2021 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 2021 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 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. 2021 wild coho run forecast summary for Puget Sound, Coastal Washington, and Lower Columbia.

	Production X	Marine Survival =	Recruits	
Production Unit	**Estimated Smolts Spring 2020**	**Predicted Marine Survival**	**Adults (Age 3)**	**Jan. (Age 3)**
Puget Sound				
Primary Units				
Skagit River	1,057,000	5.7%	60,249	74,208
Stillaguamish River	462,000	4.8%	22,176	27,314
Snohomish River	1,519,000	4.8%	72,912	89,805
Hood Canal	320,000	4.6%	14,720	18,131
Straits of Juan de Fuca	322,000	1.6%	5,152	6,346
Secondary Units				
Nooksack River	1,348,000	2.9%	39,092	48,149
Strait of Georgia	16,000	2.9%	464	572
Samish River	34,000	5.7%	1,938	2,387
Lake Washington	49,000	4.4%	2,156	2,656
Green River	48,000	4.4%	2,112	2,601
East Kitsap	92,000	4.4%	4,048	4,986
Puyallup River	435,000	4.4%	19,140	23,575
Nisqually River	79,000	4.1%	3,239	3,989
Deschutes River	15,000	4.1%	615	757
South Sound	180,000	4.1%	7,380	9,090
Puget Sound Total	5,976,000		255,393	314,566
Coast				
Quillayute River	221,000	3.2%	7,072	8,711
Hoh River	94,000	3.2%	3,008	3,705
Queets River	162,000	3.2%	5,184	6,385
Quinault River	164,000	3.2%	5,248	6,464
Independent Tributaries	148,000	3.2%	4,736	5,833
Grays Harbor				
Chehalis River	2,329,483	3.2%	74,543	91,815
Humptulips River	253,250	3.2%	8,104	9,982
Willapa Bay	595,000	3.2%	19,040	23,451
Coastal Systems Total	3,966,733		126,935	156,345
Lower Columbia Total	574,000	4.5%	25,830	31,815
GRAND TOTAL	10,516,733		408,158	502,726

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 30 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).

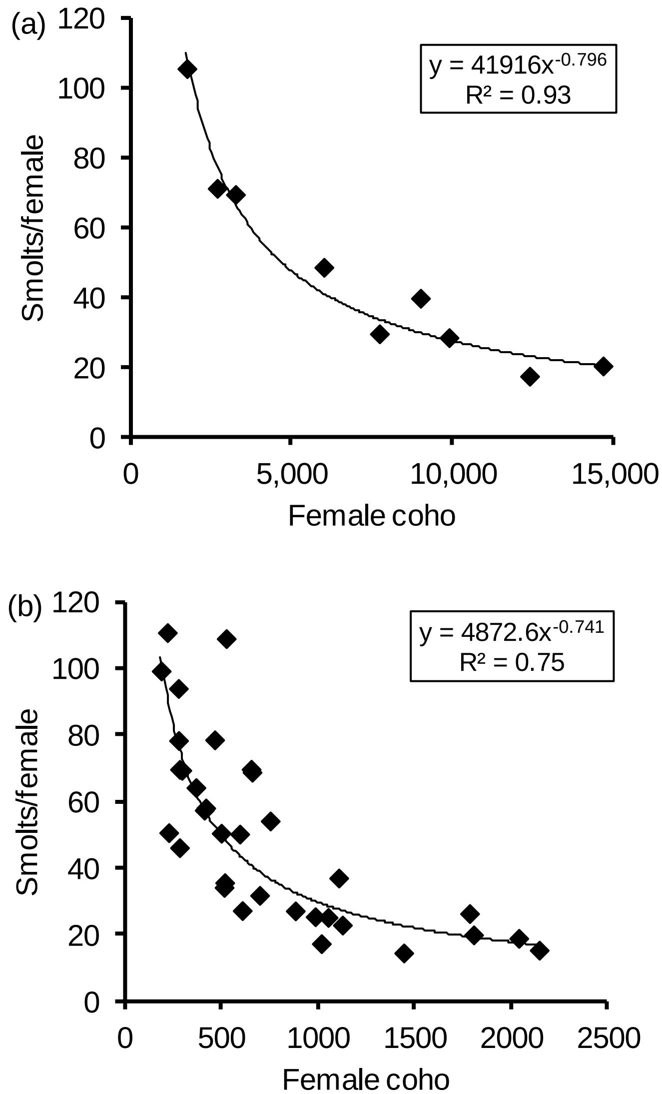

Figure 1. Freshwater productivity (juveniles/female) as a decreasing function of female coho escapement in the South Fork Skykomish (*a*, Sunset Falls, brood year 1976-1984) and Big Beef Creek (*b*, brood year 1978-2009) watersheds.

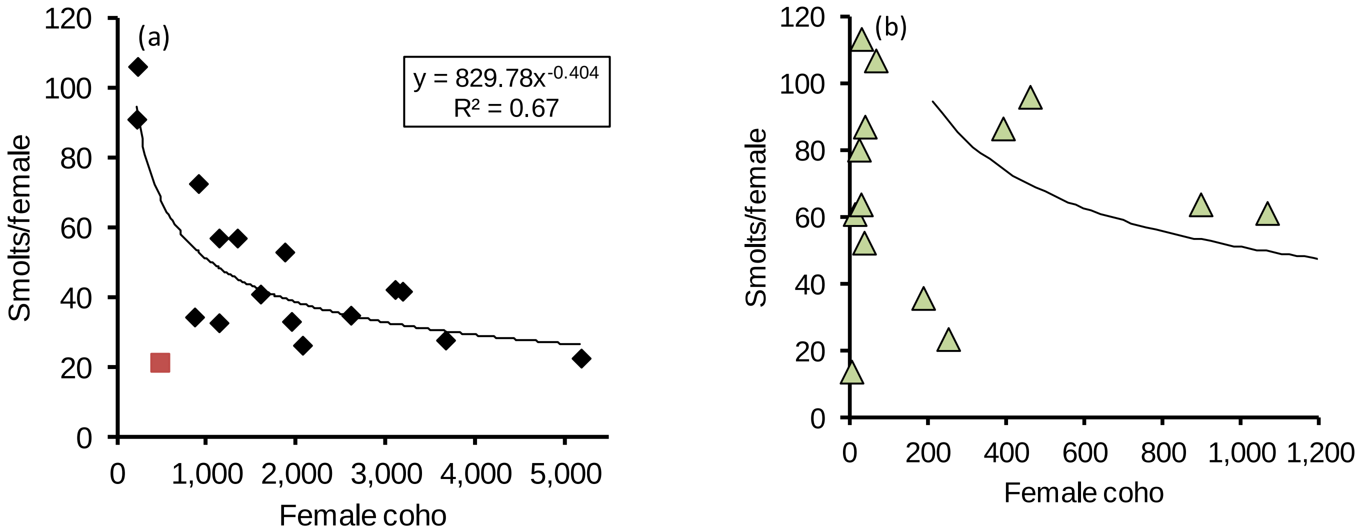

Figure 2. Freshwater productivity (juveniles/female) as a function of female coho spawners in the Deschutes River. For brood year 1978-1994 (*a*), coho productivity was a decreasing function of escapement (black square) with the exception of brood year 1989 (red square). The 1989 brood year corresponded 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 2020, WDFW measured coho smolt abundance in five of the Puget Sound management units (Skagit, Hood Canal, Lake Washington, Green, Nisqually). Smolt production data from six additional management units (Nooksack, Juan de Fuca, Stillaguamish, Puyallup, East Kitsap, South Sound) were available due to juvenile monitoring studies conducted by the Lummi, Jamestown, Elwha, Makah, Stillaguamish, Puyallup, Suquamish, and Squaxin tribes. For watersheds where trapping data were not available in 2020 (e.g., Snohomish, Samish), coho smolt abundance was indirectly estimated using several approaches.

The most commonly used approach was based on the smolt potential predicted for each watershed by Zillges (1977). Rearing habitat was 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 was 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 8% and 100% 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 2019 (corresponding to the 2020 outmigration and 2021 returning adults) had an index value of 7.0 or 87% 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	Geo mean	Min	Max	Average	Min	Max
Hood Canal							
Big Beef	43	25,352	8,115	58,136	65.7%	21.0%	150.7%
Little Anderson	27	388	45	1,969	7.6%	0.9%	38.6%
Seabeck	27	1,176	344	2,725	11.2%	3.3%	26.0%
Stavis	27	4,463	1,549	9,667	88.8%	30.8%	192.3%
Skagit River	31	1,040,290	426,963	1,884,668	75.9%	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***	22	61,213	13,322	179,915	50.6%	11.0%	148.8%
Bear Creek	22	24,634	6,004	62,970	49.2%	12.0%	125.7%
Green River	17	53,915	22,671	194,393	23.9%	10.1%	86.2%
Nisqually	12	115,685	58,930	254,456	100.1%	51.0%	220.2%
Deschutes****	40	19,566	1,187	133,198	8.9%	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.

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

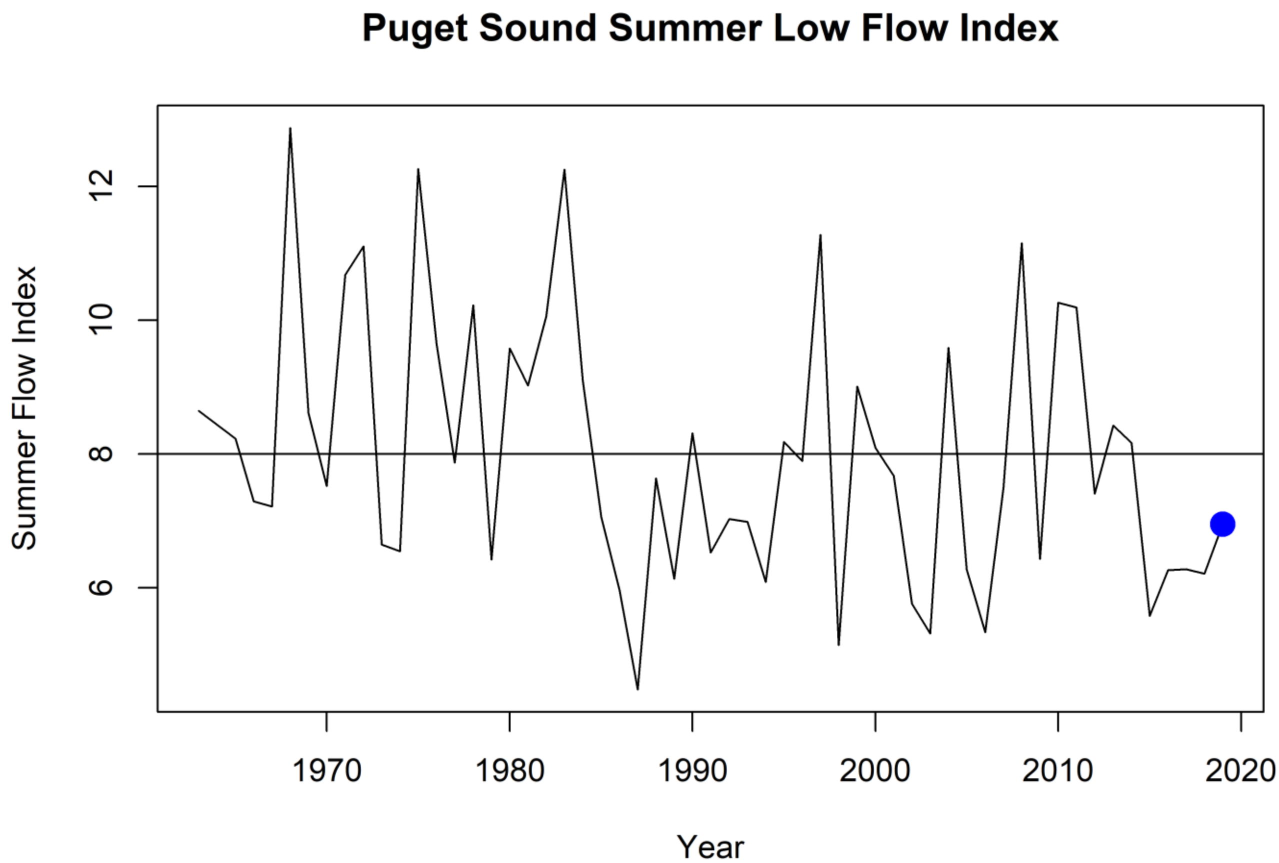

Figure 3. Puget Sound Summer Low Flow Index (PSSLFI) by summer rearing year (return year – 2). PSSLFI is based on 60-day minimum flow averages at eight stream gages in Puget Sound (see Appendix A). The minimum 60-day average flow at each gage is compared to the time series average (1963 to present) and then summed across all eight gages. Flow index corresponding to the 2021 wild coho return (7.0) shown as blue point on graph.

Puget Sound Primary Units

Skagit River

A total of 1,057,000 wild coho smolts (rounded from 1,057,204) are estimated to have emigrated from the Skagit River in 2020 (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 2020 was 1,057,204 (±192,532 95% C.I.), which represents a 2% increase from the average (geometric mean) of 1,040,290 smolts between the 1990 and 2020 ocean entry years (Table 2, Figure 4).

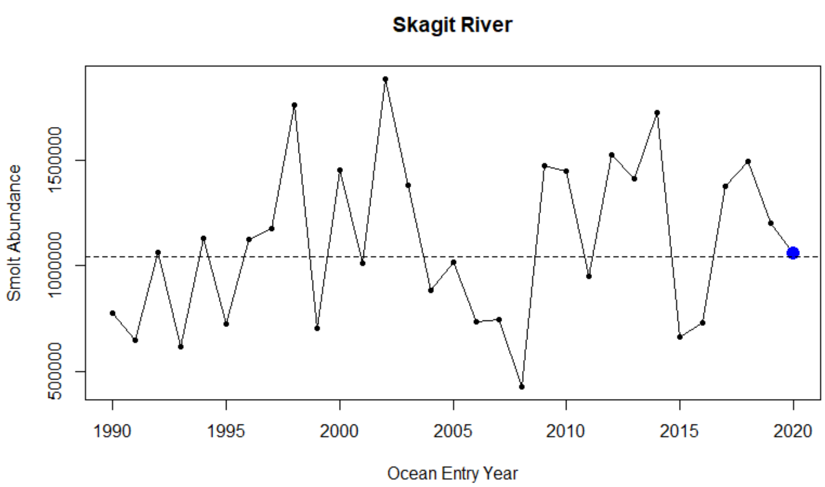

Figure 4. Time series of wild coho smolt outmigration from the Skagit River, ocean entry years 1990 to 2020. Blue point represents outmigration of the cohort included in this forecast. Horizontal line is the geometric mean of the time series.

Stillaguamish River

A total of 462,000 coho smolts (rounded from 462,210) are estimated to have emigrated from the Stillaguamish River in 2020 (Table 1). This estimate was based on a CPUE index of abundance for the 2020 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 (K. Konoski, 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 2020, 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 2014 outmigration have a geometric mean of 426,000 smolts (range 165,000 to 1,195,000), values that bracket the watershed smolt estimates calculated in 1981-1983.

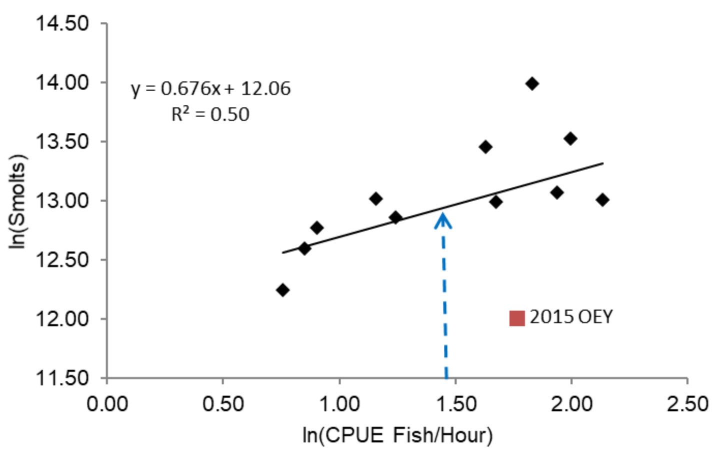

Figure 5. Correlation between CPUE of wild coho smolts in Stillaguamish smolt trap and back-calculated smolt estimates, 2003 to 2014. The 2015 ocean entry year was not used in the regression model. Dashed blue line corresponds to the 2020 ocean entry year. Smolt trap data were provided by K. Konoski (Stillaguamish Natural Resources).

A positive correlation exists between the smolt trap CPUE and the back-calculated estimates of coho smolts (Figure 5). Data were log transformed for analysis. This relationship was applied to the CPUE obtained during the 2020 outmigration (4.3 fish/hour) resulting in an estimated outmigration of 462,210 smolts. The 2015 data 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 418,663 smolts.

Snohomish River

A total of 1,519,000 (rounded from 1,518,569) coho smolts are estimated to have emigrated from the Snohomish River in 2020 (Table 1). The mark-recapture estimate of wild smolts in 2020 is not available. Therefore, the estimated production is the recent 5-year geometric mean of the time series (2015 to 2019) of coho smolt production from this management unit.

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). 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 2020 was a 19% decrease from the average (geometric mean) of 1,863,341 smolts between 2002 and 2019 ocean entry years (Figure 6).

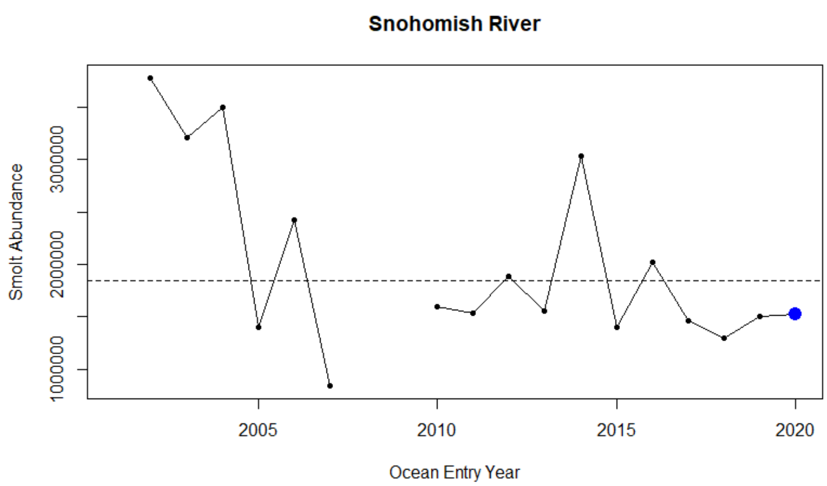

Figure 6. Time series of wild coho smolt outmigration from the Snohomish River, ocean entry years 2002 to 2020. No estimates are available for 2008 or 2009. Blue point represents outmigration of the cohort included in this forecast. The horizontal line is the geometric mean of the time series. Data provided by D. Holmgren (Tulalip Tribes).

Hood Canal

A total of 320,000 coho smolts (rounded from 320,079) are estimated to have emigrated from Hood Canal tributaries in 2020 (Table 1). This estimate is based on measured smolt abundance in select tributaries expanded to the entire management unit.

In 2020, wild coho smolt abundance was measured in Big Beef Creek (BBC; *n* = 19,499*)*, Little Anderson Creek (*n* = 57), Seabeck Creek (*n* = 344*)*, and Stavis Creek (*n* = 4,426). 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 2020 abundance of coho smolts from BBC was a decrease of 23% from the average (geometric mean) of 25,352 between the 1978 and 2020 ocean entry years (Table 2, Figure 7). Coho smolt abundances in neighboring Little Anderson, Seabeck, and Stavis creeks were decreases of 85%, 71%, and 1%, respectively, from the time series averages (geometric mean) in these watersheds (Table 2).

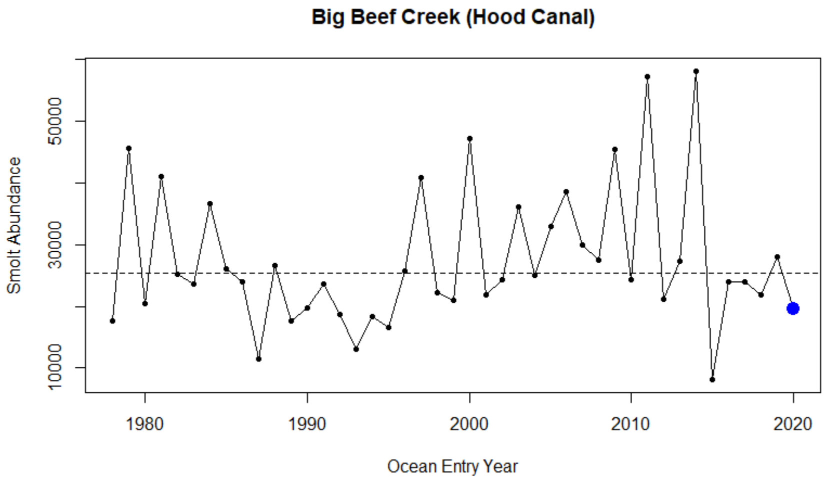

Figure 7. Time series of wild coho smolts from Big Beef Creek, ocean entry years 1978 to 2020. Blue point represents outmigration of the cohort included in this forecast. Horizontal line is the geometric mean of the time series.

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) was 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 was 4.56% of Hood Canal.

As described, the three approaches estimated that the 2020 wild coho production in Hood Canal ranged between 320,000 and 428,000 smolts. Using the Zillges approach, the total of 24,326 smolts from the four tributaries were expanded to an estimated 412,305 Hood Canal smolts. Using the second approach (HCJTC 1994 revision), the total smolts were expanded to 320,079. The third approach expanded the 19,499 smolts from Big Beef Creek to a total of 427,610 Hood Canal smolts. This forecast is based on the most conservative result, provided by the second approach.

Juan de Fuca

A total of 322,000 coho smolts (rounded from 322,153) are estimated to have emigrated from Juan de Fuca tributaries in 2020 (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 were limited in 2020 but included creeks in the eastern and 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 2020 was 16% increase from the average (geometric mean) of 277,843 smolts between the 1998 and 2020 ocean entry years (Figure 8).

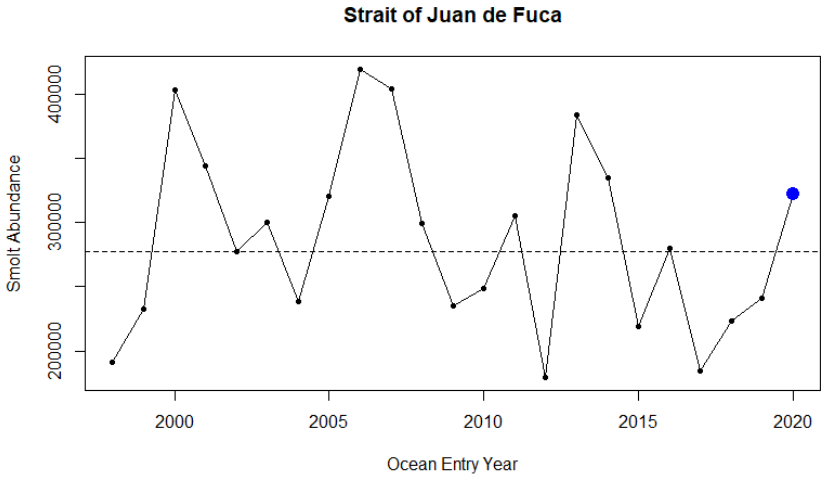

Figure 8. Time series of wild coho smolts from Strait of Juan de Fuca tributaries, ocean entry years 1998 to 2020. Blue point represents the cohort contributing to this forecast. The horizontal line is the geometric mean of the time series. Data provided by Hap Leon (Makah Tribe).

Puget Sound Secondary Units

Nooksack River

A total of 1,348,000 coho smolts (rounded from 1,348,442) are estimated to have emigrated from the Nooksack River in 2020 (Table 1). The 2020 estimate is based on a mark-recapture estimate of smolt abundance from a smolt trap operated by the Lummi Tribe. Results were provided by the Lummi Tribe (D. Flawd, Lummi Nation, personal communication).

Between the 2005 and 2020 ocean entry years, excluding 2018 when there was no smolt trap estimate, coho smolt production in the Nooksack River averaged (geometric mean) 353,515 smolts (Figure 9, range 97,615 to 1,348,442, numbers updated in 2020 by D. Flawd, Lummi Nation). An additional number of coho (0.1% 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 2020 was a 281% increase from the average (geometric mean) for the time series and the highest smolt outmigration estimate of the time series.

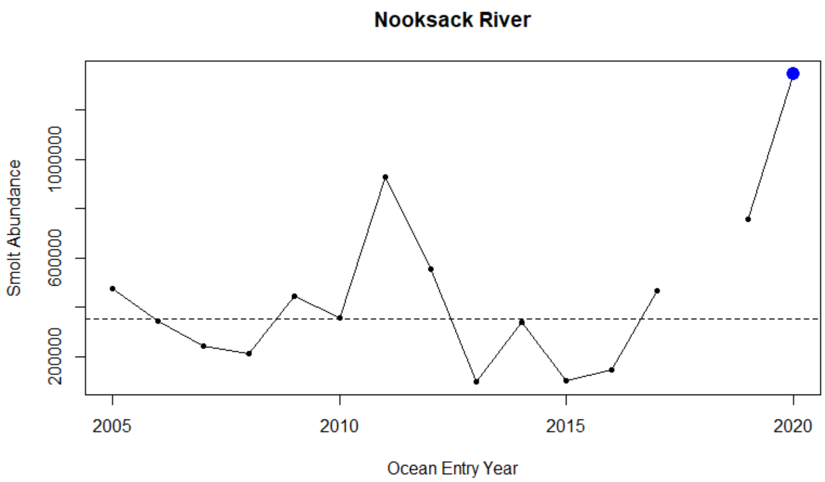

Figure 9. Time series of wild coho smolts from the Nooksack River, ocean entry years 2005 to 2020. No estimate is available for 2018. Blue point represents the cohort contributing to this forecast. The horizontal line is the geometric mean of the time series. Data provided by D. Flawd (Lummi Nation).

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 2020 (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 were slightly higher (i.e., Skagit) than average in 2020. Therefore, the 2020 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 34,000 coho smolts are estimated to have emigrated from the Samish River in 2020 (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 5.0% with an average of 5.8% in the Baker River, which is the measure of wild coho marine survival in closest geographic proximity to the Samish River. During this time period, natural coho returns to the Samish River have averaged ~2,000 adults. Assuming a marine survival rate of 5.8%, an average of 34,000 smolts will result in a return of 2,000 adult spawners. This estimate corresponds to 34 smolts/female (assume 1:1 male:female) and 20% 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 49,000 coho smolts (rounded from 48,998) were estimated to have entered Puget Sound from the Lake Washington basin in 2020 (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 a time-stratified Petersen estimator (Carlson et al. 1998; Volkhardt et al. 2007).

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 2020, coho smolt abundance from the Cedar River was estimated to be 45,132 (±23,875 95% C.I.) smolts. This production was a decrease of 26% from the geometric mean of 61,213 smolts between the 1999 and 2020 ocean entry years (Figure 10). Coho smolts from Bear Creek were estimated to be 11,854 (±4,877 95% C.I.), a 52% decrease from the geometric mean of 24,634 smolts between the 1999 and 2020 ocean entry years (Figure 10). Between 1999 and present, the difference in the number of coho smolts produced by the Cedar River and Bear Creek has increased. Smolt production appears to have followed a similar trajectory (higher or lower years) in the two watersheds since 2006. 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. Coho returns to this portion of the watershed have increased over time, and natural productivity appears to be contributing substantially to this trend (Anderson 2011).

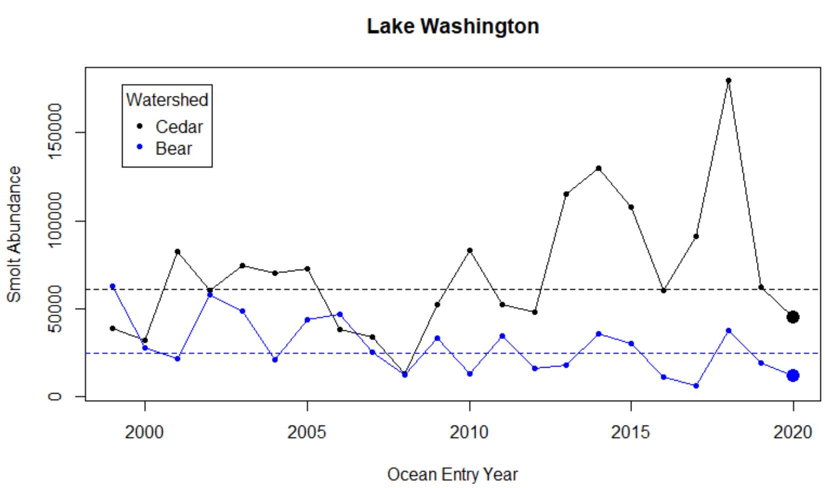

Figure 10. Time series of natural-origin coho smolts from Cedar River (black) and Bear Creek (blue), ocean entry years 1999 to 2020. Larger symbol represents outmigration of cohort contributing to this forecast. Horizontal lines are the geometric mean for the time series in each watershed.

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 was 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 2020 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 2020:2000 smolt ratio in Bear Creek. In 2020, coho smolt production in Bear Creek was 42.1% of that measured in 2000 (11,854/28,142 = 0.421). Therefore, 2020 coho production from Issaquah Creek was estimated to be 8,345 smolts (19,812 * 0.421).

The total coho production of 48,998 assumed 75% survival through Lake Washington. A total of 65,331 coho smolts were estimated to enter Lake Washington (45,132 Cedar + 11,854 Bear + 8,345 Issaquah). The 75% 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 (Pete Lisi, WDFW, unpubl. data). The true survival rate may be lower (e.g., Kiyohara and Zimmerman 2011; 2012), but no calibration of detection efficiency is currently available for these studies.

Green River

A total of 48,000 (rounded from 48,053) natural-origin coho smolts are estimated to have emigrated from the Green River in 2020 (Table 1). This estimate is the sum of 30,480 smolts upstream of the juvenile trap (river mile 34), 17,573 smolts below the juvenile trap, and zero smolts from Big Soos Creek.

In 2020, 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 was estimated using a time-stratified Petersen estimator (Carlson et al. 1998; Volkhardt et al. 2007). Production above the trap was estimated to be 30,480 (±25,448 95% C.I.) smolts. This production was a decrease of 43% from the geometric mean of 53,915 smolts between the 2000 and 2020 ocean entry years (Figure 11).

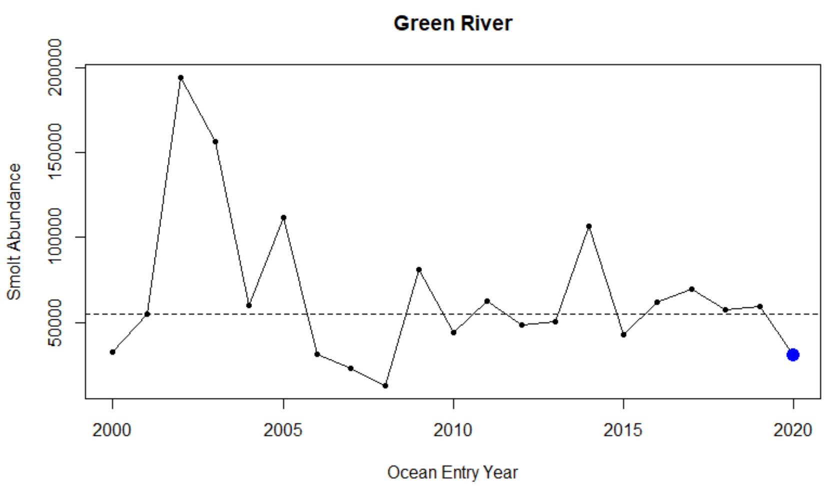

Figure 11. Time series of natural-origin coho smolts above the Green River smolt trap (river mile 34), ocean entry years 2000 to 2020. Blue point represents cohort contributing to this forecast. Horizontal line is the geometric mean for the time series.

Coho smolt production above the juvenile trap was 13.7% of the 223,106 smolt potential estimated for this portion of the watershed (Zillges 1977). Coho rearing in the main stem and tributaries (except Soos Creek) below the trap were estimated to be 17,573 smolts based 13.7% 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). The Big Soos Creek trap was not operated during 2019-2020 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 2020, it is estimated that zero natural-origin coho smolts emigrated from Big Soos Creek as no adults were passed above Soos Creek hatchery in 2018.

East Kitsap

A total of 92,000 coho smolts (rounded from 92,149) are estimated to have emigrated from East Kitsap tributaries in 2020 (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 2020 (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 2020 coho abundance of 5,747 smolts from Lost (n = 2,890) and Wildcat (n = 2,857) creeks was 59.3% of the calculated smolt potential. Total coho smolt abundance for the East Kitsap management unit was estimated to be 92,149 smolts based on 59.3% of the 155,269 smolt potential for all watersheds in this management unit.

Puyallup River

A total of 435,000 coho smolts (rounded from 435,119) are estimated to have emigrated from the Puyallup River in 2020 (Table 1). This estimate is based on measured production in the Puyallup River above the juvenile trap (102,520), estimated production from the White River (325,905), and an estimate from the Puyallup River below the Puyallup-White confluence (6,694).

In 2020, the Puyallup Tribe operated a juvenile fish trap on the Puyallup River just upstream of the confluence with the White River. A total of 102,520 coho smolts were estimated to have emigrated from the Puyallup River above the smolt trap, including production above Electron Dam (Berger 2020; A.

Berger, Puyallup Tribe, personal communication). This production represented an increase of 81% from the average (geometric mean) of 56,761 smolts between the 2005 and 2020 ocean entry years and was over double the smolt production estimated in this system each year since 2015 (Figure 12). Coho smolt production above the juvenile trap represents 16.1% 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 2020 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.

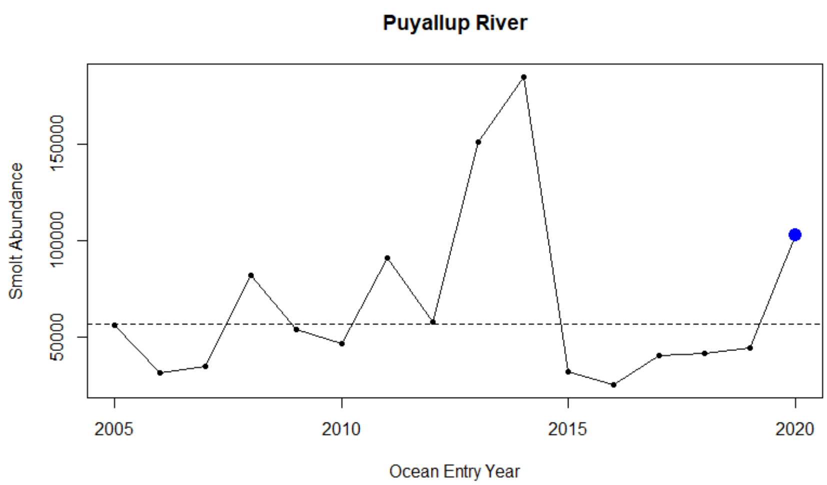

Figure 12. Time series of natural-origin coho smolts above the Puyallup River smolt trap (upstream of confluence with White River), ocean entry years 2005 to 2020. Blue point represents cohort included in this forecast. Horizontal line is the geometric mean of the time series. Data provided by A. Berger (Puyallup Tribe).

A total of 325,905 coho smolts are estimated to have emigrated from the White River, including production upstream of Mud Mountain Dam, in 2020. This estimate was derived from catch in a rotary screw trap (n = 6,973) operated in the White River above the confluence with the Puyallup River and an assumed 2.1% trap efficiency for coho smolts (A. Berger, Puyallup Tribe, personal communication). Trap efficiency was not directly measured for coho smolts. Instead a value for steelhead smolts was used (1.6% with an additional 0.5% added because coho are presumably easier to catch than steelhead due to differences in size.

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 435,119 was the sum of coho smolt production from the Puyallup River (102,520 above White River confluence), White River (325,905) above confluence with Puyallup River), and Puyallup River (6,694 below White River confluence).

Nisqually River

A total of 79,000 coho smolts (rounded from 79,173) are estimated to have emigrated from the Nisqually River in 2020 (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 62,153 (±8,490 95% C.I.) smolts. This production represented a 46% decrease from the geometric mean of 115,683 smolts between the 2009 and 2020 ocean entry years (Figure 13). This estimate was 53.8% of the 115,554 smolt potential predicted by Zillges (1977). Total smolts above and below the trap were estimated to be 79,173 assuming that smolt production below the trap was also 53.8% of the 31,643 smolt potential predicted by Zillges (1977) below the trap (= 62,153 + (31,643 * 0.538)).

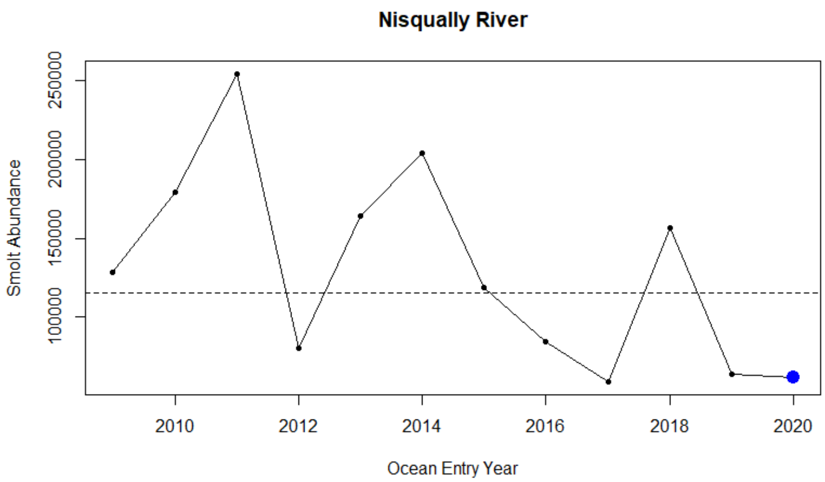

Figure 13. Time series of natural-origin coho smolts from the Nisqually River above the smolt trap (rm 12), ocean entry years 2009 to 2020. Blue point represents outmigration of the cohort included in this forecast. Horizontal line is the geometric mean for the time series.

Deschutes River

A total of 15,000 natural-origin coho smolts (rounded from 15,201) are estimated to have emigrated from the Deschutes River in 2020 (Table 1). The 2020 production estimate was the second year since 1979 not based on smolts captured at a trap below Tumwater Falls. Instead, the estimate was calculated by multiplying the number of adult females that returned to the trap in 2018 by an average (brood years 1983 through 2016) smolt-per-female production rate of 61.3 (248 * 61.3 = 15,201).

The 2020 production represents a decrease of 18% from the geometric mean of 18,521 smolts between the 1979 and 2020 ocean entry years (Figure 14) and was just 6.9% (15,201/219,574) 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 2016 brood, 697 females (combination of natural-origin and hatchery-origin) were released upstream of Tumwater Falls to spawn. Freshwater productivity from this spawner escapement was 23 smolts-per-female, much lower than productivity expected from typical density-dependent freshwater relationships for coho salmon (Figure 2).

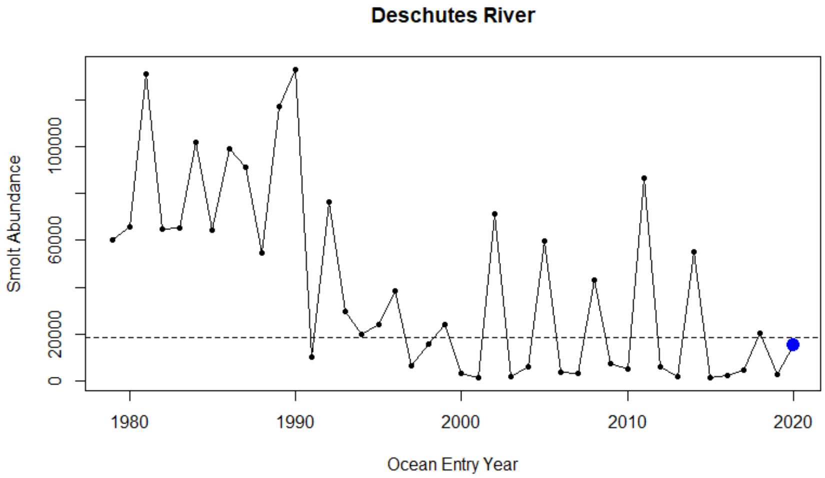

Figure 14. Time series of natural-origin coho smolts from the Deschutes River, ocean entry years 1979 to 2020. There was no trapping in 2019 and 2020. Blue point represents outmigration of cohort included in this forecast. Horizontal line is the geometric mean of the time series.

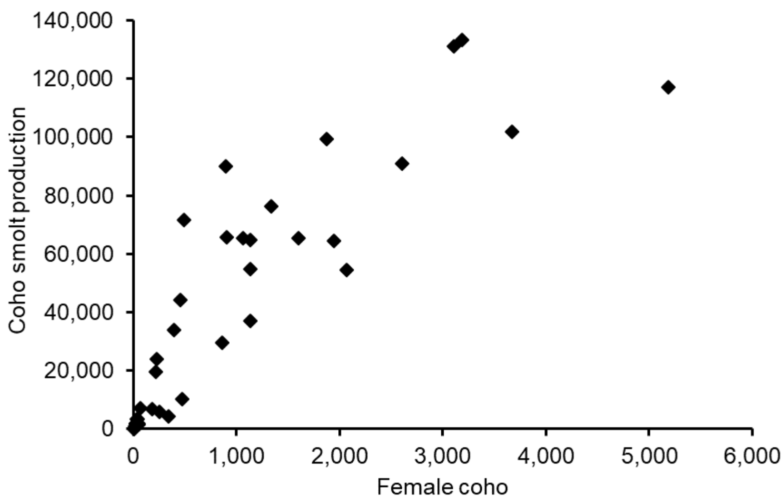

Figure 15. Coho smolt production as a function of female spawners in the Deschutes River, Washington, brood year 1978-2016.

South Sound

A total of 180,000 coho smolts (rounded from 180,348) are estimated to have emigrated from South Sound tributaries in 2020 (Table 1). This estimate was based on results of smolt monitoring in Mill, Skookum, Goldsborough, and Gosnell creeks conducted by the Squaxin Island Tribe (data provided by Daniel Kuntz, Natural Resources Department, Squaxin Island Tribe). The wild coho smolt estimate for Mill Creek was 1,536 smolts (0.3%). The smolt estimate for Skookum Creek was 519 (1.8%) and Goldsborough Creek was 131,138 smolts (183.1%). 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 produced 3,781 smolts or 26.0% of the production potential for this portion of the Mill Creek watershed. Localized conditions among small creeks, such as the Sound Sound tributaries, 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 2020 coho production for the South Sound management unit was estimated in two steps – smolt estimate for Goldsborough Creek (131,138) 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 49,210, which was 9.8% applied to the Zillges production potential of 502,142 smolts for these watersheds. The rate of 9.8% represents the 2020 proportion of the overall production potential observed in Skookum Creek and Gosnell Creek (used instead of Mill Creek). Coho production for the entire South Sound management unit was estimated to be 180,348 smolts (= 49,210 + 131,138), which is 31.4% 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 400 to 1,000 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 2020, 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. Historical smolt abundance data is also available from the Dickey and Bogachiel rivers in the Quillayute watershed. In coastal watersheds where smolt monitoring did not occur in 2020, 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. Clearwater and Queets river data 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)	39	69,217	27,314	134,052	494	195	958
Queets (no Clearwater)	37	191,431	53,473	352,694	618	172	1,138
Chehalis (Grays Harbor)[a]	36	2,151,113	502,918	3,769,789	1,018	238	1,783

[a]Data summary excludes 1993 and 2015 outmigration when tag recoveries were too few to provide a reliable estimate.

Queets River

A total of 162,000 (rounded from 161,650) wild coho smolts are estimated to have emigrated from the entire Queets River watershed in 2020 (Table 1). This estimate was based on coho smolt data collected and analyzed by the Quinault Tribe (Tyler 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 44,092 wild coho smolts (315 smolts/mi^2). Smolt abundance from the Queets River (without the Clearwater) was estimated to be 117,558 wild coho smolts (379 smolts/mi^2).

Quillayute River

A total of 221,000 coho smolts (rounded from 220,894) are estimated to have emigrated from the Quillayute River system in 2020 (Table 1). This estimate is based on historical measures of smolt abundance in two sub-basins of the Quillayute River and a current year-to-historical smolt abundance ratio in the Clearwater River (Queets management unit), where smolt abundance was measured in 2020.

In the Quillayute watershed, smolt production was measured historically in the Bogachiel and Dickey rivers. Coho smolt abundance above the Dickey River trap averaged 71,189 coho (818 smolts/mi^2) between 1992 and 1994. Coho smolt abundance in the Bogachiel River 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) and Cedar Creek (NF Lewis River, Figure 16). 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 is 306,000 smolts.

The 2020 Quillayute coho production 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 0.72 was the ratio of Clearwater River production in 2020 (44,092) to average Clearwater River production in 1992-1994 (44,092/61,000 = 0.72). Because historical smolt densities differed between the Dickey and Bogachiel rivers, separate estimates were developed for two portions of the Quillayute River watershed. The 2020 coho smolt abundance in the Dickey River was estimated to be 63,857 smolts (0.72*88,344 smolts). The 2020 coho smolt abundance in the Quillayute (excluding the

Dickey) was estimated to be 157,038 smolts (0.72*217,257 smolts). The total 2020 coho production of 221,000 smolts was the rounded sum of these estimates (63,857 + 157,038 = 220,894).

Hoh River

A total of 94,000 wild coho smolts are estimated to have emigrated from the Hoh River in 2020 (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 315 smolts/mi^2 from the Clearwater River was applied to the 299-mi^2 of the Hoh watershed and resulted in an estimated 94,000 smolts (rounded from 94,185) from the Hoh River system.

Quinault River

A total of 164,000 wild coho smolts are estimated to have emigrated from the Quinault River in 2020 (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 2020, a production rate of 379 smolts/mi^2 was applied to the 434-mi^2 Quinault River system, resulting in an estimated 164,000 smolts (rounded from 164,486).

Independent Tributaries

A total of 148,000 wild coho smolts are estimated to have emigrated from the independent tributaries of Coastal Washington in 2020 (Table 1). Coho smolt production has not been directly measured in any of the coastal tributaries. For 2020, an average production rate of 350 smolts/mi^2 was applied to the total area of these watersheds (424 mi^2; Appendix B), resulting in an estimated 148,000 smolts (rounded from 148,400).

Grays Harbor

A total of 2,583,000 (rounded from 2,582,733) wild coho smolts are predicted to have emigrated from the Grays Harbor system in 2020 (Table 1). This estimate was derived in two steps. Wild coho production was first estimated for the Chehalis River (n = 2,141,065). Smolt abundance per unit watershed area of the Chehalis River system was then applied to the Grays Harbor tributaries (n = 188,418, Hoquaim, Johns, and Elk rivers) and the Humptulips River (n = 253,250).

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 (Jim Jorgenson, 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 2019 ocean entry year (2020 return), this model predicted a smolt abundance of 2,053,869 (1,807,605 – 2,333,683, 95% C.I.) which was higher than the mark-recapture estimate of 1,516,207 (1,178,576 – 1,853,837, 95% C.I.).

In the 2020 ocean entry year, coho smolts were associated with average incubation flows, lower than average summer flows, and average overwinter flows as measured at USGS gage #12027500, Grand Mound (Figure 16). The 2020 smolt production was predicted to be 2,141,065 (1,932,132 – 2,372,592, 95% C.I.) based on the multiple regression model including summer and overwinter flows. This prediction is 0.5% lower than the time series average of 2,151,113 wild coho smolts.

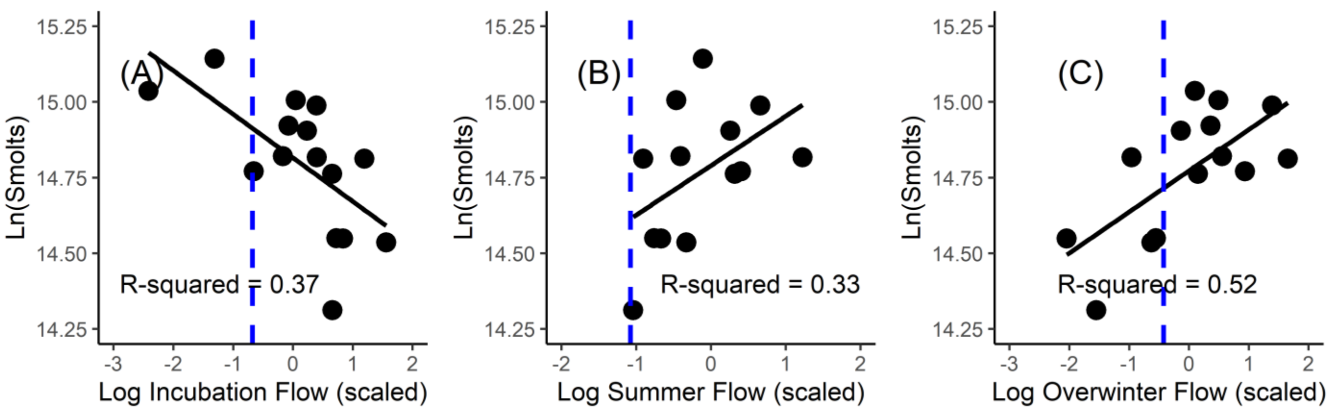

Figure 16. Chehalis River wild coho smolt production as a function of incubation flows (a), summer rearing flows (b), and overwinter rearing flows (c) for ocean entry year 2001-2020 as measured at USGS gage #12027500 in Grand Mound. Incubation flows are the cumulative daily mean flow between December 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 2020 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 1,013 smolts/mi^2 (2,141,065 smolts per 2,114 mi^2). A total of 188,418 coho smolts are estimated for the tributaries of Grays Harbor (1,013 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 253,250 smolts (1,013 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 2020 was estimated to be 2,582,733 smolts (2,141,065 + 188,418 + 253,250 = 2,582,733).

Willapa Bay

A total of 595,000 coho smolts are estimated to have emigrated from the Willapa Bay basin in 2020 (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 a number of smaller tributaries. Similar to 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 2020 (595,000 smolts) was calculated by applying 700 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 were 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 2020, 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 2020. 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 2020 estimate of 3,788 natural-origin coho smolts, the 2020 coho smolt density was estimated to be 146 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 2020 coho smolt density from these watersheds ranged between 203 and 372 smolts/mi^2 (Table 4). A total of 24,591 natural-origin coho smolts were estimated to have emigrated from all three watersheds in 2020 (Table 5). This included 9,134 smolts from Mill Creek, 10,787 smolts from Abernathy Creek, and 4,670 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 30,912 natural-origin coho smolts, captured at Swift Dam in 2020, 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 [34,961] plus the number estimated to pass through the turbine [4,538 = 39,499 – 34,961] multiplied by an assumed 85% survival [38,818 = 34,961 + 4,538 *0.85].

Based on a watershed area of 159 mi^2 and a preliminary 2020 estimate of 39,499 natural-origin smolts emigrating from the Tilton River, coho smolt density was estimated to be 248 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 127,544 smolts produced above Cowlitz Falls, coho smolt density of the Upper Cowlitz River was estimated to be 122 smolts/mi^2 in 2020 (Table 4). The total number of natural-origin coho emigrating from the Upper Cowlitz was 128,261 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 2020. 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 2020. 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 2020 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 138,611 smolts (Table 5). This estimate was derived from an average smolt production density of 172 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 157,685 smolts (Table 5). This estimate was derived from an average smolt production density of 254 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, 574,000 natural-origin coho smolts (rounded from 574,109) are estimated to have emigrated from the Washington Lower Columbia region in 2020 (Table 1). On average, the 2020 smolt production in watersheds without hatchery production had a 26% increase from the 10-yr average (2010 to 2019), whereas watersheds with hatchery production had a 33% decrease 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 (sub yearlings) are observed emigrating past the trap sites, and, if they survive, these juveniles also contribute to natural production in subsequent years.

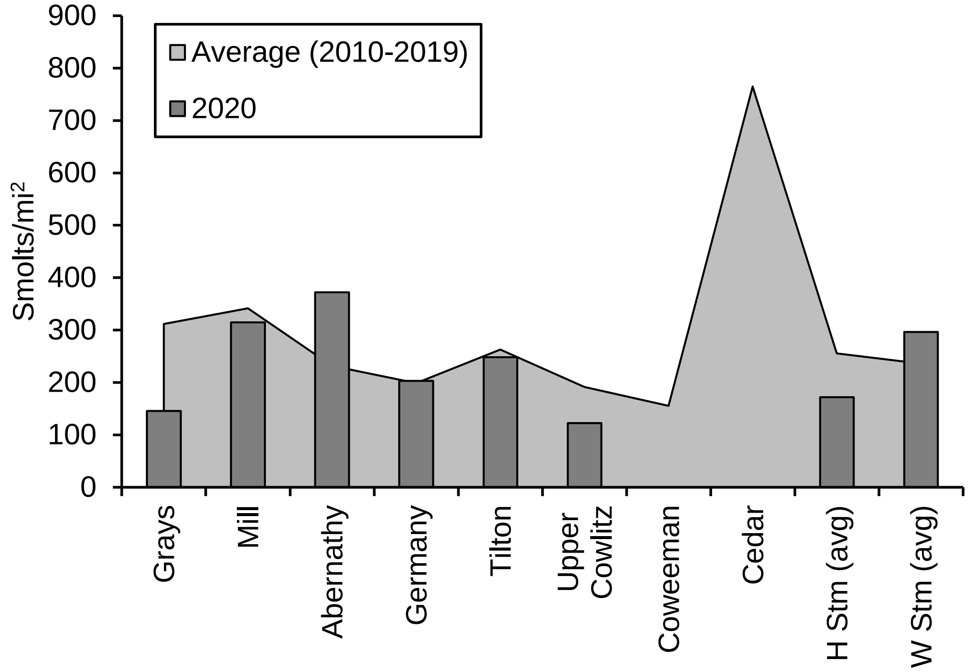

Figure 17. Coho smolt densities (smolts per mile^2 of watershed area) in eight Lower Columbia tributaries in Washington State. Graphs shows the 2020 density (bars) relative to the average smolt abundance from these watersheds (2010-2019).

Table 4. Smolt densities in 2020 from monitored coho salmon streams in the Lower Columbia River ESU. No data were collected from the Coweeman River or Cedar Creek in 2020.

Watershed	Density n/mi^2
Grays	146
Mill	315
Abernathy	372
Germany	203
Tilton	248
Upper Cowlitz	122
Coweeman*	127
Cedar*	675
Hatchery Streams	172
Wild Streams	297

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

Table 5. Coho smolt emigrants in 2020 from the Lower Columbia Evolutionary Significant Unit including monitored streams, non-monitored streams with hatcheries, and non-monitored streams without hatcheries.

Watershed	n
Grays	3,788
Mill	9,134
Abernathy	10,787
Germany	4,670
NF Lewis	30,912
Tilton	38,818
Upper Cowlitz	128,261
Coweeman*	15,148
Cedar*	36,294
Non-monitored Hatchery Streams	138,611
Non-monitored Wild Streams	157,685
Total Smolt Emigration	574,109

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

Marine Survival

Approach

Sibling regressions are a common forecasting tool and were 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. Since 2012, forecasts were developed using environmental variables as predictors of marine survival (Zimmerman 2012; 2013; 2014), updating the previous approach based on sibling regressions (Seiler 1996; Zimmerman 2011).

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 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 were 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 were 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 was further broken into “Local Scale” indicators associated with each of its oceanographic sub-basins (Babson et al. 2006; Moore et al. 2008b). Local indicators were 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 was estimated for index populations in eight coho management units (MU) – six in Puget Sound (including the 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 five management units (Green/Duwamish MU, Snohomish River 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 estimate 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), 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 Juan de Fuca management unit, marine survival was estimated from the smolts and the ocean age-3 abundance of the entire management unit. Smolt estimates are described in the section above (provided by Hap Leon, Makah Tribe). 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. 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. From 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 2020 ocean entry years, natural coho smolts from the Upper Cowlitz (above Cowlitz Falls dam) were coded-wire tagged prior to release. 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 Tim Sippel, 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 were applied, including broad scale indices such as the Pacific Decadal Oscillation (PDO) and the Oceanic Nino 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 were represented by prior winter (January to March) and ocean entry (May to September) time periods. In 2020, NPGO values in August and September of ocean entry year were unavailable at the time of the forecast. The ONI was represented by a single time period (January to June) representing the ocean entry year.

At the "Region Scale," a set of pre-developed indicators were applied to Washington Coast and Lower Columbia management units and comparable indicators for Puget Sound (Appendix C). Regional indicators for the Washington Coast 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), 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). 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 were 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 – Whidbey Basin, Central Sound, South Sound, and Hood Canal (Babson et al. 2006; Moore et al. 2008a; Moore et al. 2008b). Whidbey Basin was 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 included temperature and salinity in the upper 20 m of marine waters near each river mouth. River flows were 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 densities 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 were averaged between April and June, the time period that wild coho smolts enter marine waters. Chlorophyll and light transmission values were 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. Therefore, three stations monitored by the King County Puget Sound Marine Monitoring Program were used as proxies (see Appendix C).

Statistical Analyses

Linear regression models were used to examine the relationships between marine survival and marine environmental variables for each population. Linear models were fit with a beta distribution appropriate for modeling survival data (ratio with range between 0 and 1). The analysis was limited to ocean entry years 1998-2020 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). Predictor variables were scaled to a mean of zero and standard deviation of one prior to conducting the multiple regression. Individual linear regressions were also used to identify outlier years in the analysis. Individual variables that were determined to be significant predictors of survival ($\alpha = 0.10$) were combined into a multiple regression model to forecast survival of smolts for the 2021 return (2020 ocean entry year). When correlations among variables were high ($R > 0.7$), only one of the correlated variables was used in the multiple regression.

A backwards stepwise regression process compared nested multiple regression models (one model compared to the same model with one variable missing) using a likelihood ratio test until the inclusion of all variables significantly ($\alpha = 0.10$) improved the prediction of marine survival. Fit of the multiple regression model was evaluated with a leave-one-out cross validation. A plot of the observed versus predicted (estimated) values from the cross-validation was visually inspected. Model evaluation statistics (Haeseker et al. 2008) were derived for each multiple regression model and were used to evaluate competing models (when predictor variables were highly correlated and could not be combined into a single predictive model). 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 2021 return. Predicted marine survival for the 2021 return year (2020 ocean entry year) was provided as a median and 95% confidence intervals from the selected multiple regression model. Predictions were compared for regression model with and without outlier years to determine the sensitivity of the analysis to any outlier survival years. All analyses were completed in the R platform (R development core team 2018).

Nooksack and Strait of Georgia Management Units

Marine survival data for wild coho are not directly available from the Strait of Georgia or Nooksack management units. 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 recent study demonstrated that survival patterns for hatchery coho produced in the Nooksack River are 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 coho populations from the Strait of Georgia ranged between 1% and 2% with very little variability between 2000 and 2009 ocean entry years (Zimmerman et al. 2015). However, the 2020 smolt outmigration estimate for the Nooksack in 2020 was larger than any other year since smolt trapping began in 2005. Based on the available information, a 2.9% marine survival (50% of the predicted marine survival for the Skagit) was applied to the Strait of Georgia and Nooksack management units.

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) 6.3% (range 1.1% to 13.9%) between ocean entry years 1991 and 2019 with a declining trend over this time period (Figure 18). Marine survival data from 2019 are preliminary.

The model used for forecasting included two variables – PDO index May to September of ocean entry and sea surface salinity April to June of ocean entry, measured at the Admiralty Inlet sampling station (ADM001) of the Washington Department of Ecology Marine Waters Monitoring Program (Table 6). Note that sea surface salinity data in 2020 were measured at the Point Wells Offshore sampling station (JSUR01) of the King County Puget Sound Marine Monitoring Program, as the Washington Department of Ecology was unable to sample between March and September 2020 (see Appendix C). Higher survival was associated with lower PDO index values (cooler conditions) and lower salinity values, indicating higher stream flow during the outmigration period. Because of the uncertainty in 2020 salinity values, a second model was evaluated that only included PDO from May to September of ocean entry. The multiple regression model including PDO and salinity was selected based on model evaluation statistics (Table 6). Of note, the selected model slightly under-estimated the marine survival of wild coho returning in 2015 through 2019 (see Figure 18).

The selected multiple regression model (with PDO) predicted 5.7% (2.4% to 11.0%, 95% C.I.) marine survival for the 2021 return year (2020 ocean entry year). The regression model that included just PDO predicted 6.2% marine survival. Based on these results, a 5.7% marine survival rate was applied to the Skagit management unit as well as the Samish management unit (Table 1).

Table 6. Model evaluation statistics for multiple regression model used to predict marine survival (MS) of wild coho salmon from the Baker (Skagit) River. Model was developed and evaluated for the 1998-2020 ocean entry years (OEY). Variables include PDO.MS (PDO index May to September of ocean entry) and AT.Salinity (salinity April to June of ocean entry at WA Dept Ecology station ADM001, Admiralty Inlet) in all years except 2020, which used King County station JSUR01, Point Wells Offshore. **Model used for 2021 forecast is in blue text**.

Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2020 OEY)
MS ~ PDO.MS + AT.Salinity	0.0001	0.0240	0.0290	-36.2%	63.9%	0.0570
MS ~ PDO.MS	0.0003	0.0248	0.0291	-41.2%	69.7%	0.0618

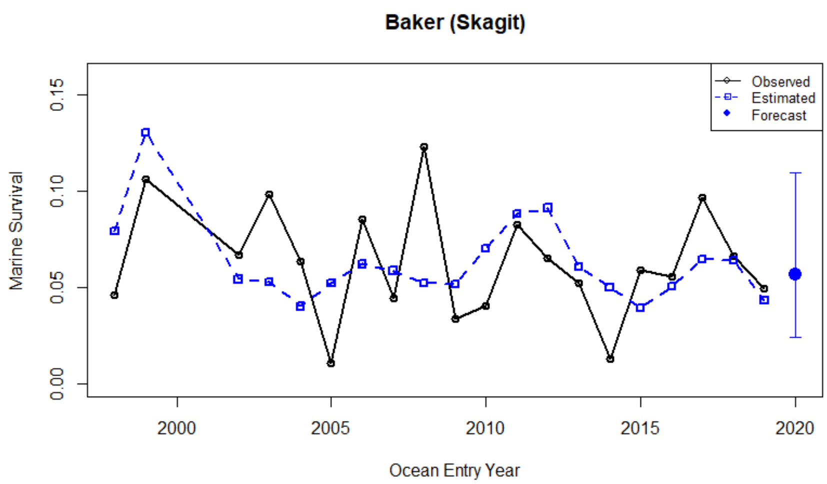

Figure 18. Marine survival of wild coho salmon from the Baker River (Skagit), ocean entry years 1998 to 2020 (excluding 2000 and 2001 for which no marine survival data were available to develop the predictive model). Black solid line shows observed marine survival. Blue dashed line shows marine survival estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±95% C.I) for the 2020 ocean entry year (2021 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% (ranged 1.7% to 27.6%) between ocean entry years 1978 and 2019 with a declining trend over this time period (Figure 19). Marine survival data frm 2019 are preliminary.

The model used for forecasting included two variables – NPGO index January to March of ocean entry year and local marine chlorophyll concentration in May (Table 7). Local marine conditions for this analysis came from the Possession Sound-Gedney Island sampling station (PSS019) of the Washington Department of Ecology Marine Waters Monitoring Program. Note that chlorophyll data in 2020 was measured at the Point Wells Offshore sampling station (JSUR01) on June 1, 2020 of the King County Puget Sound Marine Monitoring Program, as the Washington Department of Ecology was unable to sample between March and September 2020 (see Appendix C). Higher survival was associated with higher NPGO index and higher chlorophyll values. The analysis was developed for ocean entry years 2002 to 2020, excluding 2007 and 2015, due to lack of chlorophyll data from these years. Another multiple regression model was evaluated that included sea surface salinity measured at Race Rocks lighthouse in the Strait of Juan de Fuca (April to June). The model without chlorophyll was developed for ocean entry years 1998 to 2020. Marine survival for the regression model including NPGO index and salinity was predicted to be 5.7% (Table 7).

The selected multiple regression model predicted 4.8% (1.8% to 10.0%, 95% C.I.) marine survival for the 2021 return year (2020 ocean entry year). Based on these results, a 4.8% marine survival was applied to the Snohomish and Stillaguamish management units (Table 1).

Table 7. Model evaluation statistics for multiple regression model used to predict marine survival (MS) of wild coho salmon from the South Fork Skykomish River. Model was developed and evaluated for the 1998-2020 ocean entry years (OEY). Variables include NPGO.JM (NPGO index January to March of ocean entry) and Chl.Local (chlorophyll concentration in May of ocean entry measured at WA Dept Ecology station PSS019, Possession Sound-Gedney Island in all years except 2020, which used chlorophyll data measured June 1 at King County station JSUR01, Point Wells Offshore), and RR.SSS (salinity measured at Race Rocks lighthouse in the Strait of Juan de Fuca April – June of ocean entry). **Model used for 2021 forecast is in blue text**.

Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2020 OEY)
MS ~ NPGO.JM + Chl.Local [without 2007 and 2015]	-0.0008	0.0316	0.0377	-27.1%	53.7%	0.0484
MS ~ NPGO.JM + RR.SSS [all years]	-0.0019	0.0355	0.0453	-33.1%	56.3%	0.0574

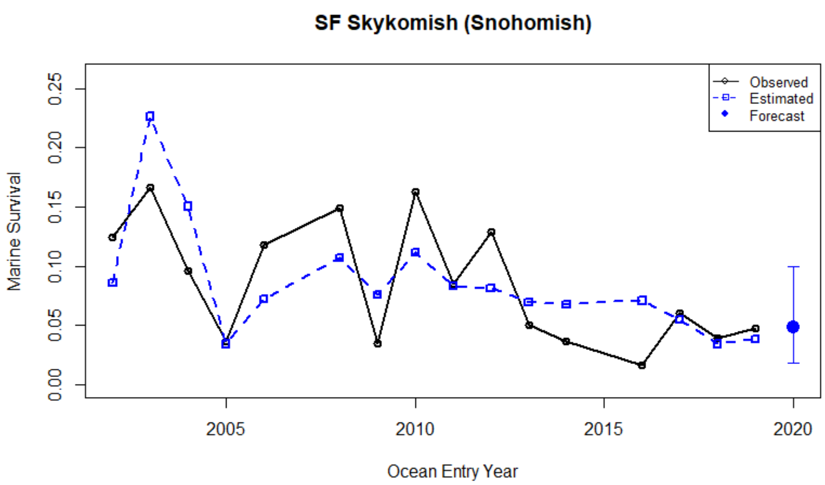

Figure 19. Marine survival of wild coho salmon in the SF Skykomish River, ocean entry years 2002 to 2020 (excluding 2007 and 2015 for which no local chlorophyll data were available to develop the predictive model). Black solid line shows observed marine survival. Blue dashed line shows marine survival estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±95% C.I) for the 2020 ocean entry year (2021 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) 4.5% with a range of 0.7% to 16.9% between the 1977 and 2018 ocean entry years and a declining trend over this time period (Figure 20). A 2019 marine survival estimate was not available.

The model used for forecasting included two variables – PDO index May to September of ocean entry and light transmission in May of ocean entry measured at the Admiralty Inlet sampling station (ADM001) of the Washington Department of Ecology Marine Waters Monitoring Program (see Appendix C). Note that light transmission data in 2020 was measured at the Point Wells Offshore sampling station (JSUR01) on June 1, 2020 of the King County Puget Sound Marine Monitoring Program as the Washington Department Ecology was unable to sample in 2020 (Table 8). Higher survival was associated with lower PDO index values and lower light transmission during ocean entry, indicating higher productivity.

The selected regression model predicted a marine survival of 4.4% (1.7% to 9.0%, 95% C.I.) for the 2021 return year (2020 ocean entry year). A separate model, including NPGO index (January to March of ocean entry) and light transmission, predicted a marine survival rate of 2.1%. Based on these results, a marine survival rate of 4.4% was applied to the Lake Washington, Green River, Puyallup, and East Kitsap MUs (Table 1).

Table 8. Model evaluation statistics for multiple regression model used to predict marine survival (MS) of hatchery coho salmon from the Green River. Model was developed and evaluated for the 1998-2020 ocean entry years (OEY). Variables include PDO.MS (PDO index from May to September of ocean entry), NPGO.JM (NPGO index January to March of ocean entry), and AT.Light (light transmission data measured at WA Dept Ecology station ADM001, Admiralty Inlet, in all years except 2020, which used King County station JSUR01, Point Wells Offshore in May [June 1 in 2020] of ocean entry instead). **Model used for 2021 forecast is in blue text**.

Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2020 OEY)
MS ~ PDO.MS + AT.Light	0.0030	0.0198	0.0297	-45.6%	75.9%	0.0440
MS ~ NPGO.JM + AT.Light	0.0030	0.0189	0.0265	-50.7%	82.9%	0.0208

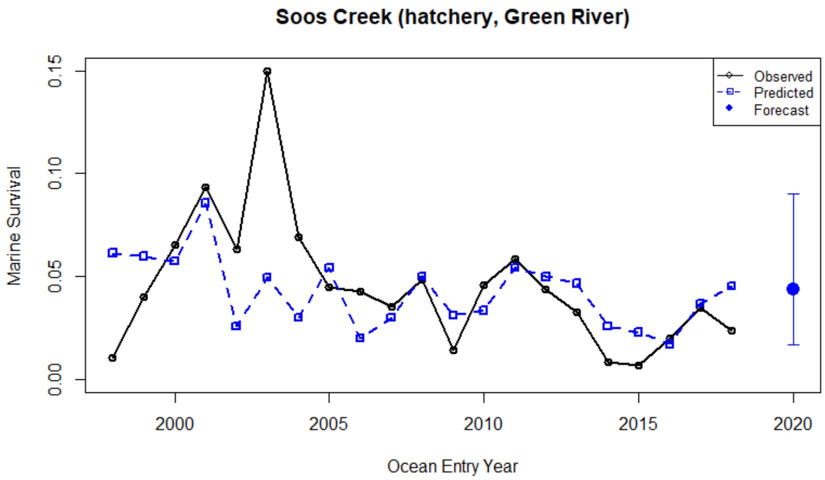

Figure 20. Marine survival of hatchery coho salmon released from Soos Creek hatchery in the Green River, ocean entry years 1998 to 2020. Black solid line shows observed marine survival. Blue dashed line shows marine survival estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±95% C.I) for the 2020 ocean entry year (2021 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) 8.1% and ranged from 1.1% to 29.5% between ocean entry years 1979 and 2019 with a declining trend over time (Figure 21). Marine survival data from 2019 are preliminary.

The model used for forecasting included three variables – PDO index May to September of ocean entry, sea surface salinity measured at Race Rocks lighthouse in the Strait of Juan de Fuca in April to June of ocean entry, and light transmission in May of ocean entry measured at the Budd Inlet – Olympia Shoal sampling station (BUD005) of the Washington Department of Ecology Marine Waters Monitoring Program (see Appendix C). Note that light transmission data in 2020 was measured at the East Passage sampling station (NSEX01) on June 2, 2020 of the King County Puget Sound Marine Monitoring Program as Washington Department of Ecology was unable to sample in 2020. Higher survival was associated with lower PDO index values (i.e., cooler ocean temperatures), higher salinity, and lower light transmission, indicating higher primary productivity. Marine survival in the Deschutes River time series is also related to the NPGO index January to March during ocean entry, although PDO and NPGO are correlated. We evaluated a second model that included NPGO (January to March). The multiple regression model with PDO was selected based on model evaluation statistics (Table 9).

The selected regression model predicted a 4.1% marine survival (3.4% to 4.9%, 95% C.I.) for the 2021 return year (2020 ocean entry year). The regression model that included NPGO predicted 2.7% marine survival. Based on these results, a marine survival of 4.1% 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 9. Model evaluation statistics for multiple regression model used to predict marine survival (MS) of natural coho salmon from the Deschutes River, Washington. Model was developed and evaluated for 1998-2020 ocean entry years (OEY); however, only ten estimates are available in this time series. Variables included PDO.MS (PDO index May to September of ocean entry), NPGO.JM (NPGO index January to March of ocean entry), salinity measured at Race Rocks lighthouse in the Strait of Juan de Fuca measured by DFO April to June of ocean entry, and PS.Light (light transmission data measured at WA Dept Ecology station BUD005, Budd Inlet – Olympia Shoal in all years except 2020, which used King County station NSEX01, East Passage) in May (June 2 in 2020) of ocean entry. **Model used for 2021 forecast is in blue text**.

Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2020 OEY)
MS ~ PDO.MS + RR.SSS + PS.Light	-0.0010	0.0065	0.0088	-6.4%	21.6%	0.0412
MS ~ NPGO.JM + RR.SSS + PS.Light	-0.0133	0.0426	0.0695	-97.7%	130.2%	0.0272

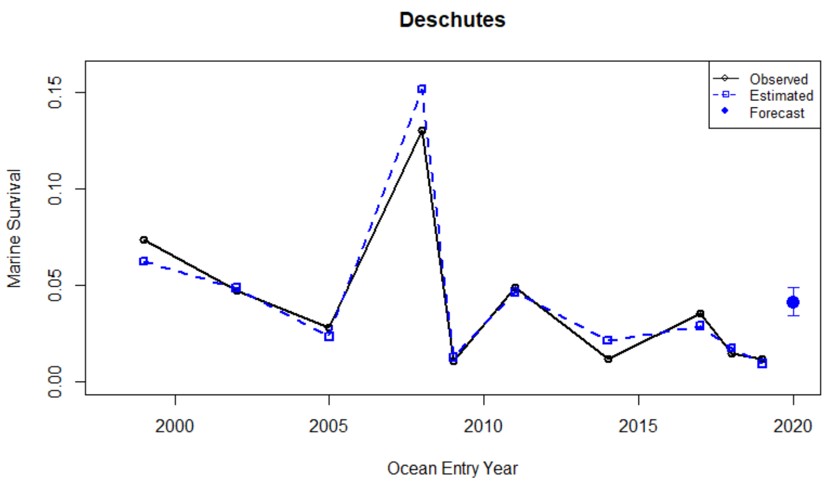

Figure 21. Marine survival of Deschutes River natural coho salmon, ocean entry years 1998 to 2020. Black solid line shows observed marine survival. Blue dashed line shows marine survival estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±95% C.I) for the 2020 ocean entry year (2021 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) 11.7% (range 2% to 32%) between ocean entry years 1977 and 2018 with a declining trend over this time period (Figure 22). A 2019 marine survival estimate was not available.

The model used for forecasting included three variables – NPGO index January to March of ocean entry, jack survival, and light transmission in May of ocean entry measured at the Admiralty Inlet sampling station (ADM001) of the Washington Department of Ecology Marine Waters Monitoring Program (see Appendix C). Note that light transmission data in 2020 was measured at the Point Wells Offshore sampling station (JSUR01) on June 1, 2020 of the King County Puget Sound Marine Monitoring Program as the Washington Department Ecology was unable to sample between March and September in 2020 (Table 10). Higher survival was associated with higher NPGO index values, higher jack survival, and lower light transmission, indicating higher primary productivity. We evaluated a second model that included NPGO (January to March), jack survival, and salinity measured at Race Rocks lighthouse in the Strait of Juan de Fuca by DFO April to June of ocean entry. The multiple regression model with light transmission was selected based on model evaluation statistics (Table 10).

The selected multiple regression model predicted a 4.6% (1.4% to 10.4%, 95% C.I.) marine survival for the 2021 return year (2020 ocean entry year). For the purpose of comparison, the regression model using salinity predicted a marine survival of 8.9%. Based on these results, a 4.6% marine survival was applied to the entire Hood Canal management unit (Table 1).

Table 10. Model evaluation statistics for multiple regression models used to predict marine survival (MS) of wild coho salmon from Big Beef Creek. Model was developed and evaluated for 1998-2020 ocean entry years (OEY). Variables include NPGO.JM (NPGO index January to March of ocean entry), jack survival, AT.Light (light transmission data measured at WA Dept Ecology station ADM001, Admiralty Inlet, in all years except 2020, which used King County station JSUR01, Point Wells Offshore in May [June 1 in 2020] of ocean entry), and RR.SSS (sea surface salinity at Race Rocks lighthouse in the Strait of Juan de Fuca, April to June of ocean entry). **Model used for 2021 forecast is in blue text**.

Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2020 OEY)
MS ~ NPGO.JM + Jacks + AT.Light	0.0002	0.0372	0.0479	-28.7%	54.2%	0.0458
MS ~ NPGO.JM + Jacks + RR.SSS	-0.0031	0.0376	0.0479	-26.9%	50.4%	0.0893

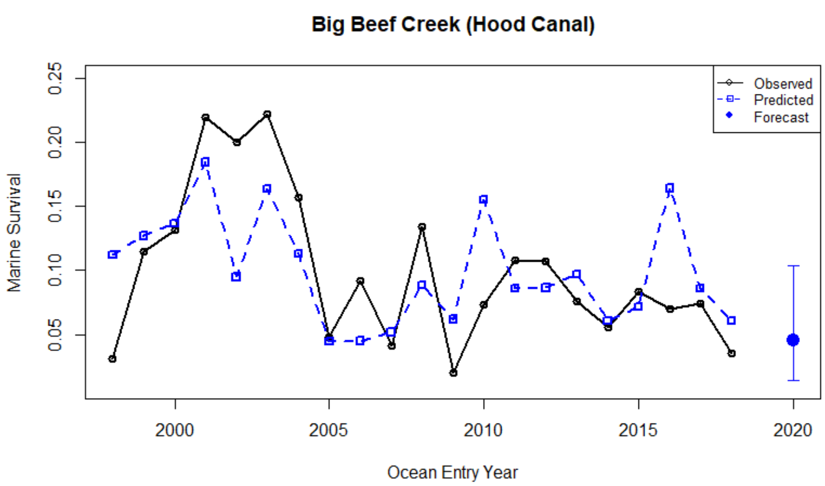

Figure 22. Marine survival of Big Beef Creek wild coho, ocean entry year 1998 to 2020. Black solid line shows observed marine survival. Blue dashed line shows marine survival estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±95% C.I) for the 2020 ocean entry year (2021 return year).

Strait of Juan de Fuca

Marine survival in the Juan de Fuca management unit has averaged (geometric mean) 4.0% and ranged from 0.9% to 12.3% between ocean entry years 1998 and 2018 with a declining trend over this time period (Figure 23). A 2019 marine survival estimate was not available.

The multiple regression model used for forecasting included two variables – NPGO index January to March of ocean entry and winter ichthyoplankton biomass (an index of prey availability following outmigration) determined in NWFSC ocean surveys (Table 11). Higher survival was associated with a higher NPGO index and higher ichthyoplankton biomass, indicating winter ocean conditions are important for setting up favorable marine survival the following spring and summer. Several of the NWFSC indicators were correlated with marine survival, therefore a second model was evaluated using principle component scores from axis 1 of a multivariate analysis of all NWFSC indicators. The model with winter NPGO and ichthyoplankton biomass was selected based on model evaluation statistics (Table 11).

The selected regression model predicted a 1.6% (0.3% to 4.5%, 95% C.I.) marine survival for the 2021 return year (2020 ocean entry year). The regression model using PC1 scores predicted a marine survival for the 2020 ocean entry year of 4.6%. Based on these results, a 1.6% marine survival was applied to the Juan de Fuca management unit (Table 1).

Table 11. Model evaluation statistics for multiple regression models used to predict marine survival (MS) of wild coho salmon in the Juan de Fuca management unit. Model was developed and evaluated for 1998-2020 ocean entry years (OEY). Variables include NPGO.JM (NPGO index January to March of ocean entry), Wint.Ichthyo (biomass of ichthyoplankton determined from January through March prior to ocean entry), and PC1 (principal component axis scores from a multivariate analysis of all NWFSC ocean indicators). Model evaluation statistics are shown for both candidate models. **Model used for 2021 forecast is in blue text**.

Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2020 OEY)
MS ~ NPGO.JM + Wint.Ichthyo	-0.0004	0.0209	0.0260	-31.8%	59.3%	0.0157
MS ~ PC1	0.0005	0.0253	0.0293	-54.7%	87.3%	0.0458

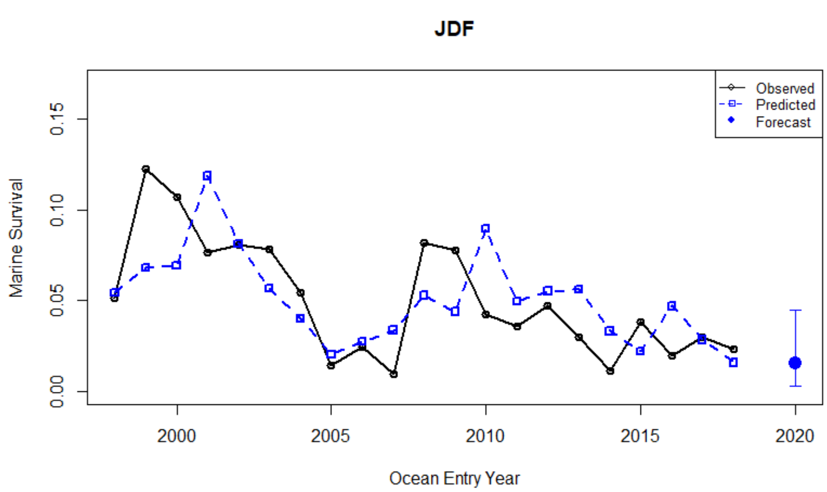

Figure 23. Marine survival of wild coho in the Strait of Juan de Fuca management unit, ocean entry year 1998 to 2020. Black solid line shows observed marine survival. Blue dashed line shows marine survival estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±95% C.I) for the 2020 ocean entry year (2021 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 4.5% (range 0.6% to 11.5%) between ocean entry years 1982 and

2019 with no apparent trend over this time period (Figure 24). Marine survival data from 2019 are preliminary.

The final model selected for forecasting included two variables – PDO index between May and September of ocean entry, and timing of the hydrographic physical spring transition from predominantly downwelling to upwelling conditions (Table 12). Higher survival was associated with lower PDO values (i.e., cooler ocean temperatures) and an earlier physical transition date. Winter ichthyoplankton biomass was also predictive of marine survival but was highly correlated with the PDO index between May and September. An alternative model including winter ichthyoplankton and physical spring transition date was included but performed more poorly by all model evaluation criteria. Another model was fit using axis 1 scores from a principal component analysis of all NWFSC salmon ocean indicators (PC1).

The selected multiple regression model predicted a 3.2% (1.4% to 6.2%, 95% C.I.) marine survival for the 2021 return year (2020 ocean entry year). Based on these results, a marine survival of 3.2% was applied to all management units in the coastal Washington region (Table 1).

Table 12. Model evaluation statistics for multiple regression models used to predict marine survival (MS) of wild coho salmon from Bingham Creek. Model was developed and evaluated for 1998-2020 ocean entry years (OEY). Variables include PDO.MS (PDO index May to September of ocean entry), Phys.Trans (day of the year representing the hydrographic physical spring transition from predominantly downwelling to upwelling conditions during year of ocean entry), and the principal components axis 1 scores (PC1), an annual value summarizing all of the ocean indicators developed by the NWFSC. Model evaluation statistics are shown for each model. **Model selected for 2021 forecast is in blue text**.

Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2020 OEY)
MS ~ PDO.MS + Phys.Trans	-0.0002	0.0163	0.0212	-20.9%	44.3%	0.0325
MS ~ Wint.Ichthyo + Phys.Trans	0.0002	0.0180	0.0220	-20.5%	46.6%	0.0344
MS ~ PC1	0.0003	0.0177	0.0217	-23.4%	50.0%	0.0440

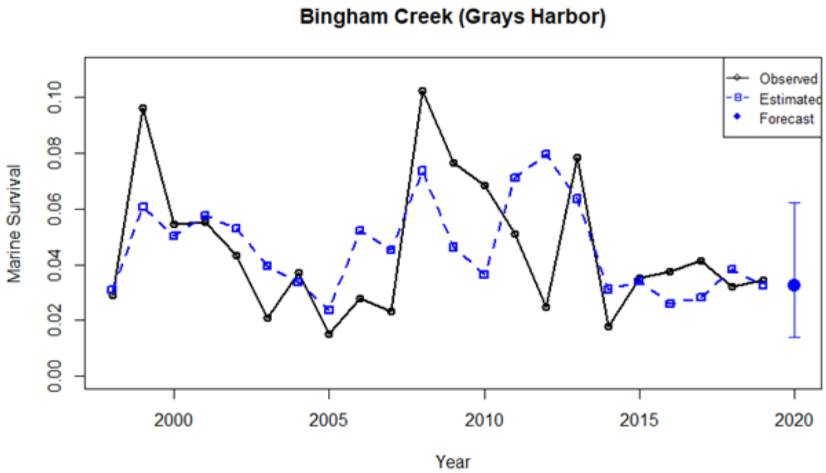

Figure 24. Marine survival of wild coho from Bingham Creek, Washington, ocean entry year 1998 to 2020. Black solid line shows observed marine survival. Blue dashed line shows marine survival estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±95% C.I) for the 2020 ocean entry year (2021 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) 3.5% (range 0.9% to 11.5%) between ocean entry years 2001 and 2019 (Figure 25). Marine survival data from 2019 are preliminary.

The final model included two variables – timing (day of the year) of the physical spring transition from predominantly downwelling to upwelling conditions off the Columbia River, based on the upwelling index at 45° North latitude, and Columbia River flow during April and June of ocean entry (Table 13). Higher marine survival was associated with an earlier transition to upwelling favorable conditions (i.e. winds from the North), indicating higher overall productivity and prey availability for smolts during early ocean residence, and higher river flow during the outmigration period. The length of upwelling conditions on the Pacific coast during the year of ocean entry was also predictive of marine survival; however, this variable was highly correlated with timing of the spring transition. Therefore, a second multiple regression model was evaluated using the length of the upwelling season and Columbia River flow from April to June. Similarly, the PDO index from December to March during the year of ocean entry was predictive of marine survival but was highly correlated with the length of upwelling conditions, and therefore not included in the set of candidate models. 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).

The multiple regression model using the timing of the physical spring transition and Columbia River flow predicted a 4.5% (2.3% to 7.8%, 95% C.I.) marine survival for the 2021 return year (2020 ocean entry year). The model using upwelling length predicted a marine survival of 2.6% and performed similarly based on model evaluation criteria (Table 13), but the flow parameter was insignificant for this model. Based on these results, a marine survival of 4.5% was applied to the Lower Columbia region (Table 1).

Table 13. Model evaluation statistics for multiple regression models used to predict marine survival (MS) of natural coho salmon from the Cowlitz River. Model was developed and evaluated for 2001-2020 ocean entry years (OEY). Variables include Phys.Trans (the timing of the physical spring transition from downwelling to upwelling conditions), Flow.AJ (freshwater flow measured at Bonneville in the Columbia River from April to June of ocean entry), and Upwell.Length (length of upwelling conditions in coastal waters at 45˚N latitude). Model evaluation statistics are shown for models including both upwelling indicators. **Model selected for the 2021 forecast is in blue text**.

Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2020 OEY)
MS ~ Phys.Trans + Flow.AJ	-0.0008	0.0150	0.0211	-24.6%	46.5%	0.0449
MS ~ Upwell.Length + Flow.AJ	0.0002	0.0149	0.0201	-25.1%	51.6%	0.0256

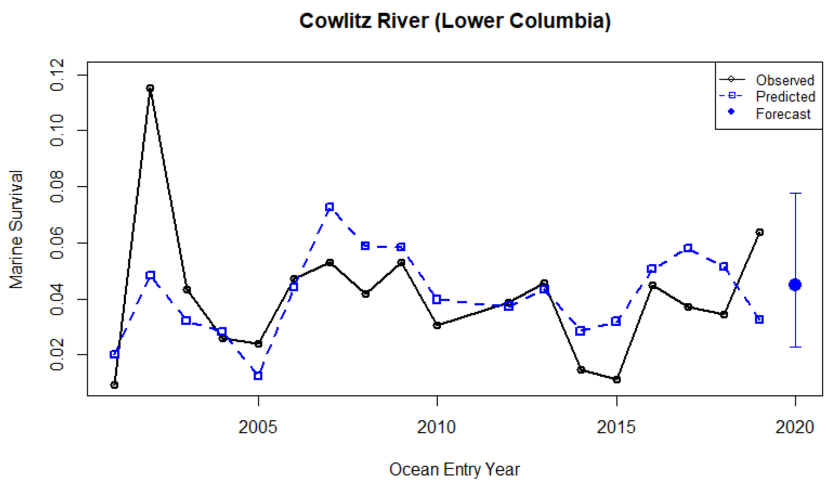

Figure 25. Marine survival of natural coho from the Lower Columbia River management unit, ocean entry year 2001 to 2020 (no marine survival data available for 2011). Black solid line shows observed marine survival. Blue dashed line shows marine survival estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±95% C.I) for the 2020 ocean entry year (2021 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 2019 (including alternate Nooksack gage), the PSSLFI has ranged between 4.5 and 12.9 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 2019 (corresponding to the 2020 outmigration and 2021 returning adults) had an index value of 7.0 or 87% 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 2021 wild coho return shown as blue point in graph.

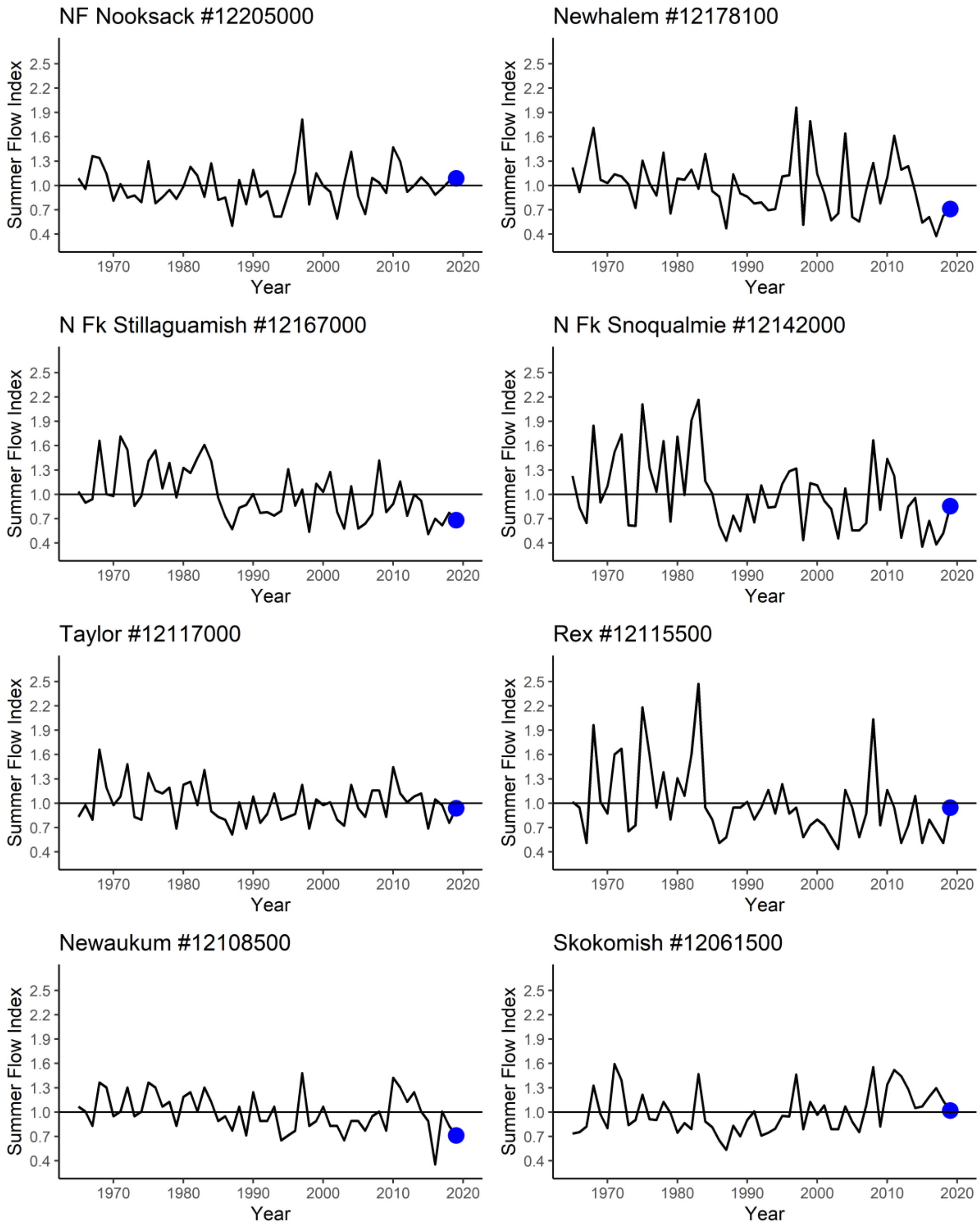

Table - Appendix B. Drainage areas of coastal Washington watersheds. Data are total watershed areas and area of each watershed where coho production has been measured with juvenile trapping studies.

	Drainage area (mi^2)	
Watershed	**Total**	**Measured**
Quillayute	629	
Dickey		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 eight 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	SKGT	SFSKY	GREEN	DESCH	BBC	JDF			Data Source
O/P	PDO (Dec-Mar)	X	X	X	X	X	X	X	X	NWFSC[1]
O/P	PDO (May-Sept)	X	X	X	X	X	X	X	X	NWFSC[1]
O/P	ONI (Jan-Jun)	X	X	X	X	X	X	X	X	NWFSC[1]
O/P	NPGO (Jan-Mar)	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	E. Di Lorenzo[2]
R/P	Race Rocks SST (Apr-Jun)	X	X	X	X	X	X	---	---	DFO[4]
R/P	Race Rocks SSS (Apr-Jun)	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	45˚N	45˚N	NWFSC[1], PFEL[5]
R/P	Temp 20 m (Apr-Jun)	ADM001	ADM001	ADM001	ADM001	ADM001	ADM001	---	---	WA ECY-MWMP[8,9]
R/P	Salinity 20 m (Apr-Jun)	ADM001	ADM001	ADM001	ADM001	ADM001	ADM001	---	---	WA ECY-MWMP[8,9]
R/P	Chlorophyll 20 m (May)	ADM001	ADM001	ADM001	ADM001	ADM001	ADM001	---	---	WA ECY-MWMP[8,9]
R/P	Light transmission (May)	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	NWFSC[1]
L/P	River Flow (Apr-Jun)	12200500	12200500	12113000	12089500	12061500	---	FPC	FPC	USGS[6], FPC[7]
L/P	Temp 20 m Apr-Jun	SAR003	PSS019	PSB003	BUD005	HCB003	---	---	---	WA ECY-MWMP[8,9]

L/P	Salinity 20 m Apr-Jun	SAR003	PSS019	PSB003	BUD005	HCB003	---	---	---	WA ECY-MWMP[8,9]
L/B	Chlorophyll 20 m (May)	SAR003	PSS019	PSB003	BUD005	HCB003	---	---	---	WA ECY-MWMP[8,9]
L/B	Light transmission (May)	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.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/index.cfm

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

[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: http://www.fpc.org/river/flowspill/FlowSpill.asp

[8]Marine waters data from Puget Sound were 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 were provided by WA Department of Ecology.

[9]Marine waters data from Puget Sound in 2020 were 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 were classified as May samples.

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