivers in the WIllapa Bay management unit are low gradient with rain-dominant hydrology. But in comparison to Grays Harbor, Willapa Bay has a high harvest rate (limiting escapement) and degraded freshwater habitat which may result in lower wild coho smolt densities than observed in the Chehalis Basin. Wild coho production in 2023 (680,000 smolts) was calculated by applying 800 smolts/mi^2 production rate to the total basin area (850 mi^2).

Lower Columbia Smolt Abundance

Approach

Coho smolt abundance is monitored in a subset of Lower Columbia watersheds. The association between coho salmon smolt abundance and watershed size is observed across the Pacific Northwest from Oregon to British Columbia (Bradford et al. 2000). In this forecast, coho smolt abundance in non-monitored watersheds was estimated based on the size of the non-monitored watersheds and smolt densities in monitored watersheds (smolts per watershed area). As described below, the extrapolation to non-monitored watersheds was done separately for systems with primarily natural spawners versus those influenced by hatchery programs.

In 2023, coho smolt abundance was directly monitored in seven watersheds using floating surface collectors or partial-capture juvenile traps and a mark-recapture study design. Coho salmon smolt abundance estimates were calculated using a mark-recapture study design appropriate for single trap designs (Bjorkstedt 2005; Carlson et al. 1998). Estimates are preliminary where noted. The numbers used for this forecast are believed to be relatively unbiased because estimates were obtained from a census or mark-recapture study, where care was taken to meet the assumptions required for unbiased abundance estimates (Seber 1982; Volkhardt et al. 2007). Monitored watersheds include Grays River, Mill Creek, Abernathy Creek, Germany Creek, upper North Fork Lewis River, Tilton River, and upper Cowlitz/Cispus rivers.

The smolt monitoring sites were not randomly selected but represent a range of types of watersheds in Washington portion of lower Columbia River ESU. They include streams with a range of hatchery spawner proportions as well as streams of varying size and habitat condition. Watersheds ranged in size from 26 square miles in the Grays River to 1,042 square miles in the Upper Cowlitz River. Habitat in monitored sub-watersheds includes land managed for timber production, agriculture, and rural development. Monitored populations were partitioned into “hatchery” and “wild” systems. “Hatchery monitored” systems were the Grays River, upper North Fork Lewis River, Upper Cowlitz, and Tilton River, where high levels of hatchery coho in the spawning population result from hatchery production in the watershed (i.e., Grays) or deliberate releases of hatchery coho for recolonization purposes (i.e., Tilton, Upper Cowlitz). “Wild monitored” populations were Mill Creek, Abernathy Creek, and Germany Creek. Although these watersheds have no operating coho hatcheries, hatchery coho salmon do stray and spawn in them. In addition, the forecast made use of historical time series from Coweeman River, a “wild” system, and Cedar Creek, which were not monitored in 2023. Cedar Creek is not considered to be representative of unmonitored watersheds because coho smolt production densities in this low gradient watershed are consistently more than twice that of other watersheds (Zimmerman 2015).

Non-monitored watersheds were also partitioned into “hatchery” and “wild” for the purpose of extrapolating smolt production. “Non-monitored hatchery” watersheds included the Elochoman, Green, Kalama, Lower Cowlitz, Lewis, and Washougal rivers. Non-monitored smolt abundance from the Toutle and NF Toutle Rivers included only drainage areas from tributaries. Habitat in the Toutle mainstem, which is still recovering from the eruption of Mt. St. Helens, was assumed to produce few smolts.

Grays River

The Grays River juvenile trap is located at river mile 6. Based on a watershed area of 26 mi^2 and a 2023 estimate of 2,978 natural-origin yearling smolts and 1,166 subyearling smolts, the 2023 coho smolt total was 4,144 with a density of 159 smolts/mi^2 (Table 4 and Table 5).

Mill, Abernathy, and Germany Creeks

Juvenile traps on Mill, Abernathy, and Germany creeks are located near the mouth of each creek. The 2023 coho smolt density from these watersheds ranged between 337 and 601 smolts/mi^2 (Table 4). A total of 37,827 natural-origin yearling coho smolts were estimated to have emigrated from all three watersheds in 2023 (Table 5). This included 9,763 smolts from Mill Creek, 17,435 smolts from Abernathy Creek, and 10,629 smolts from Germany Creek.

North Fork Lewis River

The North Fork Lewis River juvenile trap is the collection facility at Swift Dam. Smolt data were provided by Chris Karchesky (Pacificorps). A total smolt production estimate from the 731 mi^2 of watershed above the dams is not available. A total of 70,913 natural-origin coho parr and smolts, captured at Swift Dam between October 2022 and July 2023, were transported, and released into the North Fork Lewis River below the dams (Table 5).

Tilton River

Juveniles emigrating from the Tilton River are captured at Mayfield Dam in the Cowlitz River watershed. Smolt data were provided by Scott Gibson (Tacoma Power). Annual efficiency data are not available but preliminary collection efficiency for this site in 2013 was estimated to be 88.5% by Tacoma Power and Hydroacoustic Technology Inc. (M. LaRiviere, Tacoma Power, personal communication). The smolt estimate included the coho smolts captured at the Mayfield downstream collector (30,294) plus the number estimated to pass through the turbine (3,932 = 34,226 – 30,294) multiplied by an assumed 85% survival (33,636 = 30,294 + 3,932 * 0.85).

Based on a watershed area of 159 mi^2 and a preliminary 2023 estimate of 34,226 natural-origin smolts emigrating from the Tilton River, coho smolt density was estimated to be 215 smolts/mi^2 (Table 4 and Table 5).

Upper Cowlitz River

The Upper Cowlitz River juvenile trap is the collection facility at Cowlitz Falls Dam. Based on a watershed area of 1,042 mi^2 and an estimate of 171,901 smolts produced above Cowlitz Falls, coho smolt density of the Upper Cowlitz River was estimated to be 165 smolts/mi^2 in 2023 (Table 4). Smolt data were provided by John Serl (WDFW) on behalf of Tacoma Power. The total number of natural-origin coho emigrating from the Upper Cowlitz is the sum of all smolts captured at Cowlitz Falls Dam that were transported and released into the Lower Cowlitz River (Table 5).

Coweeman River

Coho smolt abundance from the Cowlitz River was not monitored in 2023. Historically, a rotary screw trap was operated at river mile 7.5 of the Coweeman River, a tributary to the Cowlitz River and recent (10-yr) smolt abundance averaged 15,148 (2009-2018 geometric mean, Table 5). Based on a watershed area of 119 mi^2, the natural-origin coho smolt density from the Coweeman River averaged 127 smolts/mi^2 (Table 4 and Table 5).

Cedar Creek

Coho smolt production from Cedar Creek, a tributary to the NF Lewis, was not monitored in 2023. Historically, a juvenile trap was operated at river mile 2 of Cedar Creek and annual smolt abundance averaged 36,294 smolts (2007 to 2016 geometric mean, Table 5). This estimate includes smolts resulting from the Remote Site Incubation (RSI) program that has been in place in Cedar Creek since 2004. Based on a watershed area of 53 mi^2, the natural-origin coho smolt density of Cedar Creek averaged 675 smolts/mi^2 during the time frame that the trap was operated (2007 to 2016 geometric mean, Table 4).

Cedar Creek coho smolt densities are consistently higher than other Lower Columbia watersheds. Higher densities may be due to abundant low gradient habitat in this sub-watershed, seeding of this habitat with hatchery and wild spawners, and ongoing recovery activities including placement of surplus hatchery carcass and habitat restoration. For these reasons, Cedar Creek smolt densities were not applied to smolt densities in non-monitored watersheds. The 2023 smolt production was assumed to be the time series average of 36,294 smolts.

Wind River

As in previous years, all coho salmon juveniles captured in the Wind River were classified as parr, and no coho smolt estimate was generated for this sub-basin.

Non-monitored "Hatchery" Watersheds

Coho smolt production from non-monitored "hatchery" watersheds was estimated to be 144,808 smolts (Table 5). This estimate was derived from an average smolt production density of 180 smolts/mi^2 in "hatchery monitored" watersheds and an estimated 805 mi^2 of non-monitored drainage area.

Non-monitored "Wild" Watersheds

Coho smolt production from non-monitored "wild" watersheds was estimated to be 289,341 smolts (Table 5). This estimate was derived from an average smolt production density of 467 smolts/mi^2 in "wild monitored" watersheds and an estimated 620 mi^2 of non-monitored drainage area.

Total Lower Columbia Smolt Abundance

In total, 804,000 natural-origin coho smolts (rounded from 804,012) are estimated to have emigrated from the Washington Lower Columbia region in 2023 (Table 1). The 2023 smolt production in watersheds with hatchery production had an 12% decrease from the 10-yr average (2013 to 2022), and watersheds without hatchery production had a 86% increase from the 10-yr average (Figure 17). This smolt abundance should be considered a minimum number as the number of coho rearing and smolting in the Columbia River proper is unknown. Each year, coho parr (subyearlings) are observed emigrating past the trap sites, and, if they survive, these juveniles also contribute to natural production in subsequent years.

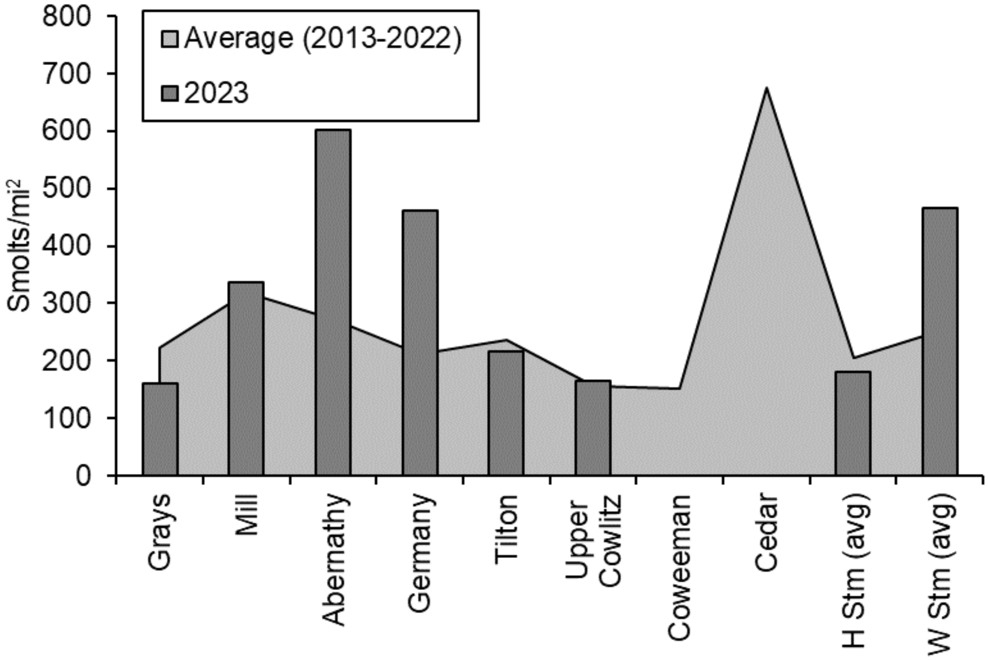

Figure 17. Coho smolt densities (smolts per mile^2 of watershed area) in eight Lower Columbia tributaries in Washington State. Graphs shows the 2023 density (bars) relative to the average smolt abundance from these watersheds (2013-2022).

Table 4. Smolt densities in 2023 from monitored coho salmon streams in the Lower Columbia River ESU. No data were collected from the Coweeman River or Cedar Creek in 2023.

Watershed	Density n/mi^2
Grays	159
Mill	337
Abernathy	601
Germany	462
Tilton	215
Upper Cowlitz	165
Coweeman*	127
Cedar*	685
Hatchery Streams	180
Wild Streams	467

*Values based on recent (10-yr) geometric means

Table 5. Coho smolt emigrants in 2023 from the Lower Columbia Evolutionary Significant Unit including monitored streams, non-monitored streams with hatcheries, and non-monitored streams without hatcheries.

Watershed	n
Grays	4,144
Mill	9,763
Abernathy	17,435
Germany	10,629
NF Lewis	70,913
Tilton	33,636
Upper Cowlitz	171,901
Coweeman*	15,148
Cedar*	36,294
Non-monitored Hatchery Streams	144,808
Non-monitored Wild Streams	289,341
Total Smolt Emigration	804,012

* Values based on recent (10-yr) geometric means

Marine Survival

Approach

Sibling regressions are a common forecasting tool and have been used to predict marine survival in earlier wild coho forecasts produced by WDFW Fish Science (Seiler 1996; Zimmerman 2011). If survival of coho salmon in the first few months of marine rearing sets the survival trajectory for the 18-month ocean period (Beamish and Mahnken 2001; Beamish et al. 2004), then one might expect that jack coho (males that rear for just 6 months in marine waters) should be a consistent proportion of the adult (age-3) coho returning one year later. However, recent inter-annual variation in the jack:adult return ratios for wild coho salmon have led to the need for alternate predictors of adult coho marine survival. Work to improve marine survival predictions has been fueled by the increasing interest in ocean indicators, both through ocean monitoring and research on the continental coastal shelf off Oregon and Washington states (NWFSC surveys) and through the Salish Sea Marine Survival project facilitated by Long Live the Kings (Sobocinski et al. 2021). Beginning in 2012, multiple regression forecasts were developed using environmental variables as predictors of marine survival (e.g., Zimmerman 2012; Kendall et al. 2019; Litz 2020), updating the previous approach based on sibling regressions (Seiler 1996; Zimmerman 2011). For this forecast, environmental indicators were applied using generalized additive models, updating previous methods of using sibling or multiple regression. Promising new work (DeFilippo et al. 2021) using a spatiotemporal integrated population model is also being explored as an alternative forecasting approach for the future.

Indices of North Pacific atmospheric conditions are broadly predictive of salmon marine survival (Beamish et al. 1999; Beamish et al. 2000; Mantua et al. 1997) and multiple studies have demonstrated predictive correlations between physical conditions in the ocean (e.g., sea surface temperature, upwelling, spring transition timing) and coho marine survival (Logerwell et al. 2003; Nickelson 1986; Ryding and Skalski 1999). For Washington stocks, salmon marine survival is positively correlated with salinity (high salinity = high survival) and negatively correlated with temperature (low temperature = high survival). Despite the available support for these predictive correlations, the ecosystem mechanisms that explain connections between ocean processes, indicator values, and salmon survival are less well understood.

Studies that have explored synchronicity across stocks have identified a spatial structure to coho salmon survival occurring at a finer scale than the atmospheric/ocean indicators (Beetz 2009; Teo et al. 2009; Zimmerman et al. 2015). For this reason, a suite of “Ocean Scale,” “Region Scale,” and “Local Scale” indicators were selected to predict marine survival for Washington coho stocks. A detailed description of the indicator data and their sources are provided in Appendix C. “Ocean Scale”, or atmospheric indicators are the broadest scale and were applied to all coho stocks. “Region Scale” indicators were differentially selected for the Washington Coast and Lower Columbia stocks versus the Puget Sound stocks. Selection of Region Scale indicators assumed that different oceanographic processes affect early rearing in the Puget Sound estuary than the Pacific Ocean coastal shelf of Oregon and Washington states. This assumption is supported by the findings that Puget Sound oceanographic properties are more closely correlated with local environmental parameters than large-scale climate indices (Moore et al. 2008a) and the observation that temporal patterns of coho salmon marine survival have differed between these regions (Beetz 2009; Coronado 1998; Zimmerman et al. 2015). The Puget Sound region is further broken into "Local Scale" indicators associated with each of its oceanographic sub-basins (Babson et al. 2006; Moore et al. 2008b). Local indicators are selected based on the variables previously identified as contributing to local oceanographic conditions within each basin (Babson et al. 2006; Moore et al. 2008a).

Marine Survival Estimates

Marine survival is estimated for index populations in nine coho management units (MU) – seven in Puget Sound (including the Strait of Georgia/Nooksack and Strait of Juan de Fuca), one in coastal Washington, and one in the Lower Columbia. Four of the monitored populations (Big Beef Creek in Hood Canal MU, Baker River in Skagit MU, Deschutes River in Deschutes MU, Bingham Creek in Grays Harbor MU) were established by WDFW as long-term wild coho monitoring programs in the late 1970s. Marine survival time series in the remaining four management units (Strait of Georgia/Nooksack MU, Green/Duwamish MU, Snohomish MU, Strait of Juan de Fuca MU, Lower Columbia MU) have been derived more recently in order to better represent the geographic extent of Washington stocks. The methods used for these latter estimates are subject to additional uncertainty based on various assumptions made in the calculations.

In management units with index populations that are part of WDFW's long-term coho monitoring program (Hood Canal MU, Skagit River MU, Deschutes River MU, Grays Harbor MU), marine survival is estimated based on the release and recovery of coded-wire tagged coho for each index population. Wild coho smolts are coded-wire tagged during the outmigration period and recaptured as jack (age-2) and adult (age-3) coho during fishery sampling and in upstream weir traps. The smolt tag group is adjusted downward by 16% for tag-related mortality (Blankenship and Hanratty 1990) and 4% for tag loss (WDFW, unpubl. data). Jack return rate is the harvest (minimal to none) and escapement of tagged jacks divided by the adjusted number of tagged smolts. Adult marine survival is the sum of all tag recoveries (harvest + escapement) divided by the adjusted number of tagged smolts. Coast-wide tag recovery data were accessed through the Regional Mark Information System database (RMIS, https://www.rmpc.org/).

In management units in the central basin of Puget Sound (Lake Washington, Green River, East Kitsap, Puyallup), identifying an appropriate data source has been problematic due to the lack of a coho life cycle monitoring program in this sub-basin of Puget Sound. The marine survival estimate used for these MUs is based coded-wire tagged coho releases and recoveries of hatchery smolts released from Soos Creek hatchery (smolts/[harvest + escapement]). Forecasts based on the survival time series of hatchery coho are likely to predict marine survivals that will be lower compared to wild coho marine survivals (Zimmerman et al. 2015). Future work is needed to develop a wild coho adjustment factor or initiate a wild coho life cycle monitoring program in the Puget Sound central basin.

In the Snohomish and Stillaguamish management units, marine survival is estimated from data collected in the South Fork Skykomish River (Snohomish). Marine survival for the South Fork Skykomish River was directly measured using coded-wire tags for ocean entry year 1978 through 1986. For ocean entry year 1987 and later, marine survival has been estimated from historical average smolt production above Sunset Falls (276,000 smolts if adult escapement ≥9,000 or 198,000 smolts if adult escapement is <9,000), adult coho escapement at the Sunset Falls trap, and exploitation rates calculated from Wallace hatchery coho coded-wire tag groups (CWT/non-mark since 1996). This estimate assumes that average smolt production above Sunset Falls has not changed and that harvest rates of hatchery and wild coho are comparable (non-marked hatchery coho since 1996).

In the Strait of Georgia management unit, marine survival is estimated from the smolts and ocean age-3 abundance measured at Black Creek in British Columbia, Canada. In the Juan de Fuca management unit, marine survival is estimated from the smolts and the ocean age-3 abundance of the entire management unit. Smolt estimates for the Juan de Fuca management unit are described in the section above (provided by Hap Leon, Makah Tribe). Ocean age-3 abundance is the summed estimate of coho spawner escapement and harvest (terminal and pre-terminal) and is calculated annually by the Coho Technical Committee of the Pacific Salmon Commission. This time series is available between the 1998 ocean entry year and present, although the ocean-age 3 reconstruction is two years delayed from the current return year.

In the Lower Columbia River management unit, a time series for natural-origin coho marine survival is available from the Cowlitz River. For the 2001 to 2010 ocean entry years, natural coho smolts from the Tilton River (above Mayfield dam) were coded-wire tagged prior to outmigration. For the 2012 to 2022 ocean entry years, natural coho smolts from the Upper Cowlitz (above Cowlitz Falls dam) were coded-wire tagged prior to release (data provided by J. Serl, WDFW). Returns of tagged coho to the barrier dam collection facility were expanded by the Columbia River natural coho exploitation rates calculated by the Oregon Production Index Technical Team (OPITT data provided by S. Conley, WDFW).

Variables Selected as Potential Indicators

Additional detail and data sources for marine variables explored in this forecast are provided in Appendix C.

At the “Ocean Scale,” indices provided by NOAA Northwest Fisheries Science Center (NWFSC) ocean monitoring research program are applied, including broad scale indices such as the Pacific Decadal Oscillation (PDO) and the Oceanic Niño Index (ONI, Appendix C). The PDO is based on patterns of variation in sea surface temperature in the North Pacific Ocean (Mantua et al. 1997). The ONI is based on conditions in equatorial waters that result from the El Niño Southern Oscillation. El Niño conditions result in the transport of warm water northward along the coast of North America and have variable effects on Washington coastal waters. In 2015, a third ocean scale indicator was added to the list of environmental indicators. The North Pacific Gyre Oscillation (NPGO) index is an indicator of salinity and nutrients in the areas of the North Pacific Ocean (Di Lorenzo et al. 2008) and is correlated with marine survival of coho salmon in Oregon coastal rivers (Rupp et al. 2012). The PDO and NPGO index are represented by prior winter (January to March) and ocean entry (May to September) time periods. Beginning in 2022, another factor was included in the analyses. Regime represents annual ocean conditions and is categorized as “cool” during brood years <2000 and strong La Niña years and “warm” during brood years ≥2000 and strong El Niño years. This index captures non-stationary variation in wild coho productivity through time (Litz et al. 2021)

At the “Region Scale,” a set of pre-developed indicators are applied to Washington Coast, Strait of Georgia, Strait of Juan de Fuca, and Lower Columbia management units and comparable indicators for Puget Sound. Regional indicators for the Washington Coast, Strait of Juan de Fuca, and Lower Columbia include temperature and salinity data as well as plankton and fish indices compiled and derived by the NWFSC ocean monitoring research program. The basis for these indicators and their relationship to

Columbia River salmon is updated annually by NWFSC scientists (Peterson et al. 2014). Regional indicators for Puget Sound include temperature and salinity data from in the Strait of Juan de Fuca, physical and biological data from Admiralty Inlet (WA Dept Ecology monitoring station), zooplankton data from the eastern Strait of Juan de Fuca (Keister et al. 2022), and the strength of upwelling at 48°N latitude, where smolts enter the Pacific Ocean from the Strait of Juan de Fuca. Strait of Juan de Fuca temperature and salinity data were compiled and derived from the Race Rocks lighthouse data set. Data from Admiralty Inlet was compiled from buoy data provided by the Washington Department of Ecology Marine Waters Monitoring Program (MWMP). Zooplankton data (Axis 2 from nonmetric multidimensional scaling ordinations May through September) provided by the University of Washington. Both Race Rocks and Admiralty Inlet were selected to represent the exchange of waters coming into and out of Puget Sound (Babson et al. 2006). The Bakun upwelling anomaly at 48°N was selected to represent the nutrient rich deep-sea water available for transport into Puget Sound. The time period selected for these indicators (April to June) represents conditions when wild coho salmon enter the marine environment.

At the "Local Scale," several variables are included as indicators as they relate to oceanographic sub-basins (and their respective management units) within Puget Sound. Oceanographic literature has described differences in circulation and conditions among these regions – San Juan Islands, Whidbey Basin, Central Sound, South Sound, and Hood Canal (Babson et al. 2006; Moore et al. 2008a; Moore et al. 2008b). Whidbey Basin is further split into the Skagit and Snohomish/Stillaguamish on the availability of coho marine survival data. Physical and biological data in these sub-basins are gathered at buoys deployed by the Washington Department of Ecology's MWMP. Physical variables include temperature and salinity in the upper 20 m of marine waters near each river mouth. River flows are obtained from the largest river in each sub-basin based on USGS stream flow gages. Freshwater flows may be linked to predation risk during outmigration or stratification of the early marine environment. Biological variables at the local scale included chlorophyll-a concentration and light transmission (%) in the upper 20 m of marine waters near each river mouth. Light transmission was assumed to be a proxy for plankton biomass (an assumption that will warrant further testing once a plankton sampling program becomes established in Puget Sound). A depth of 20 m was consistent with temperature indicators used by the NWFSC ocean monitoring research program and with observed swimming depths of juvenile coho salmon (Beamish et al. 2012). Temperature and salinity data are averaged between April and June, the time period that wild coho smolts enter marine waters. Chlorophyll-a and light transmission values are selected for the month of May, representing conditions at the peak of the wild coho outmigration into marine waters. In 2020, the Washington Department of Ecology MWMP was unable to sample from March to September due to the COVID-19 pandemic. Therefore, in 2020, three stations monitored by the King County Puget Sound Marine Monitoring Program were used as proxies.

Statistical Analyses

Generalized additive models (GAMs) are used to examine the relationships between marine survival and marine environmental variables for each population (Wood 2017). The analysis is limited to ocean entry years 1998-2022 to align survival estimates with available time series for indicator datasets. This date range also corresponds to the ecosystem conditions following the described regime shift for the northeast Pacific ecosystem in 1998 (Overland et al. 2008; Peterson and Schwing 2003) and includes the more recent period since 2014 characterized by non-stationary relationships between salmon production and climate indices (Litzow et al. 2020). The GAM modeling approach is flexible and can capture stationary (i.e., linear) or non-stationary relationships between indicators and marine survival. All analyses are completed in the R platform (R Core Team 2021).

Two GAM modeling approaches are used to estimate marine survival. The first uses a full-subsets information theoretic approach from a set of functions (FSSgam; https://github.com/beckyfisher/FSSgam) available for the R language (Burnham and Anderson 2002; Fisher et al. 2018). For this approach, a range of biologically relevant marine environmental variables are first scaled (i.e., transformed to have mean of zero and standard deviation of one) and then compared to each other with a correlation matrix using Pearson's correlation coefficient. The explanatory variables are ordered based on hierarchical clustering, such that groups (i.e., clusters) of highly correlated variables (r > 0.6) are determined. Continuous variables are selected from each cluster to avoid issues with multicollinearity and variance inflation in candidate forecast models. In addition to continuous variables, a fixed factor predictor variable representing thermal regime (cool regime: brood years <2000 plus strong La Niña years, warm regime: brood years 2000-2020 plus strong El Niño years) is included in the candidate set of possible indicators of marine survival. GAMs are fit with all possible combinations of fixed explanatory variables given that the estimated pairwise correlation between any two predictors in the same model is <0.28, consistent with recommendations from Fisher et al. (2018) and Graham (2003). The resulting list of candidate GAMs are then compared using Akaike information criterion corrected for small sample size (AICc). Models built within this framework assume wild coho marine survival has a gaussian distribution with an identity link function, and dimensions of the smooth function (thin-plate regression spline) for each parameter is restricted to 5 five (i.e., degrees of freedom) to prevent overfitting.

The second approach uses a global generalized additive mixed model (GAMM), evaluated by dredging, to select the most parsimonious model based on AICc with the MuMIn package in R. These models are an extension of GAMs in that they allow for the inclusion of random effects and correlation structures. In this case, the global GAMM includes an autoregressive corAR1 error structure by ocean entry year to account for temporal autocorrelation (representing an autocorrelation structure of order one, to control for the lack of independence at adjacent time points), and random effect of ocean entry year to explore yearly variability and possible non-linear trends not captured by fixed effects. All other model arguments are similar to the first approach (i.e., full-subsets GAM approach). Explanatory variables included in the global model are selected if they fall within ten AICc of the top model using the full-subsets GAM approach. The output of the top model is assessed using the gam.check function.

For each of the two forecasting approaches (full-subsets GAM and GAMM) the gam.predict function is used to generate annual survival estimates. The predictive performance of each of the top candidate models using the GAM and GAMM approaches are assessed using one-step ahead forecasting (where training data used for the prediction model is limited to all years before the prediction year, and an estimate predicted for one-year ahead). Recent five-year predictions are compared to observed values using model evaluation statistics (Haeseker et al. 2008). These statistics may also be useful as common metrics to compare the predicted marine survivals in this forecast with alternate models derived by other scientists or managers during the finalization of forecasts for the 2024 return. Predicted marine survival for the 2024 return year (2023 ocean entry year) is provided as a mean and 95% confidence intervals from the selected model.

Nooksack and Strait of Georgia Management Units

Marine survival data of wild coho from Black Creek in the South Coast British Columbia Strait of Georgia was used to represent the Nooksack and U.S. Strait of Georgia management units (K. Cantera, DFO, personal communication). In recent years, the run size forecasts produced by the WDFW Science Division have applied the predicted marine survival for the Skagit River to these management units. However, a study demonstrated that survival patterns for hatchery coho produced in the Nooksack River were more coherent with survival patterns observed for Canadian coho populations from the Strait of Georgia than with U.S. coho populations from Puget Sound (Zimmerman et al. 2015). Marine survival of Canadian wild coho populations from the Strait of Georgia has averaged (geometric mean) 2.4% (range 0.2% and 12.9%) between ocean entry years 1989 and 2021 and was higher earlier in the time series but has been increasing since 2015 (Figure 18). A marine survival estimate from 2022 ocean entry year was not available.

The generalized additive model used for forecasting included a single variable – North Pacific Gyre Oscillation (NPGO) index from January to March of ocean entry and accounted for temporal autocorrelation (Table 6). Higher survival was associated with positive NPGO values, related to higher salinity and nutrient levels prior to the outmigration period. A second model was evaluated that included NPGO without temporal autocorrelation. The model with temporal autocorrelation was selected based on model evaluation statistics. Light transmission (%) measured at the Admiralty Inlet sampling station (ADM001) of the Washington Department of Ecology Marine Waters Monitoring Program in May of ocean entry was also related to marine survival but adding this variable did not improve model performance.

The selected generalized additive model predicted 1.7% (1.0% to 2.5%, 95% C.I.) marine survival for the 2024 return year (2023 ocean entry year). The model that included NPGO without temporal autocorrelation predicted 2.0% marine survival. Based on these results, a 1.7% marine survival rate was applied to the Nooksack and U.S. Strait of Georgia management units (Table 1).

Table 6. Model evaluation statistics for generalized additive model used to predict marine survival (MS) of wild coho salmon from Black Creek (Strait of Georgia). Model was developed and evaluated for the 1998-2023 ocean entry years. Variable is NPGO.JM (NPGO index January to March of ocean entry). **Model used for 2024 forecast is in red text**.

Model	Type	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2023 OEY)
MS ~ NPGO.JM	GAMM	0.0040	0.0059	0.0086	8.5%	23.2%	0.0167
MS ~ NPGO.JM	GAM	0.0048	0.0079	0.0099	8.6%	36.9%	0.0204

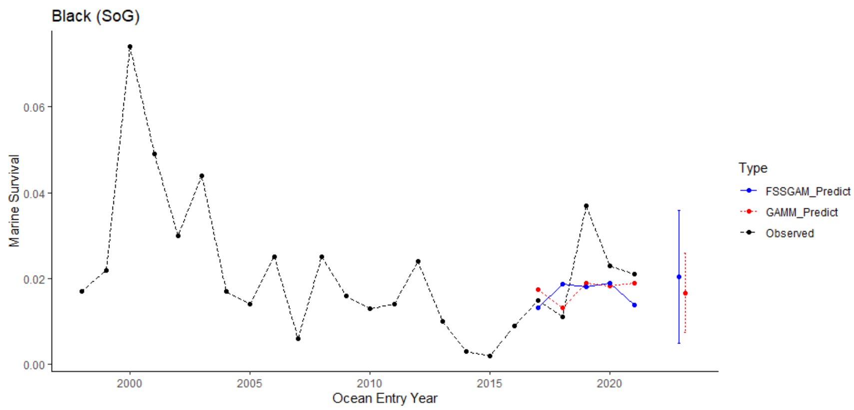

Figure 18. Marine survival of wild coho salmon from Black Creek (SoG), ocean entry years 1998 to 2023. Black dashed line shows observed marine survival. Red dashed line (GAMM) and blue solid line (GAM) show marine survival estimated by one-step ahead forecasting. Dashed red point is the forecasted marine survival (±95% C.I.) for the 2023 ocean entry year (2024 return year).

Skagit and Samish Management Units

Marine survival of wild coho from the Baker River was used to represent the Skagit and Samish management units. Marine survival of wild coho from the Baker River has averaged (geometric mean) 6.8% (range 1.1% to 13.9%) between ocean entry years 1991 and 2022 and has been increasing since 2014 (Figure 19). The marine survival estimate from 2022 ocean entry year is preliminary.

The generalized additive model used for forecasting included two variables – ocean entry year and chlorophyll-a concentration (µg L^{-1}) measured at the Admiralty Inlet sampling station (ADM001) of the Washington Department of Ecology Marine Waters Monitoring Program in May of ocean entry (Table 7). Higher survival was associated with lower chlorophyll-a concentrations in Admiralty Inlet, possibly related to higher stream flow during outmigration. A second model was evaluated that included Pacific Decadal Oscillation (PDO) index May to September of ocean entry and accounted for temporal autocorrelation. The model based on ocean entry year and chlorophyll-a concentration at Admiralty Inlet was selected based on model evaluation statistics. Salinity measured at Race Rocks lighthouse in the Strait of Juan de Fuca by DFO April to June of ocean entry year was also associated with marine survival but was correlated with the PDO index May to September of ocean entry and therefore not included in the final model.

The selected generalized additive model predicted 11.4% (7.7% to 15.1%, 95% C.I.) marine survival for the 2024 return year (2023 ocean entry year). The model that included PDO with temporal autocorrelation predicted 10.8% marine survival. Based on these results, a 11.4% marine survival rate was applied to the Skagit and Samish management units (Table 1).

Table 7. Model evaluation statistics for generalized additive model used to predict marine survival (MS) of wild coho salmon from the Baker (Skagit) River. Model was developed and evaluated for the 1998-2023 ocean entry years. Variables include OEY (ocean entry year), AT.Chl (chlorophyll-a concentration [µg L^{-1}] measured at WA Dept Ecology station ADM001, Admiralty Inlet in May of ocean entry), and PDO.MS (PDO index May to September of ocean entry). **Model used for 2024 forecast is in blue text**.

Model	Type	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2023 OEY)
MS ~ OEY + AT.Chl	GAM	0.0030	0.0220	0.0236	-3.2%	22.5%	0.1140
MS ~ PDO.MS	GAMM	0.0186	0.0192	0.0272	15.0%	15.8%	0.1079

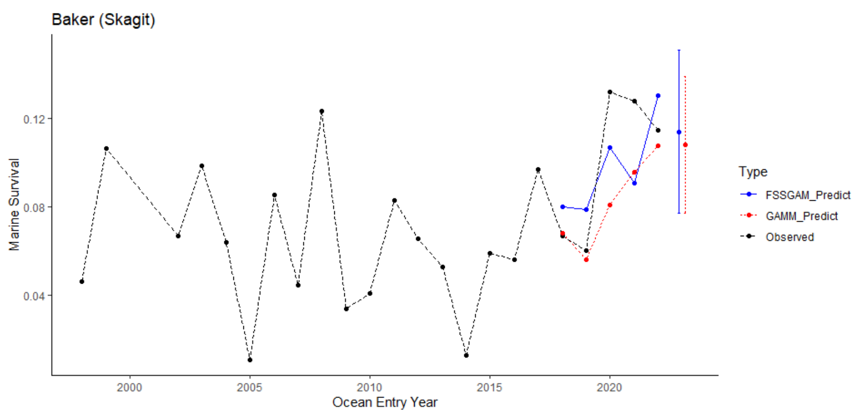

Figure 19. Marine survival of wild coho salmon from the Baker River (Skagit), ocean entry years 1998 to 2023 (excluding 2000 and 2001 for which no marine survival data were available to develop the predictive model). Black dashed line shows observed marine survival. Red dashed line (GAMM) and blue solid line (GAM) show marine survival estimated by one-step ahead forecasting. Solid blue point is the forecasted marine survival (±95% C.I.) for the 2023 ocean entry year (2024 return year).

Snohomish and Stillaguamish Management Units

Marine survival of wild coho from the South Fork Skykomish River was used to represent the Stillaguamish and Snohomish management units. Marine survival of wild coho in the South Fork Skykomish River has averaged (geometric mean) 10.2% (range 1.7% to 27.6%) between ocean entry years 1978 and 2022 with an increasinging trend since 2016 ocean entry year (Figure 20). The marine survival estimate for 2022 ocean entry year is preliminary.

The model used for forecasting included one variable – North Pacific Gyre Oscillation (NPGO) index May to September of ocean entry (Table 8). Higher survival was associated with higher NPGO values, typically associated with increased salinity and nutrients, indicating productive early ocean conditions.

The selected generalized additive model accounting for temporal autocorrelation predicted 4.6% (2.1% to 7.1%, 95% C.I.) marine survival for the 2024 return year (2023 ocean entry year). Another model was evaluated that included NPGO from May to September of ocean entry year without temporal autocorrelation. Marine survival for the NPGO model without temporal autocorrelation was also predicted to be 4.6%. Based on these results, a 4.6% marine survival was applied to the Snohomish and Stillaguamish management units (Table 1).

Table 8. Model evaluation statistics for generalized additive model used to predict marine survival (MS) of wild coho salmon from the South Fork Skykomish River. Model was developed and evaluated for the 1998-2023 ocean entry years. Variable is NPGO.MS (NPGO index May to September of ocean entry). **Model used for 2024 forecast is in red text.**

Model	Type	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2023 OEY)
MS ~ NPGO.MS	GAMM	0.0348	0.0354	0.0579	28.7%	30.2%	0.0459
MS ~ NPGO.MS	GAM	0.0340	0.0355	0.0583	26.6%	30.4%	0.0464

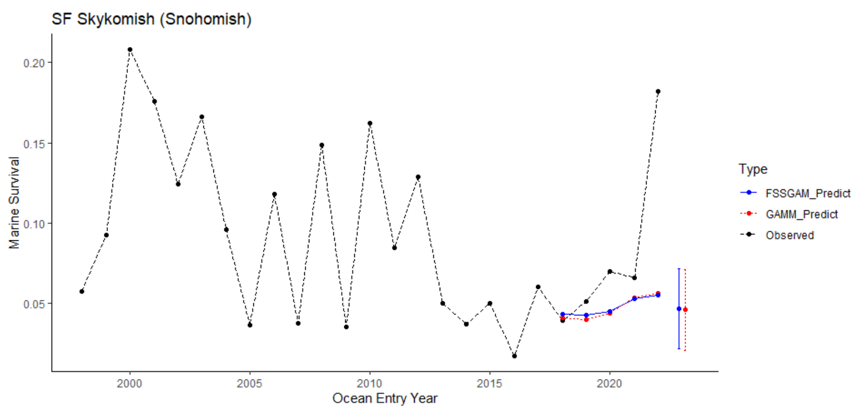

Figure 20. Marine survival of wild coho salmon in the SF Skykomish River, ocean entry years 2002 to 2023. Black dashed line shows observed marine survival. Red dashed line (GAMM) and blue solid line (GAM) show marine survival estimated by one-step ahead forecasting. Solid red point is the forecasted marine survival (±95% C.I.) for the 2023 ocean entry year (2024 return year).

Lake Washington, Green River, East Kitsap, and Puyallup Management Units

Marine survival for hatchery coho salmon from Soos Creek hatchery was used to represent the Lake Washington, Green River, East Kitsap, and Puyallup management units. Marine survival of hatchery coho from Soos Creek has averaged (geometric mean) 4.0% with a range of 0.7% to 16.9% between the 1977 and 2021 ocean entry years with a declining trend over time (Figure 21). A marine survival estimate from 2022 ocean entry year was not available.

The model used for forecasting included two variables –North Pacific Gyre Oscillation (NPGO) index January to March of ocean entry and light transmission (%) measured at the Admiralty Inlet sampling station (ADM001) of the Washington Department of Ecology Marine Waters Monitoring Program April to June of ocean entry (Table 9). Higher survival was associated with higher winter NPGO index values and lower light transmission values near Admiralty Inlet during ocean entry, indicating coho marine survival was higher when nearshore primary productivity was greater during the spring of ocean entry.

The selected generalized additive model predicted a marine survival of 5.4% (3.1% to 7.6%, 95% C.I.) for the 2024 return year (2023 ocean entry year). A separate model, including NPGO index and light transmission measured at Admiralty Inlet with temporal autocorrelation, predicted a marine survival rate of 4.2%. Based on these results, a marine survival rate of 5.4% was applied to the Lake Washington, Green River, Puyallup, and East Kitsap MUs (Table 1).

Table 9. Model evaluation statistics for generalized additive model used to predict marine survival (MS) of hatchery coho salmon from the Green River. Model was developed and evaluated for the 1998-2023 ocean entry years. Variables include NPGO.JM (NPGO index January to March of ocean entry) and AT.Light (light transmission [%] measured at WA Dept Ecology station ADM001, Admiralty Inlet April to June of ocean entry). **Model used for 2024 forecast is in blue text**.

Model	Type	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2023 OEY)
MS ~ NPGO.JM + AT.Light	GAM	0.0021	0.0082	0.0095	-19.6%	52.6%	0.0536
MS ~ NPGO.JM + AT.Light	GAMM	0.0012	0.0083	0.0099	-19.9%	51.0%	0.0420

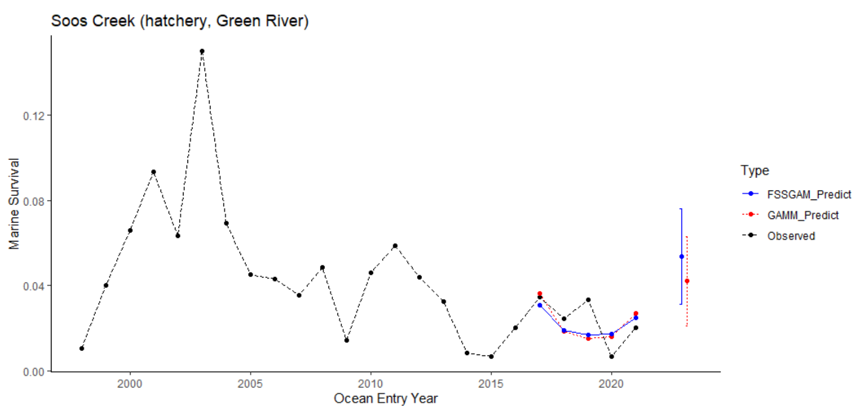

Figure 21. Marine survival of hatchery coho salmon released from Soos Creek hatchery in the Green River, ocean entry years 1998 to 2023. Black dashed line shows observed marine survival. Red dashed line (GAMM) and blue solid line (GAM) show marine survival estimated by one-step ahead forecasting. Solid blue point is the forecasted marine survival (±95% C.I.) for the 2023 ocean entry year (2024 return year).

Deschutes River, South Sound, and Nisqually Management Units

Marine survival of Deschutes River natural coho was used to represent the Nisqually, Deschutes River, and South Sound management units. Marine survival of natural coho from the Deschutes River has averaged (geometric mean) 7.2% and ranged from 1.1% to 29.5% between ocean entry years 1979 and 2022 with a declining trend over time (Figure 22). The marine survival estimate from 2022 ocean entry year is preliminary.

The model used for forecasting included a single variable – North Pacific Gyre Oscillation (NPGO) index May to September of ocean entry and accounted for temporal autocorrelation (Table 10). The NPGO index characterizes variability in sea surface height associated with salinity, nutrients, and chlorophyll-a concentration. Higher survival was was associated with higher NPGO values, indicating greater levels of salinity, nutrients and primary productivity during the early ocean rearing period. A second model was evaluated that included NPGO without temporal autocorrelation and predicted 4.2% marine survival. The generalized additive model accounting for temporal autocorrelation was selected based on model evaluation statistics.

The selected generalized additive model predicted an 4.3% marine survival (2.9% to 5.7%, 95% C.I.) for the 2024 return year (2023 ocean entry year). Based on these results, a marine survival of 4.3% was applied to the Deschutes as well as South Sound and Nisqually MUs which share the same oceanographic basin as the Deschutes River (Table 1).

Table 10. Model evaluation statistics for generalized additive model used to predict marine survival (MS) of natural coho salmon from the Deschutes River, Washington. Model was developed and evaluated for 1998-2023 ocean entry years; however, only 14 estimates were available in this time series. Variable is NPGO.MS (NPGO index May to September of ocean entry). **Model used for 2024 forecast is in red text**.

Model	Type	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2023 OEY)
MS ~ NPGO.MS	GAMM	0.0021	0.0086	0.0117	-9.2%	29.8%	0.0430
MS ~ NPGO.MS	GAM	0.0019	0.0087	0.0120	-10.8%	30.1%	0.0424

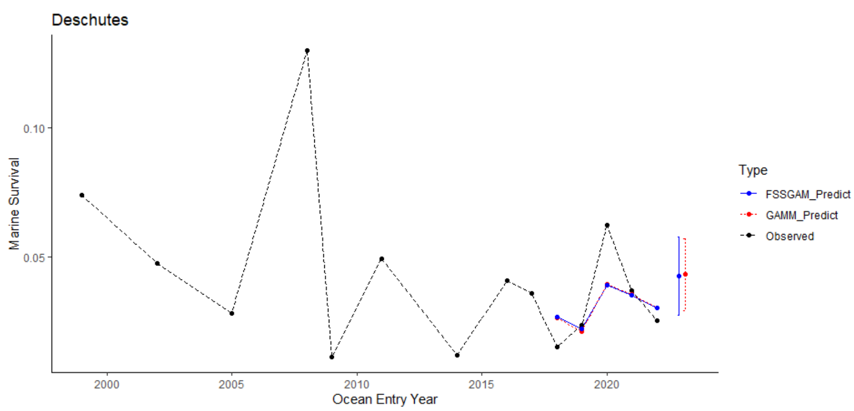

Figure 22. Marine survival of Deschutes River natural coho salmon, ocean entry years 1998 to 2023 (excluding years for which no marine survival data were available). Black dashed line shows observed marine survival. Red dashed line (GAMM) and blue solid line (GAM) show marine survival estimated by one-step ahead forecasting. Solid red point is the forecasted marine survival (±95% C.I.) for the 2023 ocean entry year (2024 return year).

Hood Canal Management Unit

Marine survival of wild coho from Big Beef Creek, which enters the westside of Hood Canal from the Kitsap Peninsula, was used to represent the Hood Canal management unit. Marine survival of wild coho in Big Beef Creek (Hood Canal Management Unit) has averaged (geometric mean) 10.9% (range 2.0% to 32.0%) between ocean entry years 1977 and 2022 with a declining trend over time (Figure 23). The marine survival estimate from 2022 ocean entry year is preliminary.

The model used for forecasting included one variable –NPGO index January to March of ocean entry year and accounted for temporal autocorrelation (Table 11). Higher survival was associated with higher NPGO values, indicating greater levels of salinity, nutrients, and primary productivity during the early ocean rearing period. We evaluated a second model without temporal autocorrelation that included the NPGO index from January to March of ocean entry year, salinity measured at Race Rocks lighthouse in the Strait of Juan de Fuca by DFO April to June of ocean entry year, and light transmission (%) measured at the Admiralty Inlet sampling station (ADM001) of the Washington Department of Ecology Marine Waters Monitoring Program April to June of ocean entry year. The generalized additive model with NPGO was selected based on model evaluation statistics.

The selected generalized additive model predicted 3.7% (0% to 8.0%, 95% C.I.) marine survival for the 2024 return year (2023 ocean entry year). For comparison, the model using NPGO predicted a marine survival of 10.1%. Based on these results, a 3.7% marine survival was applied to the entire Hood Canal management unit (Table 1).

Table 11. Model evaluation statistics for generalized additive model used to predict marine survival (MS) of wild coho salmon from Big Beef Creek. Model was developed and evaluated for 1998-2023 ocean entry years. Variables include NPGO.JM (NPGO index January to March of ocean entry), RR.SSS (sea surface salinity measured at Race Rocks lighthouse in the Strait of Juan de Fuca, April to June of ocean entry), and AT.Light (light transmission [%] measured at WA Dept Ecology station ADM001, Admiralty Inlet April to June of ocean entry). **Model used for 2024 forecast is in blue text**.

Model	Type	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2023 OEY)
MS ~ NPGO.JM	GAMM	0.0014	0.0190	0.0244	-11.1%	35.2%	0.0368
MS ~ NPGO.JM + RR.SSS + AT.Light	GAM	-0.0067	0.0191	0.0253	-19.5%	38.5%	0.1009

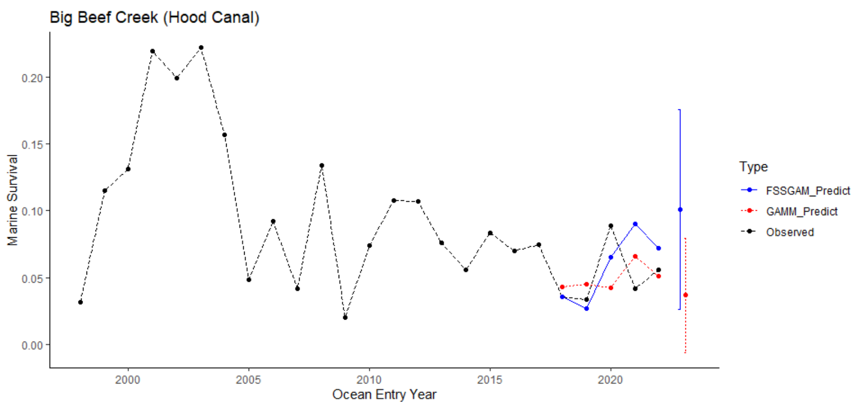

Figure 23. Marine survival of Big Beef Creek wild coho, ocean entry year 1998 to 2023. Black dashed line shows observed marine survival. Red dashed line (GAMM) and blue solid line (GAM) show marine survival estimated by one-step ahead forecasting. Dashed red point is the forecasted marine survival (±95% C.I.) for the 2023 ocean entry year (2024 return year).

Strait of Juan de Fuca

Marine survival in the Juan de Fuca management unit has averaged (geometric mean) 4.4% and ranged from 0.9% to 13.4% between ocean entry years 1998 and 2021 with an increasing trend since 2014 (Figure 24). A marine survival estimate from 2022 ocean entry year was not available.

The generalized additive model used for forecasting included two variables – ocean entry year and southern copepod biomass (mg C m^{-3}) anomaly measured along the Newport Hydrographic Line May to September of ocean entry (Table 12). The southern copepod biomass anomaly indicator represents smaller-bodied, lipid-poor zooplankton species present in higher abundance during warmer ocean conditions. These are not considered high quality juvenile coho prey. Higher marine survival was associated with negative southern copepod biomass anomalies, indicating salmon survived better in cooler years when southern copepods were less abundant. A second model was evaluated that included southern copepod biomass and accounted for temporal autocorrelation. The model that included ocean entry year was selected based on model evaluation statistics.

The selected generalized additive model predicted a 6.8% (4.2% to 9.5%, 95% C.I.) marine survival for the 2024 return year (2023 ocean entry year). The generalized additive model with southern copepod biomass anomaly and temporal autocorrelation predicted a marine survival for the 2023 ocean entry year of 6.6%. Based on these results, a 6.8% marine survival was applied to the Juan de Fuca management unit (Table 1).

Table 12. Model evaluation statistics for generalized additive model used to predict marine survival (MS) of wild coho salmon in the Juan de Fuca management unit. Model was developed and evaluated for 1998-2023 ocean entry years. Variables include OEY (ocean entry year) and S.Cop.B (southern copepod biomass anomaly measured along the Newport Hydrographic Line May to September of ocean entry). Model evaluation statistics are shown for both candidate models. **Model used for 2024 forecast is in blue text**.

Model	Type	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2023 OEY)
MS ~ OEY + S.Cop.B	GAM	0.0008	0.0112	0.0117	-10.2%	24.7%	0.0682
MS ~ S.Cop.B	GAMM	-0.0033	0.0147	0.0156	-24.6%	37.0%	0.0658

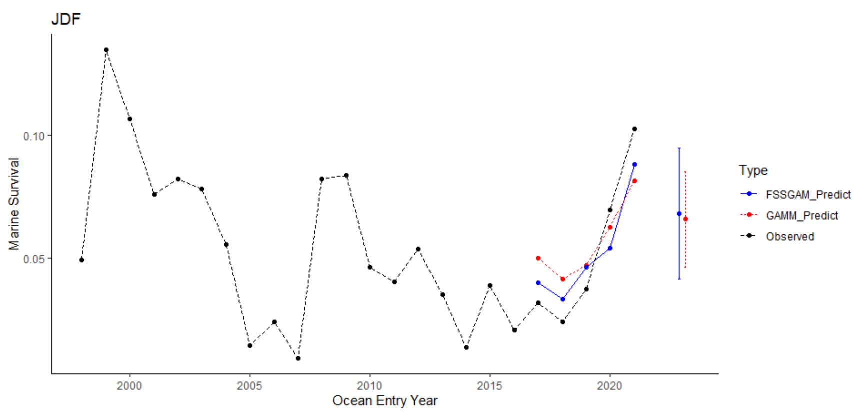

Figure 24. Marine survival of wild coho in the Strait of Juan de Fuca management unit, ocean entry year 1998 to 2023. Black dashed line shows observed marine survival. Red dashed line (GAMM) and blue solid line (GAM) show marine survival estimated by one-step ahead forecasting. Solid blue point is the forecasted marine survival (±95% C.I.) for the 2023 ocean entry year (2024 return year).

Washington Coast

Marine survival of wild coho in the coastal Washington region is measured at Bingham Creek, a tributary to the East Fork Satsop River (a right bank tributary to the Chehalis River). Marine survival of Bingham Creek wild coho has averaged (geometric mean) 3.8% (range 0.6% to 11.5%) between ocean entry years 1982 and 2022 and has been increasing since 2014 (Figure 25). The marine survival estimate from 2022 ocean entry year is preliminary.

The final model selected for forecasting included three variables – Axis 1 scores from a Principal Components Analysis of the NOAA stoplight chart of ecosystem indicators, timing of the hydrographic physical spring transition date from predominantly downwelling to upwelling conditions based on upwelling intensity, and thermal regime, with cool regime associated with brood years before 2000 plus strong La Niña years and warm regime associated with brood years ≥2000 plus strong El Niño years. (Table 13). Axis 1 scores (PC1) distill all the ecosystem indicators, many of which are correlated, into a single index. PC1 and zooplankton and ichthyoplankton values were highly correlated. Higher survival was associated with negative PC1 values, especially during cool years, and early than average physical spring transition date, indicating higher survival during cool years with an early spring transition date when there was an abundance of nutritious prey. An alternative model was evaluated that included coho jack survival. The model that included PC1, physical spring transition date, and thermal regime was selected based on model evaluation statistics.

The selected generalized additive model predicted a 2.6% (1.4% to 3.8%, 95% C.I.) marine survival for the 2024 return year (2023 ocean entry year). The generalized additive model with coho jacks and temporal autocorrelation predicted a marine survival for the 2023 ocean entry year of 3.5%. Based on these results, a marine survival of 2.6% was applied to all management units in the coastal Washington region (Table 1).

Table 13. Model evaluation statistics for generalized additive model used to predict marine survival (MS) of wild coho salmon from Bingham Creek. Model was developed and evaluated for 1998-2023 ocean entry years (OEY). Variables include PC1 (Axis 1 scores from a Principal Components Analysis of 2023 salmon ecosystem indicators), Phys.Trans.UI (day of the year representing the physical spring transition from predominantly downwelling to upwelling conditions based on upwelling intensity during year of ocean entry), thermal regime (cool = brood years <2000 and strong La Niña years, warm = brood years ≥2000 and strong El Niño years), and Jacks (coho jack survival in year of ocean entry). Model evaluation statistics are shown for each model. **Model selected for 2024 forecast is in blue text.**

Model	Type	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2023 OEY)
MS ~ PC1 + Phys.Trans.UI + Regime	GAM	0.0038	0.0092	0.0114	0.7%	17.4%	0.0260
MS ~ Jacks	GAMM	0.0010	0.0132	0.0173	-11.5%	31.1%	0.0354

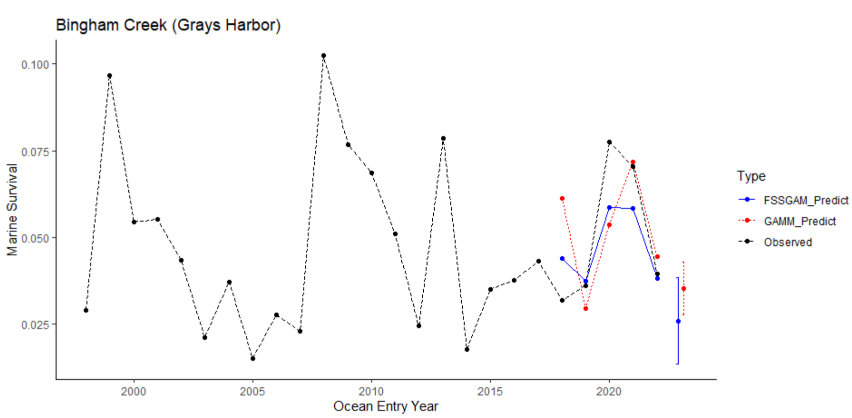

Figure 25. Marine survival of wild coho from Bingham Creek, Washington, ocean entry year 1998 to 2023. Black dashed line shows observed marine survival. Red dashed line (GAMM) and blue solid line (GAM) show marine survival estimated by one-step ahead forecasting. Solid blue point is the forecasted marine survival (±95% C.I.) for the 2023 ocean entry year (2024 return year).

Lower Columbia River

Marine survival in the lower Columbia River is measured in the Cowlitz River. Marine survival of natural-origin coho from the Cowlitz River has averaged (geometric mean) 3.9% (range 0.9% to 11.5%) between ocean entry years 2001 and 2022 and has been increasing since 2015 (Figure 26). The marine survival estimate from 2022 ocean entry year is preliminary.

The final model included two variables – ocean entry year and Columbia River flow April to June of ocean entry year (Table 14). Higher marine survival was associated with average flow values during the spring freshet. Several indicators were also correlated with marine survival including Pacific Decadal Oscillation (PDO) index, timing and length of the upwelling season, zooplankton community measured off Oregon, and jack survival in ocean entry year. Variables that correlated with marine survival of Columbia River coho were consistent with correlates identified for Oregon coastal natural coho (Logerwell et al. 2003) and Washington hatchery coho (Ryding and Skalski 1999). A separate model using PDO index summed from December to March during the year of ocean entry adjusted for temporal autocorrelation was also evaluated. The generalized additive model that included ocean entry year and Columbia River flow April to June of ocean entry without temporal autocorrelation was selected based on model evaluation statistics.

The selected generalized additive model predicted 7.7% (4.9% to 10.5%, 95% C.I.) marine survival for the 2024 return year (2023 ocean entry year). The model using PDO with temporal autocorrelation predicted a marine survival of 6.5% (Table 13). Based on these results, a marine survival of 7.7% was applied to the Lower Columbia region (Table 1).

Table 14. Model evaluation statistics for generalized additive model used to predict marine survival (MS) of natural coho salmon from the Cowlitz River. Model was developed and evaluated for 2001-2023 ocean entry years. Variables include OEY (ocean entry year), Flow.AJ (Columbia River flow measured at Bonneville April to June of ocean entry), and PDO.DM (Pacific Decadal Oscillation index summed from December to March prior to ocean entry). Model evaluation statistics are shown for both models. **Model selected for the 2024 forecast is in blue text**.

Model	Type	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2023 OEY)
MS ~ OEY + Flow.AJ	GAM	0.0023	0.0151	0.0166	-3.9%	25.6%	0.0768
MS ~ PDO.DM	GAMM	0.0135	0.0169	0.0203	15.4%	25.3%	0.0646

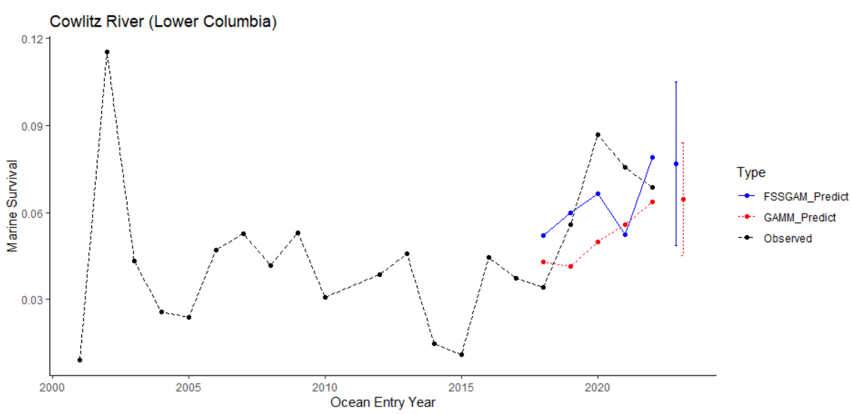

Figure 26. Marine survival of natural coho from the Lower Columbia River management unit, ocean entry year 2001 to 2023 (no marine survival data available for 2011). Black dashed line shows observed marine survival. Red dashed line (GAMM) and blue solid line (GAM) show marine survival estimated by one-step ahead forecasting. Solid blue point is the forecasted marine survival (±95% C.I.) for the 2023 ocean entry year (2024 return year).

Appendix A. Puget Sound Summer Low Flow Index.

The Puget Sound Summer Low Flow Index (PSSLFI) is a metric of low flow during the coho rearing period. This metric is calculated from a representative series of Puget Sound stream gages using daily mean flows recorded from 1963 to present. Historically, eight USGS gages have been used for this index – South Fork Nooksack (#12209000), Newhalem (#12178100), North Fork Stillaguamish (#12167000), North Fork Snoqualmie (#12142000), Taylor Creek (#12117000), Rex River (#12115500), Newaukum (#12108500), and Skokomish River (#12061500). Challenges to maintaining the integrity of this data set are inevitable given the length of the time series; two of the most significant issues (Nooksack River, Skokomish River) are described below.

An alternate gage on the Nooksack River (Nooksack at Ferndale, #12213100) was selected beginning with the 2011 wild coho forecast because the previously used gage (South Fork Nooksack gage #12209000) was discontinued as of September 30, 2008. Flows from the Ferndale gage were correlated with those from the South Fork Nooksack and the newly selected gage values were used to recalculate the PSSLFI for all previous years.

Over the time series, summer flows recorded by the Skokomish River gage are confounded by changes in water management. The USGS stream gage is located downstream of the confluence with the north and south forks of the Skokomish River and flows from 2009 and later are influenced (increased) by a change in water management. In 2009, a settlement agreement associated with the Cushman Hydroelectric Project required a Tacoma Power to maintain a minimum level of summer base flows in the North Fork Skokomish River below Cushman Dam. This requirement increased water flowing into the NF Skokomish River. There is no other suitable long-term flow gage within the basin and therefor the gage has been retained for the PSSLFI. However, the Skokomish River summer flow index followed a different pattern (higher than long-term average) than other Puget Sound stream flow indices.

The PSSLFI is calculated each year and is the sum of low flow indices from each of the eight gages. Summer low flows corresponding to each brood year were averaged for 60-day intervals between March and November (i.e., coho summer rearing period). Low flow period typically occurs in late August or September. Watershed-specific flow index for a given year was the minimum 60-day average flow for that year divided by the time series average. This index was calculated based on flow data from 1963 to present. The PSSLFI is the sum of all eight watershed indices.

Based on flow data compiled between 1963 and 2023 (including alternate Nooksack gage), the PSSLFI has ranged between 4.5 and 13.1 with an average of 8.0. During this period, site-specific indices were closely correlated with each other, supporting the concept that summer rearing flows are coordinated among Puget Sound basins. Summer low flows in 2022 (corresponding to the 2023 outmigration and 2024 returning adults) had an index value of 5.3 or 67% of the time series average.

Figure - Appendix A. Summer Low Flow Index by summer rearing year (return year – 2) for each of the eight watersheds used for the Puget Sound Summer Low Flow Index. The minimum annual 60-day average flow at each gage is compared to the time series average (1963 to present) and then summed across all eight gages. Flow index corresponding to the 2024 wild coho return shown as blue point in graph.

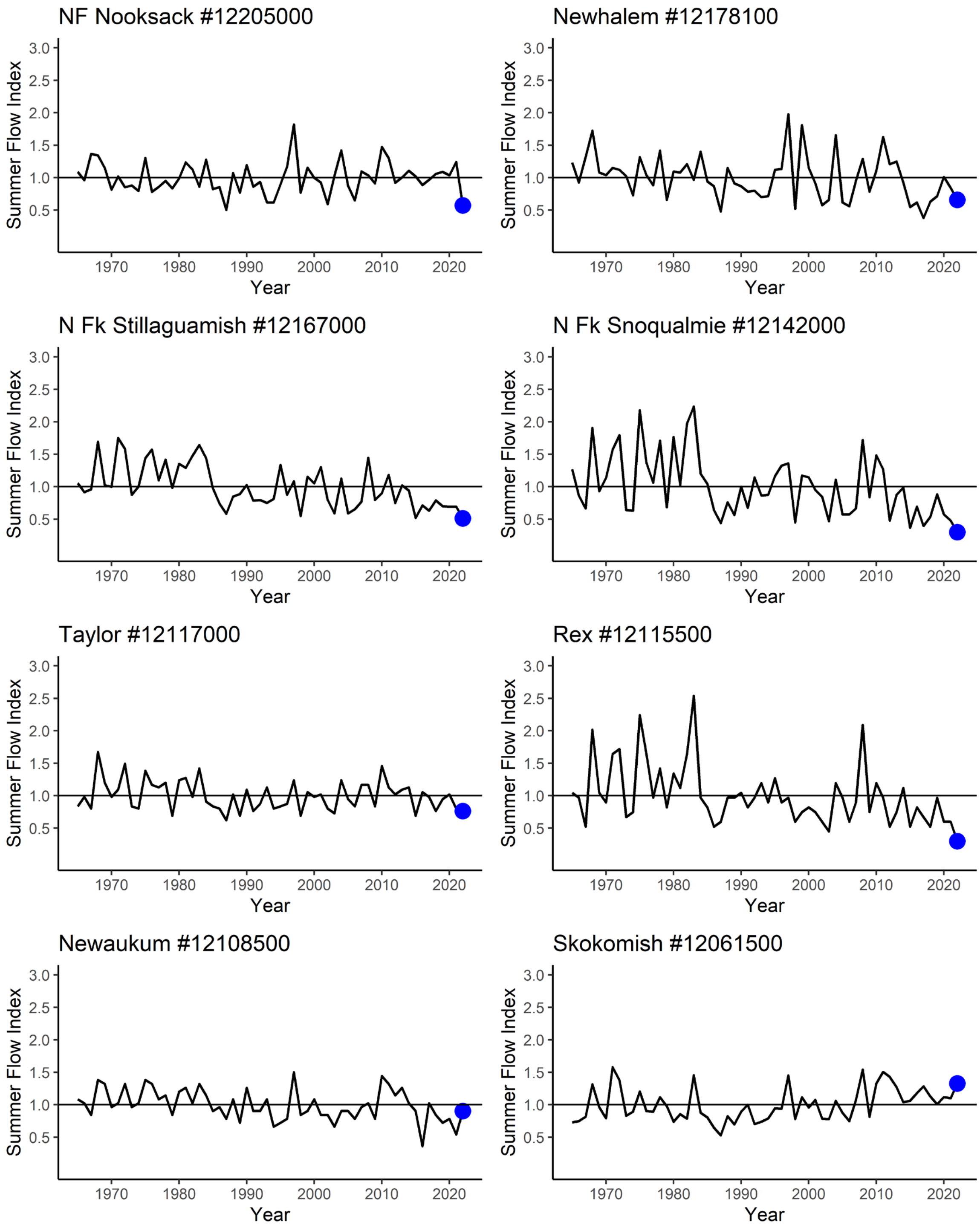

Table - Appendix B. Drainage areas of coastal Washington watersheds. Data are total watershed areas and area of each watershed where coho production has been measured with juvenile trapping studies.

	Drainage area (mi^2)	
Watershed	**Total**	**Measured**
Quillayute	629	
Dickey	108	87
Bogachiel		129
Hoh	299	
Queets (no Clearwater)	310	450
Clearwater	140	140
Quinault	434	
Independent Tributaries		
Waatch River	13	
Sooes River	41	
Ozette River	88	
Goodman Creek	32	
Mosquito Creek	17	
Cedar Creek	10	
Kalaloch Creek	17	
Raft River	77	
Camp Creek	8	
Duck Creek	8	
Moclips River	37	
Joe Creek	23	
Copalis River	41	
Conner Creek	12	
Grays Harbor		
Chehalis	2,114	2,114
Humptulips	250	
Southside tribs*	186	
Willapa Bay	850	

* Southside tributaries below the Grays Harbor terminal fishery

Appendix C. Environmental indicators explored as predictors of coho salmon marine survival in nine index populations in Puget Sound, Coastal Washington, and Lower Columbia River. Scale type is ocean (O), regional (R), and local (L) and physical (P) and biological (B). 'X' indicates the same value was used in all analyses. '---' indicates the variable was not included in the analysis for that index population. Specific location data are provided when different locations were applied to different index populations.

		PUGET SOUND							COAST	LCR	
	Indicator	SoG	SKGT	SFSKY	GREEN	DESCH	BBC	JDF			Data Source
O/P	PDO (Dec-Mar)	X	X	X	X	X	X	X	X	X	NWFSC[1]
O/P	PDO (May-Sept)	X	X	X	X	X	X	X	X	X	NWFSC[1]
O/P	ONI (Jan-Jun)	X	X	X	X	X	X	X	X	X	NWFSC[1]
O/P	NPGO (Jan-Mar)	X	X	X	X	X	X	X	X	X	E. Di Lorenzo[2]
O/P	NPGO (May-Sept)	X	X	X	X	X	X	X	X	X	E. Di Lorenzo[2]
O/P	Thermal Regime	X	X	X	X	X	X	X	X	X	M. Litz[3]
R/P	Race Rocks SST (Apr-Jun)	X	X	X	X	X	X	X	---	---	DFO[4]
R/P	Race Rocks SSS (Apr-Jun)	X	X	X	X	X	X	X	---	---	DFO [4]
R/P	Phys. Spring Transition Date	----	----	---	---	---	---	---	46050	46050	NWFSC[1]
R/P	Upwelling Anomaly (Apr-May)	48˚N	48˚N	48˚N	48˚N	48˚N	48˚N	48˚N	45˚N	45˚N	NWFSC[1], PFEL[5]
R/P	Temp 20 m (Apr-Jun)	ADM001	ADM001	ADM001	ADM001	ADM001	ADM001	ADM001	---	---	WA ECY-MWMP[8,9]
R/P	Salinity 20 m (Apr-Jun)	ADM001	ADM001	ADM001	ADM001	ADM001	ADM001	ADM001	---	---	WA ECY-MWMP[8,9]
R/P	Chlorophyll-a 20 m (May)	ADM001	ADM001	ADM001	ADM001	ADM001	ADM001	ADM001	---	---	WA ECY-MWMP[8,9]
R/P	Light transmission (May)	ADM001	ADM001	ADM001	ADM001	ADM001	ADM001	ADM001	---	---	WA ECY-MWMP[8,9]
R/P	Sea Surface Temp 46N (May-Sept)	----	----	---	---	---	---	---	46050	46050	NWFSC[1]
R/P	NH05. 20mTemp (Nov-Mar)	----	----	---	---	---	---	---	46050	46050	NWFSC[1]
R/P	NH05. 20mTemp (May-Sept)	----	----	---	---	---	---	---	46050	46050	NWFSC[1]
R/P	NH05.DeepTemp (May-Sept)	----	----	---	---	---	---	---	46050	46050	NWFSC[1]
R/P	NH05DeepSalinity (May-Sept)	----	----	---	---	---	---	---	46050	46050	NWFSC[1]
R/P	Length Upwelling	---	---	---	---	---	---	---	45˚N	45˚N	NWFSC[1]
R/B	Copepod Richness (May, Sept)	---	---	---	---	---	---	---	X	X	NWFSC[1]
R/B	N Copepod Biomass (May, Sept)	---	---	---	---	---	---	---	X	X	NWFSC[1]
R/B	S Copepod Biomass (May, Sept)	---	---	---	---	---	---	---	X	X	NWFSC[1]
R/B	Biological Transition	---	---	---	---	---	---	---	X	X	NWFSC[1]
R/B	Winter Ichthyoplankton	---	---	---	---	---	---	---	X	X	NWFSC[1]
R/B	Chinook CPUE (June)	---	---	---	---	---	---	---	X	X	NWFSC[1]
R/B	Coho CPUE (June)	---	---	---	---	---	---	---	X	X	NWFSC[1]
R/B	Copepod Comm. Structure	X	X	X	X	X	X	X	X	X	NWFSC[1], UW[10]
L/P	River Flow (Apr-Jun)	12205000	12200500	12200500	12113000	12089500	12061500	---	FPC	FPC	USGS[6], FPC[7]

L/P	Temp 20 m Apr-Jun	BLL009	SAR003	PSS019	PSB003	BUD005	HCB003	---	---	---	WA ECY-MWMP[8,9]
L/P	Salinity 20 m Apr-Jun	BLL009	SAR003	PSS019	PSB003	BUD005	HCB003	---	---	---	WA ECY-MWMP[8,9]
L/B	Chlorophyll 20 m (May)	BLL009	SAR003	PSS019	PSB003	BUD005	HCB003	---	---	---	WA ECY-MWMP[8,9]
L/B	Light transmission (May)	BLL009	SAR003	PSS019	PSB003	BUD005	HCB003	---	---	---	WA ECY-MWMP[8,9]
L/B	Percent Jack Return	---	---	---	---	---	X	---	X	X	WDFW Science, OPITT

[1]Ocean indicator data for the Pacific coast continental shelf were from ocean monitoring program developed by Bill Peterson and colleagues at the Northwest Fisheries Science Center in Newport, OR. Data and their descriptions are available at: https://www.fisheries.noaa.gov/west-coast/science-data/ocean-conditions-indicators-trends

[2]Monthly NPGO indices are available at http://www.o3d.org/npgo/npgo.php.

[3]Thermal regime indicator developed for wild coastal coho to explain differences observed in survival by Marisa Litz and colleagues at WDFW. Description available at: https://npafc.org/wp-content/uploads/technical-reports/Tech-Report-17-DOI/13_Litz-et-al.pdf

[4]Daily values of sea surface temperature and salinity observed at Race Rocks lighthouse. Light keepers at this location have measured monthly sea surface temperature and salinity since 1921 (mostly recently maintained by Mike Slater and Lester Pearson College). Data are available at

http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/lightstations-phares/index-eng.html

[5]Bakun upwelling index at 48° N, 125°W provided by Pacific Fisheries Environmental Laboratory. Data are available at: http://www.pfel.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/upwell_menu_NA.html

[6]River flow from all rivers except the Columbia River was daily average flow measured at USGS gage stations in associated rivers. Gage station IDs are provided in basin specific cells. Data are available at http://waterdata.usgs.gov/wa/nwis/current/?type=flow

[7]River flow from the Columbia River was average daily flow measured at Bonneville Dam. Data are available at: https://www.fpc.org/fpc_homepage.php

[8]Marine waters data from Puget Sound provided by the WA Department of Ecology Marine Waters Monitoring Program. Average water temperature (°C), salinity (PSU), chlorophyll (ug/l), and light transmission (%) in upper 20 m at the marine stations indicated. A regional indicator was developed from the mooring at Admiralty Inlet and local indicators were developed from mooring stations near associated river mouth. Station IDs are provided in basin specific cells. Data provided by WA Department of Ecology.

[9]Marine waters data from Puget Sound in 2020 provided by the King County Puget Sound Marine Monitoring Program. Average water temperature (°C), salinity (PSU), chlorophyll (ug/l), and light transmission (%) in upper 20 m at the marine stations indicated. The WA Department of Ecology Admiralty Inlet (ADM001), Saratoga Passage (SAR003), Possession Sound (PSS019), and Hood Canal (HCB003) stations were substituted using the King County Point Wells Offshore station (JSUR01), the Puget Sound Main Basin (PSB003) station was substituted using the West Point Outfall (KSSK02) station, and the Budd Inlet (BUD005) station was substituted using the East Passage (NSEX01) station. Data collected June 1-2, 2020 classified as May samples.

[10]Zooplankton data from station SJF002 in eastern Strait of Juan de Fuca provided by University of Washington as part of the Joint Effort to Monitor Strait program and long-term monitoring program managed by WA Department of Ecology.

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