2018 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 (Sharma and Hilborn 2001; Lawson et al. 2004) and marine environments (Nickelson 1986; Ryding and Skalski 1999; Logerwell et al. 2003) 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 similar to 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 2018 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. 2018 wild coho run forecast summary for Puget Sound, Coastal Washington, and Lower Columbia.

Production Unit	Production X Estimated Smolts Spring 2017	Marine Survival = Predicted Marine Survival	Recruits Adults (Age 3)	Recruits Jan. (Age 3)
Puget Sound				
Primary Units				
Skagit River	1,376,000	5.9%	81,184	99,994
Stillaguamish River	337,000	4.5%	15,165	18,679
Snohomish River	1,984,000	4.5%	89,280	109,965
Hood Canal	359,000	7.6%	27,284	33,605
Straits of Juan de Fuca	184,000	4.0%	7,360	9,065
Secondary Units				
Nooksack River	466,000	2.0%	9,320	11,479
Strait of Georgia	21,000	2.0%	420	517
Samish River	33,000	5.9%	1,947	2,398
Lake Washington	78,000	2.6%	2,028	2,498
Green River	110,000	2.6%	2,860	3,523
East Kitsap	55,000	2.6%	1,430	1,761
Puyallup River	248,000	2.6%	6,448	7,942
Nisqually River	65,000	1.3%	845	1,041
Deschutes River	4,500	1.3%	59	72
South Sound	152,000	1.3%	1,976	2,434
Puget Sound Total	5,472,500		247,606	304,974
Coast				
Quillayute River	345,000	2.8%	9,660	11,898
Hoh River	147,000	2.8%	4,116	5,070
Queets River	173,000	2.8%	4,844	5,966
Quinault River	146,000	2.8%	4,088	5,035
Independent Tributaries	148,000	2.8%	4,144	5,104
Grays Harbor				
Chehalis River	3,249,680	2.8%	90,991	112,073
Humptulips River	353,250	2.8%	9,891	12,183
Willapa Bay	765,000	2.8%	21,420	26,383
Coastal Systems Total	5,326,930		149,154	183,712
Lower Columbia Total	331,000	3.9%	12,909	15,900
GRAND TOTAL	11,130,430		409,669	504,585

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 (Smoker 1955; Mathews and Olson 1980), 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, recent increases in odd-year pink salmon returns to Puget Sound 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).

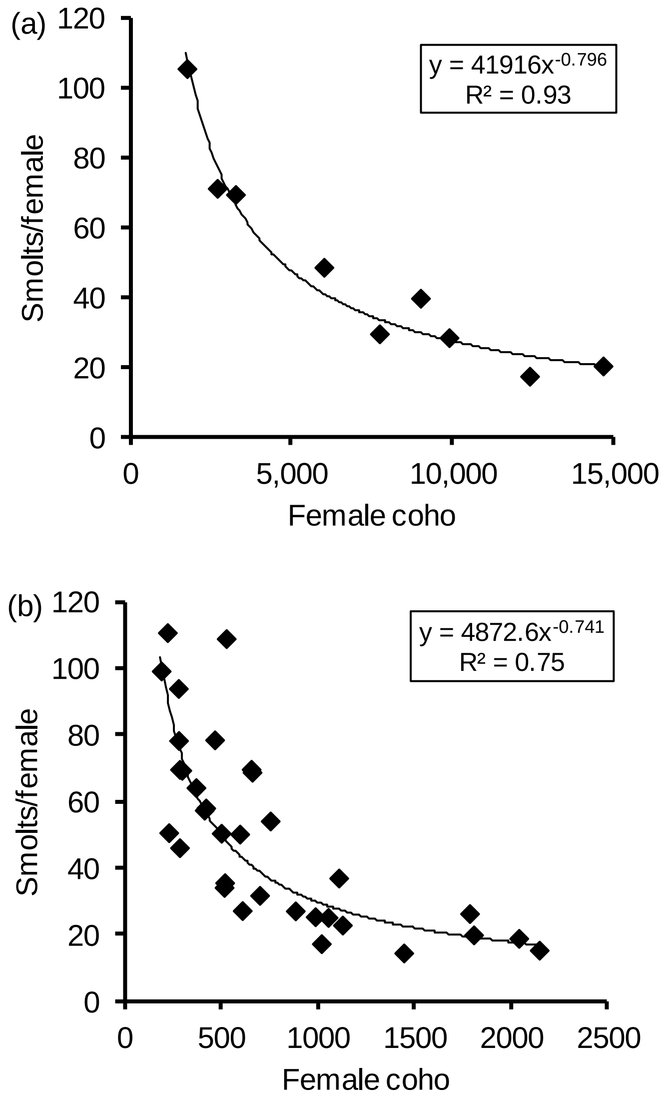


Figure 1. Freshwater productivity (juveniles/female) as a decreasing function of female coho escapement in the South Fork Skykomish (*a*, Sunset Falls, brood year 1976-1984) and Big Beef Creek (*b*, brood year 1978-2009) watersheds.

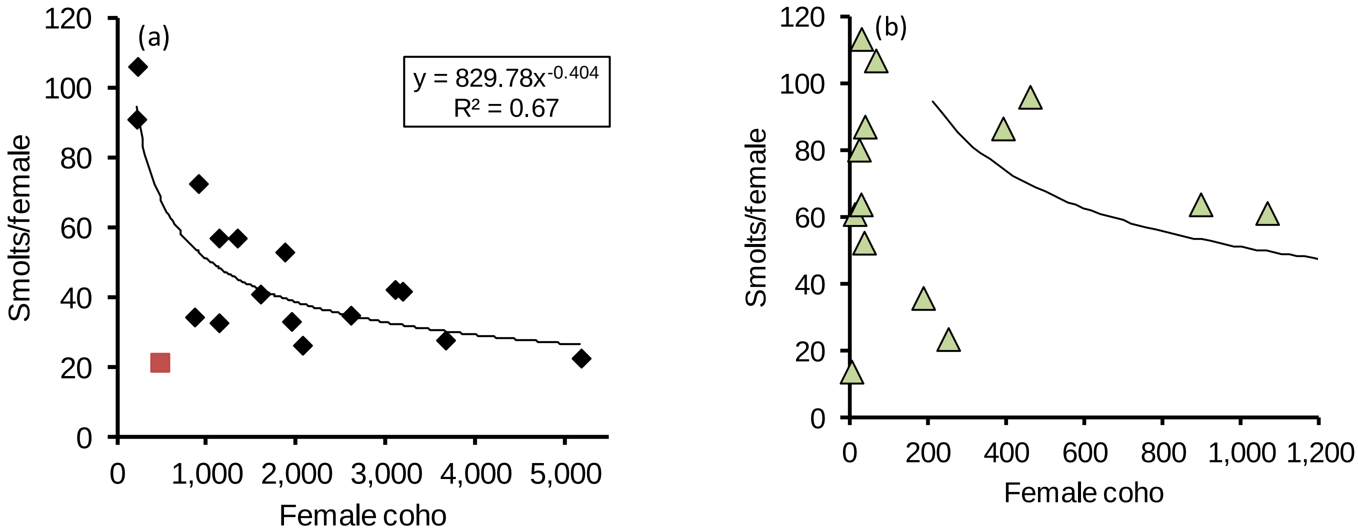


Figure 2. Freshwater productivity (juveniles/female) as a function of female coho spawners in the Deschutes River. For brood year 1978-1994 (*a*), coho productivity was a decreasing function of escapement (black square) with the exception of brood year 1989 (red square). The 1989 brood year corresponded 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 2017, WDFW measured coho smolt abundance in six of the Puget Sound management units (Skagit, Hood Canal, Lake Washington, Green, Nisqually, and Deschutes). Smolt production data from eight additional management units (Nooksack, Juan de Fuca, Stillaguamish, Snohomish, Green (Soos), Puyallup, East Kitsap, South Sound) were available due to juvenile monitoring studies conducted by the Lummi, Jamestown, Elwha, Makah, Tulalip, Stillaguamish, Muckleshoot, Puyallup, Suquamish, and Squaxin tribes. For watersheds where trapping data were not available in 2017, 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 13% and 122% 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 (Smoker 1955; Mathews and Olson 1980). Summer flows in Puget Sound rivers can be described by the Puget Sound Summer Low Flow Index (PSSLFI,

Appendix A). The PSSLFI index 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 2016 (corresponding to the 2017 smolts and 2018 returning adults) had an index value of 6.09 or 76% of the average for the time series (Figure 3). In past years, this index has 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 of each time series.

		Smolt production above trap			Zillges (1977) potential above trap		
Stream	No. Years	Average	Min	Max	Average	Min	Max
Hood Canal							
Big Beef	40	27,718	8115	58136	71.9%	21.0%	150.7%
Little Anderson	24	648	45	1,969	12.7%	0.9%	38.6%
Seabeck	24	1,324	496	2,725	12.6%	4.7%	26.0%
Stavis	24	5,107	1,549	9,667	101.6%	30.8%	192.3%
Skagit River	28	1,091,616	426,963	1,884,668	79.6%	31.1%	137.5%
SF Skykomish R	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%
Green River							
Lake Washington	19	66,282	13,322	129,666	54.8%	11.0%	107.3%
Cedar River**	19	29,891	6,208	62,970	59.7%	12.4%	125.7%
Bear Creek	14	64,488	22,671	194,393	28.6%	10.1%	86.2%
Nisqually	9	141,387	58,930	228,054	122.4%	51.0%	197.4%
Deschutes***	38	43,012	1,187	133,198	19.6%	0.5%	60.7%

* Summary statistics in this table do not include the three years when smolt production was limited by experimental escapement reduction.
** Cedar River production potential does not include new habitat open to coho above Landsburg Dam beginning in 2003.
*** Deschutes smolt production in this table include yearling and sub yearling smolts as both age classes are known to contribute to adult returns.

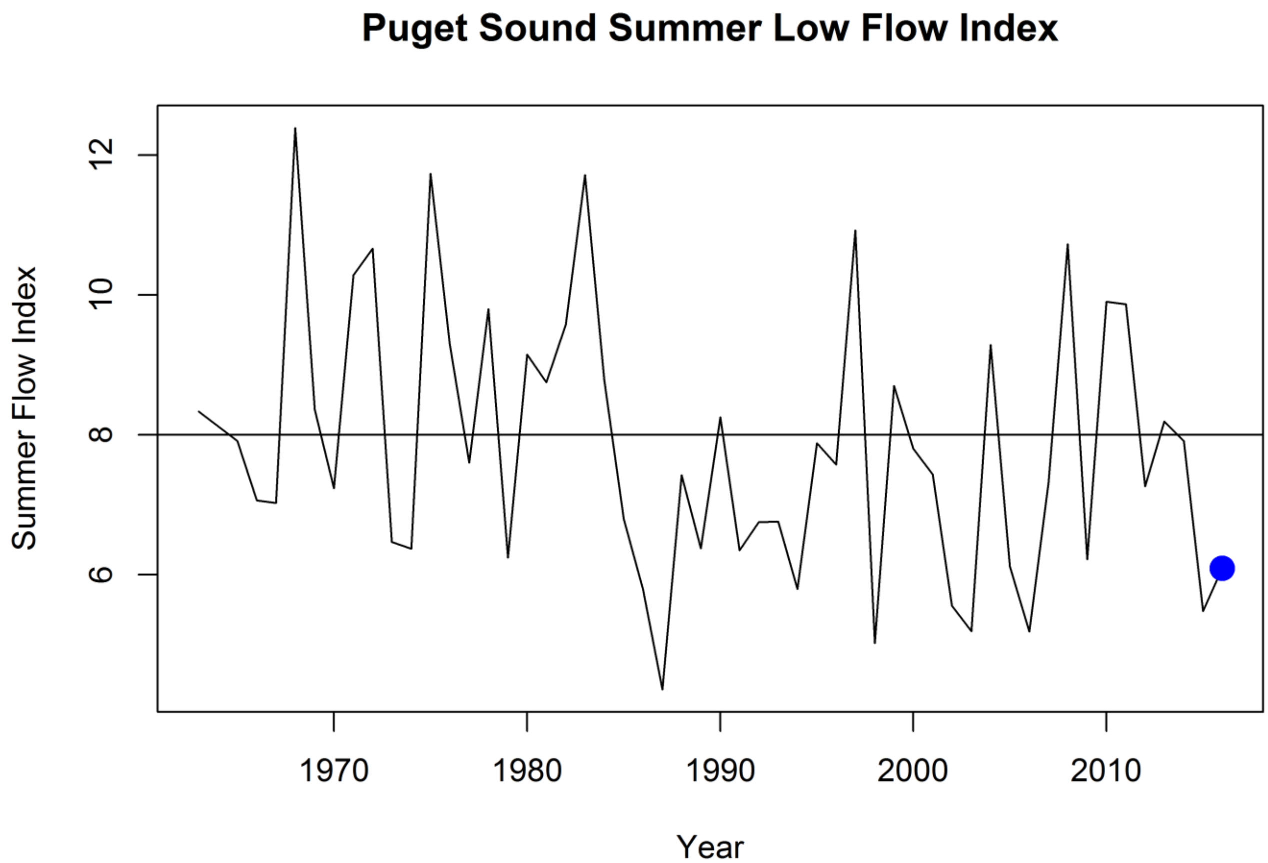


Figure 3. Puget Sound Summer Low Flow Index (PSSLFI) by summer rearing year (return year – 2). PSSLFI is based on 60-day minimum flow averages at eight stream gages in Puget Sound (see Appendix A). The minimum 60-day average flow at each gage is compared to the time series average (1963 to present) and then summed across all eight gages. Flow index corresponding to the 2018 wild coho return shown as blue point on graph.

Puget Sound Primary Units

Skagit River

A total of 1,376,000 (±414,000, 95% C.I.) wild coho smolts are estimated to have emigrated from the Skagit River in 2017 (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 2017 was 35% increase from the average (geometric mean) of 1,021,141 smolts between the 1990 and 2016 ocean entry years (Table 2, Figure 4).

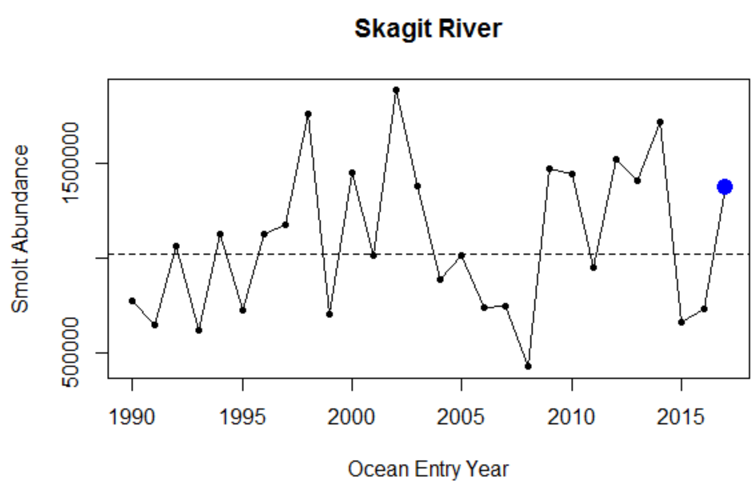


Figure 4. Time series of wild coho smolt outmigration from the Skagit River, ocean entry years 1990 to 2017. Blue point represents outmigration of the cohort included in this forecast. Horizontal line is the geometric mean of the time series.

Stillaguamish River

A total of 337,000 coho smolts are estimated to have emigrated from the Stillaguamish River in 2017 (Table 1). This estimate was based on a CPUE index of abundance for the 2017 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 370,000 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 2017, CPUE has averaged 4.2 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 2015 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.

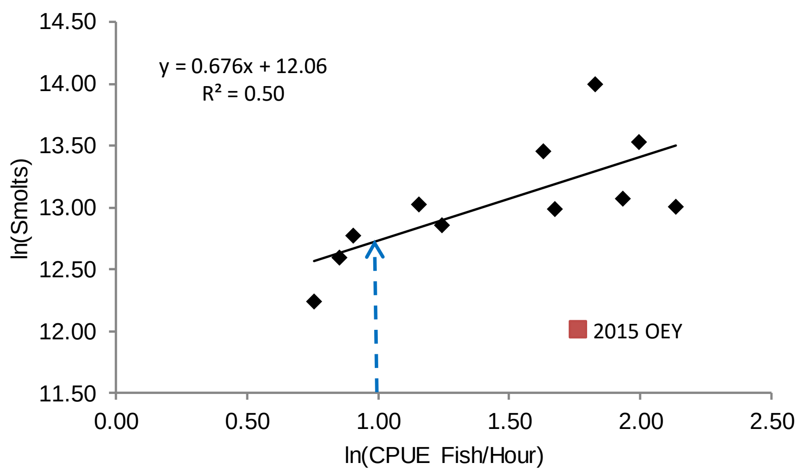


Figure 5. Correlation between CPUE of wild coho smolts in Stillaguamish smolt trap and back-calculated smolt estimates, 2003 to 2014. The 2015 ocean entry year was not used in the regression model. Dashed blue line corresponds to the 2017 ocean entry year. Smolt trap data were provided by K. Konoski, 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 2017 outmigration (2.7 fish/hour) resulting in an estimated outmigration of 337,000 smolts (rounded from 336,520). 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 324,287 smolts.

Snohomish River

A total of 1,984,000 coho smolts are estimated to have emigrated from the Snohomish River in 2017 (Table 1). The mark-recapture estimate of wild coho smolts in 2017 is not available at the time of this forecast. Therefore, the estimated production is the geometric mean of the time series (2002 – 2016) 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 operated on the Snoqualmie River (river mile 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).

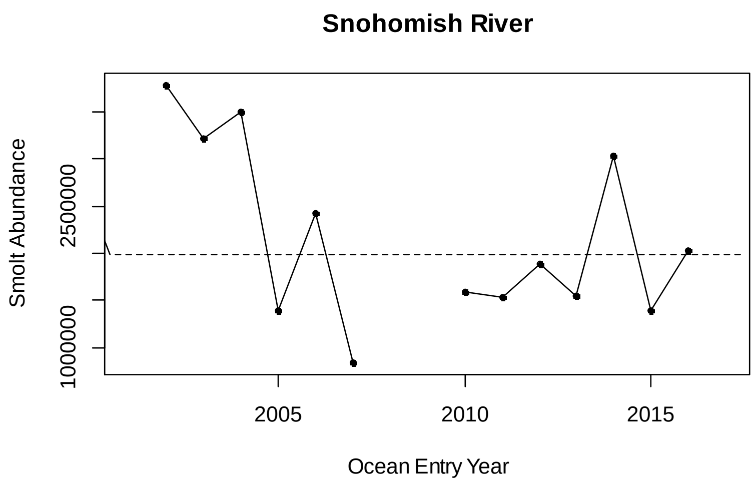


Figure 6. Time series of wild coho smolt outmigration from the Snohomish River, ocean entry years 2002 to 2016. No estimates are available for 2008 or 2009. The 2017 estimate was not available at the time of this forecast. The horizontal line is the geometric mean of the time series. Data provided by D. Holmgren (Tulalip Tribes).

Hood Canal

A total of 359,000 (rounded from 358,579) coho smolts are estimated to have emigrated from Hood Canal tributaries in 2017 (Table 1). This estimate is based on measured smolt abundance in select tributaries expanded to the entire management unit.

In 2017, wild coho smolt abundance was measured in Big Beef Creek (*n* = 23,912*)*, Little Anderson Creek (*n* = 161), Seabeck Creek (*n* = 1,317*)*, and Stavis Creek (*n* = 1,812). 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 2017 abundance of coho smolts from Big Beef Creek a decrease of 6% from the average (geometric mean) between the 1978 and 2016 ocean entry years (Table 2, Figure 7). Coho smolt abundances in neighboring Little Anderson and Stavis creeks were a 61% and 59% decrease from the time series averages (geometric mean) in these watersheds respectively whereas the coho smolt abundance in Seabeck Creek was a 7% increase from the time series average (Table 2).

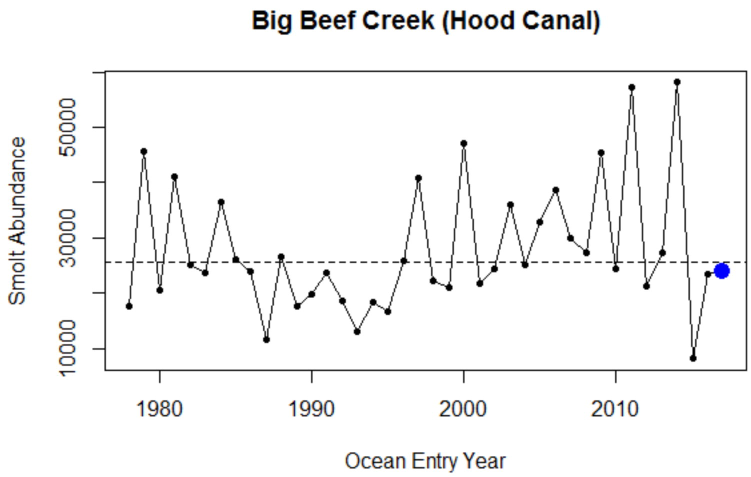


Figure 7. Time series of wild coho smolts from Big Beef Creek, ocean entry years 1978 to 2017. Blue point represents outmigration of the cohort included in this forecast. Horizontal line is the geometric mean of the time series.

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 2017 wild coho production in Hood Canal ranged between 359,000 and 524,000 smolts. Using the Zillges approach, the total of 27,252 smolts from the four tributaries were expanded to an estimated 461,898 Hood Canal smolts. Using the second approach (HCJTC 1994 revision), the total of 27,252 smolts from the four tributaries were expanded to 358,579 Hood Canal smolts. The third approach expanded the 23,912 smolts from Big Beef Creek to a total of 524,386 Hood Canal smolts. This forecast is based on the most conservative result, provided by the second approach.

Juan de Fuca

A total of 184,000 coho smolts (rounded from 184,140) are estimated to have emigrated from Juan de Fuca tributaries in 2017 (Table 1). This estimate is based on measured smolt abundance in select tributaries expanded to the entire management unit. A total of ten tributaries were monitored in the Strait of Juan de Fuca in 2017 through a collaborative effort by WDFW, Jamestown S'Klallam Tribe, Elwha Tribe, and the Makah Tribe. Monitored tributaries were Jimmy Comelately, Siebert, Bell, McDonald, and Snow creeks in the eastern part of the Strait, and Salt, East Twin, West Twin, Deep, and Little Hoko in the western part of the Strait. Measured smolt abundance was extrapolated to all tributaries in the Juan de Fuca management unit based on the proportion of summer rearing habitat represented in the monitored tributaries (calculations provided by Hap Leon, Makah Tribe). The Elwha and Dungeness rivers are managed separately from the Juan de Fuca management unit and are not included in this forecast. Coho smolt production from the Juan de Fuca tributaries in 2017 was 34% decrease from the average (geometric mean) of 280,810 smolts between the 1998 and 2016 ocean entry years (Figure 8).

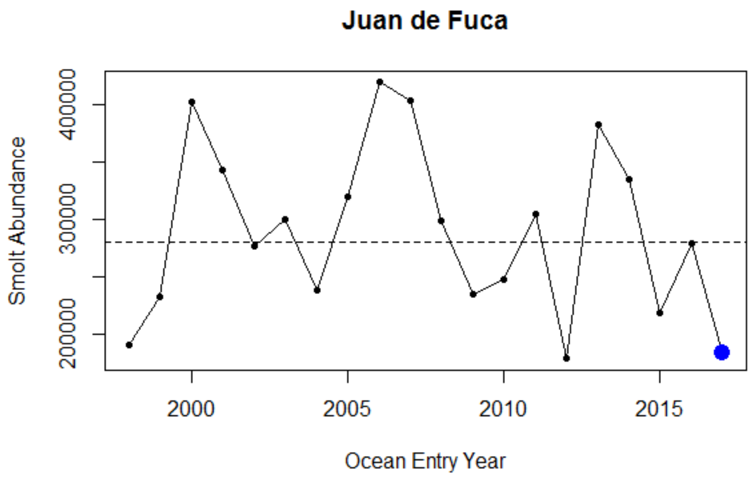


Figure 8. Time series of wild coho smolts from Strait of Juan de Fuca tributaries, ocean entry years 1998 to 2017. Blue point represents the cohort contributing to this forecast. The horizontal line is the geometric mean of the time series. Data provided by Hap Leon.

Puget Sound Secondary Units

Nooksack River

A total of 466,000 coho smolts (rounded from 465,727) are estimated to have emigrated from the Nooksack River in 2017 (Table 1). The 2017 estimate is based on a mark-recapture estimate of smolt abundance from a smolt trap operated operated by the Lummi Tribe. Results were provided by the Lummi Tribe (E. Brown, personal communication).

Between the 2005 and 2017 ocean entry year, coho smolt production in the Nooksack River has averaged (geometric mean) 301,000 smolts (Figure 9, range 98,000 to 929,000, numbers updated in 2017 by E. Brown, Lummi Tribe). An additional number of coho (0.1% to 4% 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. Coho smolt production from the Nooksack River in 2017 was 55% increase from the average (geometric mean) for the time series.

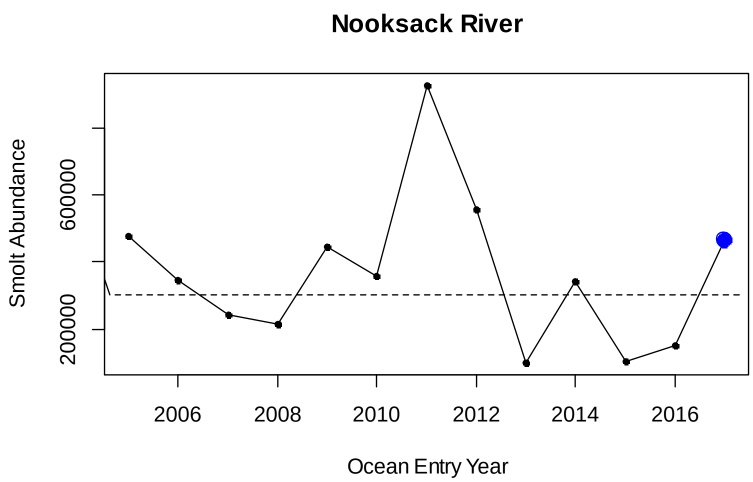


Figure 9. Time series of wild coho smolts from the Nooksack River, ocean entry years 2005 to 2017. Blue point represents the cohort contributing to this forecast. The horizontal line is the geometric mean of the time series. Data provided by Evelyn Brown.

Strait of Georgia

A total of 21,000 coho smolts are estimated to have emigrated from the Straits of Georgia watersheds in 2017 (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 conditions of low 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 Straits of Georgia have 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 higher than average in 2017 (i.e., Skagit, Nooksack). Therefore, the 2017 coho production was estimated to be 21,000 smolts (rounded from 20,728), 40% of the total production potential for these watersheds (51,821 smolts per Zillges 1977).

Samish River

A total of 33,000 coho smolts are estimated to have emigrated from the Samish River in 2017 (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 6.9% with an average of 5.8% in the Skagit 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 6%, an average of 33,000 smolts will result in a return of 2,000 adult spawners. This estimate corresponds to 33 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 78,000 coho smolts are estimated to have entered Puget Sound from the Lake Washington basin in 2017 (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 2017, coho smolt abundance from the Cedar River was estimated to be 92,863 (±30,028 95% C.I.) smolts. This production was an increase of 58% from the geometric mean of 58,768 smolts between the 1999 and 2016 ocean entry years (Figure 10). In comparison, coho smolts from Bear Creek were estimated to be 6,208 (±3,993 95% C.I.); this was the lowest smolt production estimate in the time series and represented a decrease of 76% from the geometric mean of 25,398 smolts between the 1999 and 2016 ocean entry years. 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).

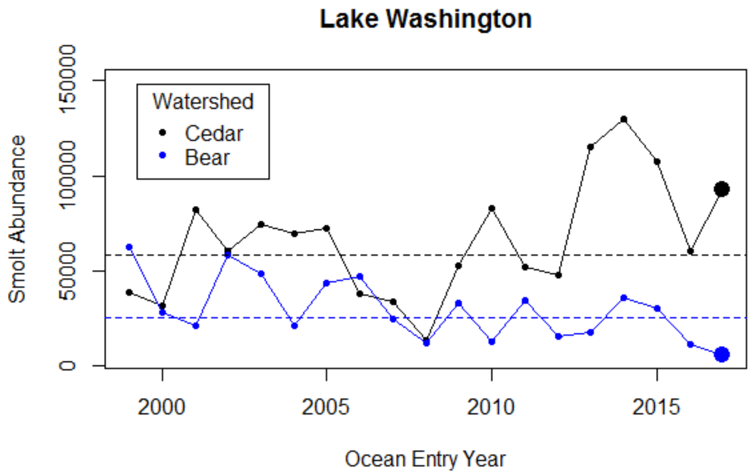


Figure 10. Time series of natural-origin coho smolts from Cedar River (black) and Bear Creek (blue), ocean entry years 1999 to 2017. Larger symbol represents outmigration of cohort contributing to this forecast. Horizontal lines are the geometric mean for the time series in each watershed.

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 2017 coho production from Issaquah Creek was estimated by scaling the 2000 estimate for this creek (19,812 smolts; Seiler et al. 2002a) by the 2017 to 2000 smolt ratio in Bear Creek. In 2017, coho smolt production in Bear Creek was 22% of that measured in 2000 (6,208/28,142 = 0.22). Therefore, 2017 coho production from Issaquah Creek was estimated to be 4,370 smolts (19,812 * 0.22).

The total coho production of 78,000 smolts (rounded from 77,581) assumed 75% survival through Lake Washington. A total of 103,441 coho smolts were estimated to enter Lake Washington (92,863 Cedar + 6,208 Bear + 4,370 Issaquah). The 75% survival rate was estimated from historical detections of Passive Integrated Transponder (PIT) tags applied to coho smolts caught in the traps and redetected at the Ballard Locks (WSPE unit, unpubl. data). Recent work has suggested that the true survival rate may be lower (Kiyohara and Zimmerman 2011; Kiyohara and Zimmerman 2012); however, no calibration of detection efficiency is currently available for these studies.

Green River

A total of 110,000 (rounded from 109,520) natural-origin coho smolts are estimated to have emigrated from the Green River in 2015 (Table 1). This estimate is the sum of 69,469 smolts upstream of the juvenile trap (river mile 34), 40,052 smolts below the juvenile trap, and 60,493 smolts from Big Soos Creek.

In 2017, 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 69,469 (±24,092 95% C.I.) smolts. This production was an increase of 23% from the geometric mean of 55,507 smolts between the 2000 and 2016 ocean entry years (Figure 11).

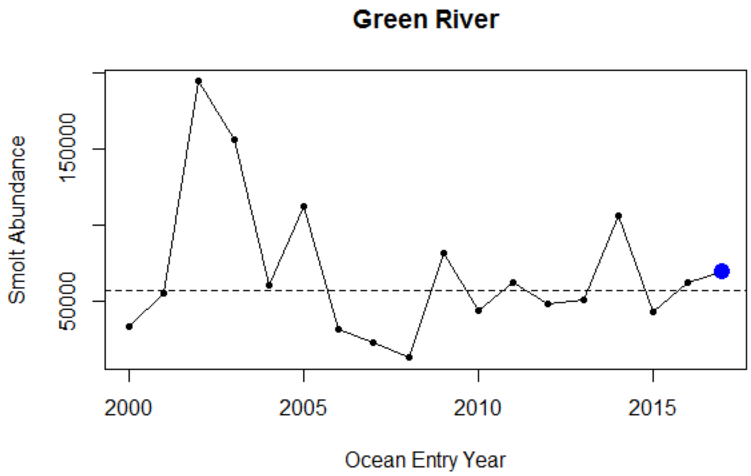


Figure 11. Time series of natural-origin coho smolts above the Green River smolt trap (river mile 34), ocean entry years 2000 to 2017. Blue point represents cohort contributing to this forecast. Horizontal line is the geometric mean for the time series.

Coho smolt production above the juvenile trap was 31.1% 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 40,052 smolts based 31.1% 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). In 2017, the Muckleshoot Indian Tribe operated a rotary screw trap in Big Soos Creek and estimated that the annual production was 60,493 (±16,579 95% C.I.) natural-origin coho smolts (Curtis Nelson, Muckleshoot Indian Tribe, personal communication).

East Kitsap

A total of 55,000 coho smolts (rounded from 54,934) are estimated to have emigrated from East Kitsap tributaries in 2017 (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 2017 (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 2017 coho abundance of 4,793 smolts from Lost (*n* = 1,267) and Wildcat (*n* = 2,159) creeks was 35.4% of the calculated smolt potential. Total coho smolt abundance for the East Kitsap management unit was estimated to be 54,934 smolts based on 35.4% of the 155,269 smolt potential for all watersheds in this management unit.

Puyallup River

A total of 248,000 coho smolts (rounded from 248,156) are estimated to have emigrated from the Puyallup River in 2017 (Table 1). This estimate is based on measured production in the Puyallup River above the juvenile trap (40,729), estimated production from the White River (200,733), and an estimate from the Puyallup River below the Puyallup-White confluence (6,694).

In 2017, the Puyallup Tribe operated a juvenile fish trap on the Puyallup River just upstream of the confluence with the White River. A total of 40,729 coho smolts were estimated to have emigrated from the Puyallup River above the smolt trap, including production above Electron Dam(Berger et al. 2016)(Berger et al. 2016)(Berger et al. 2016)(Berger et al. 2016)(Berger et al. 2016)(Berger et al. 2016)(Berger et al. 2016)(Berger et al. 2016)(Berger et al. 2016) (A. Berger, Puyallup Tribe, personal communication). This production represented a decrease of 28% from the average (geometric mean) of 56,609 smolts between the 2005 and 2016 ocean entry years and was the third consecutive year that smolt production fell below this average (Figure 12). Coho smolt production above the juvenile trap represents 14.8% 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 2017 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.

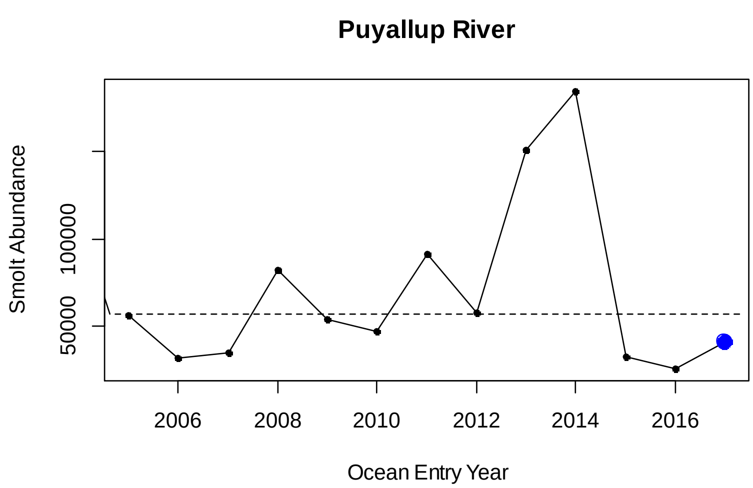


Figure 12. Time series of natural-origin coho smolts above the Puyallup River smolt trap (upstream of confluence with White River), ocean entry years 2005 to 2017. Blue point represents cohort included in this forecast. Horizontal line is the geometric mean of the time series. Data provided by Andrew Berger (Puyallup Tribe).

A total of 200,733 coho smolts are estimated to have emigrated from the White River, including production upstream of Mud Mountain Dam. This estimate was derived from catch in a rotary screw trap (n = 5,199) operated in the White River above the confluence with the Puyallup River in 2017 and an assumed 2.59% trap efficiency for coho smolts (A. Berger, Puyallup Tribe, personal communication). Trap efficiency was not directly measured for coho smolts; however, trap efficiency measured for steelhead smolts averaged 2.09% in 2016 and 2017.

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 248,000 (rounded from 248,156) was the sum of coho smolt production from the Puyallup River (40,729 above White River confluence), White River (200,733) above confluence with Puyallup River), and Puyallup River (6,694 below White River confluence).

Nisqually River

A total of 65,000 coho smolts (rounded from 65,478) are estimated to have emigrated from the Nisqually River in 2017 (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 58,930 (±8,103 95% C.I.) smolts. This production was the lowest in the time series and represented a decrease of 54% from the geometric mean of 128,093 smolts between the 2009 and 2016 ocean entry years (Figure 13). This estimate was 51% of the 115,554 smolt potential predicted by Zillges (1977). Total smolts above and below the trap were estimated to be 65,478 assuming that 10% of coho rearing occurred below the trap.

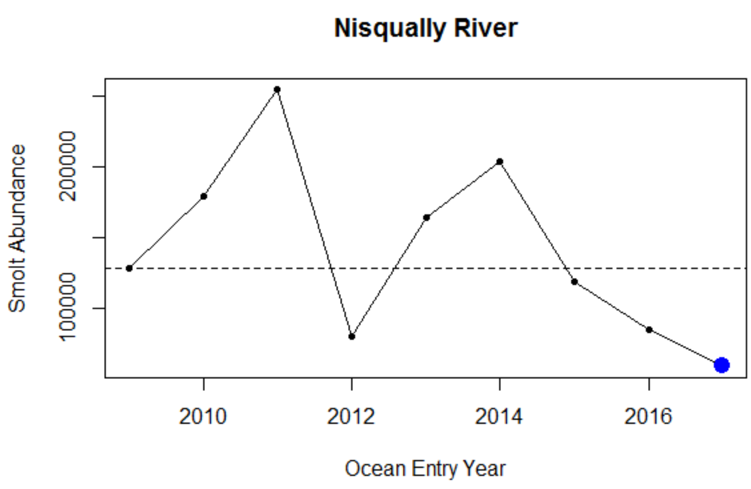


Figure 13. Time series of natural-origin coho smolts from the Nisqually River above the smolt trap (rm 12), ocean entry years 2009 to 2017. Blue point represents outmigration of the cohort included in this forecast. Horizontal lines are the time series average.

Deschutes River

A total of 4,500 natural-origin coho smolts (rounded from 4,536) are estimated to have emigrated from the Deschutes River in 2017 (Table 1). This estimate is based on catch of coho smolts in a juvenile trap operated below Tumwater Falls. A catch of 875 natural-origin smolts was expanded by a trap efficiency of 19.3%.

The 2017 production represents a decrease of 76% from the geometric mean of 19,330 smolts between the 1979 and 2016 ocean entry years (Figure 14) and was just 2.1% (1,400/219,574) 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 2015 brood, 340 females (combination of natural-origin and hatchery-origin) were released upstream of Tumwater Falls to spawn. Freshwater productivity from this spawner escapement was 13 smolts/female, much lower than productivity expected from typical density-dependent freshwater relationships for coho salmon (Figure 2).

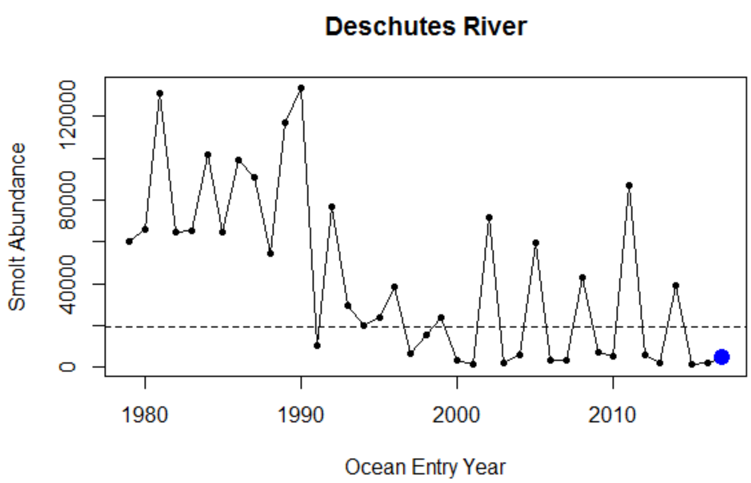


Figure 14. Time series of natural-origin coho smolts from the Deschutes River, ocean entry years 1979 to 2017. Blue point represents outmigration of cohort included in this forecast. Horizontal line is the geometric mean of the time series.

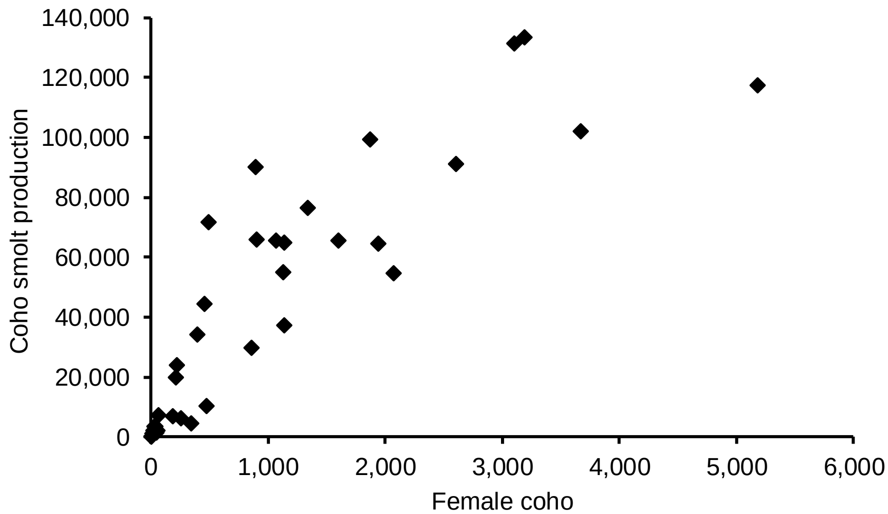


Figure 15. Coho smolt production as a function of female spawners in the Deschutes River, Washington, brood year 1978-2015.

South Sound

A total of 152,000 coho smolts are estimated to have emigrated from South Sound tributaries in 2017 (Table 1). This estimate was based on results of smolt monitoring in Mill, Goldsborough, and Gosnell creeks conducted by the Squaxin Island Tribe (data provided by Daniel Kuntz, Natural Resources Department, Squaxin Island Tribe). The natural-origin coho smolt estimate for Mill Creek was 8,390 smolts (15%) and Goldsborough Creek was 76,452 smolts (106.7%). 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 2,207 smolts or 15.2% 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 12-year 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 2017 coho production for the South Sound management unit was estimated in two steps – smolt estimate for Goldsborough Creek (76,452) was added to an extrapolated estimate for all other tributaries in this management unit. The extrapolated estimate for other tributaries (does not include Goldsborough Creek) was 75,321, which was 15% applied to the Zillges production potential of 502,142 smolts for these watersheds. The rate of 15% represented the 2017 proportion of the overall production potential observed in Mill Creek. Coho production for the entire South Sound management unit was estimated to be 152,000 smolts (151,773 = 76,452 + 75,321), which is 26.5% of the 573,770 smolt potential for all watersheds in this management unit (including production above Minter hatchery rack) predicted by Zillges (1977).

Coastal Systems Smolt Abundance

Approach

Major coho producing basins in Coastal Washington range in watershed characteristics and hydrology. On the north coast, the rivers drain westward from the Olympic Mountains and are higher gradient with a transitional hydrology influenced by both winter rains and spring snow melt. In the southwest coast, rivers are low gradient with rain-fed rivers that drain into Grays Harbor and Willapa Bay. Additional independent tributaries lack the complexity of the larger watersheds and have primarily rain-driven hydrology. Where juvenile trapping studies have been conducted, smolt production has averaged 400 to 900 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 2017, 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 2017, 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 Tribe.

		Coho smolt production			Production/mi^2		
Watershed	Number 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)	36	69,731	27,314	134,052	498	195	958
Queets (no Clearwater)	33	193,740	53,473	352,694	625	172	1,138
Chehalis (Grays Harbor)[a]	33	2,110,000	502,918	3,769,789	998	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 173,000 (rounded from 172,872) wild coho smolts are estimated to have emigrated from the entire Queets River watershed in 2017 (Table 1). This estimate was based on coho smolt data collected and analyzed by the Quinault Tribe (Rick Costow, 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 68,807 wild coho smolts (491 smolts/mi^2). Smolt abundance from the Queets River (without the Clearwater) was estimated to be 104,065 wild coho smolts (336 smolts/mi^2).

Quillayute River

A total of 345,000 coho smolts (rounded from 345,329) are estimated to have emigrated from the Quillayute River system in 2017 (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 2017.

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 different 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 2017 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 1.13 was the ratio of Clearwater River production in 2017 (68,807) to average Clearwater River production in 1992-1994 (68,807/61,000 = 1.13). Because historical smolt densities differed between the Dickey and Bogachiel rivers, separate estimates were developed for two portions of the Quillayute River watershed. The 2017 coho smolt abundance in the Dickey River was estimated to be 99,829 smolts (1.13*88,344 smolts). The 2017 coho smolt abundance in the Quillayute (excluding the

Dickey) was estimated to be 245,500 smolts (1.13*217,257 smolts). The total 2017 coho production of 428,000 smolts was the rounded sum of these estimates (99,829 + 245,500 = 345,329).

Hoh River

A total of 147,000 wild coho smolts are estimated to have emigrated from the Hoh River in 2017 (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 491 smolts/mi^2 from the Clearwater River was applied to the 299-mi^2 of the Hoh watershed and resulted in an estimated 147,000 smolts (rounded from 146,809) from the Hoh River system.

Quinault River

A total of 146,000 wild coho smolts are estimated to have emigrated from the Quinault River in 2017 (Table 1). Smolt abundance was not directly measured in this watershed; therefore, the estimate was based on smolt densities in the Queets River system. In 2017, a production rate of 336 smolts/mi^2 was applied to the 434-mi^2 Quinault River system, resulting in an estimated 146,000 smolts (rounded from 145,824).

Independent Tributaries

A total of 148,000 wild coho smolts are estimated to have emigrated from the independent tributaries of Coastal Washington (Table 1). Coho smolt production has not been directly measured in any of the coastal tributaries. In 2017, 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 3,603,000 wild coho smolts are predicted to have emigrated from the Grays Harbor system in 2017 (Table 1). This estimate was derived in two steps. Wild coho production was first estimated for the Chehalis River (n = 2,986,880). Smolt abundance per unit watershed area of the Chehalis River system was then applied to the Grays Harbor tributaries (n = 262,800, Hoquaim, Johns, and Elk rivers) and the Humptulips River (n = 353,250).

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 2016 ocean entry year (2017 return), this model predicted a smolt abundance of 3,234,000 smolts (2,906,000 – 3,599,000 95% C.I.) which was very similar to the mark-recapture estimate of 3,231,000 (2,059,000 – 4,403,000 95% CI).

In the 2017 ocean entry year, coho smolts were associated with higher than average incubation flows, lower than average summer flows, and higher than average overwinter flows as measured at USGS gage #12027500, Grand Mound (Figure 16). The 2017 smolt production was predicted to be 2,986,880 (2,555,079- 3,491,654, 95% confidence intervals) based on the multiple regression model including summer and overwinter flows. This prediction is 41% higher than time series average of 2,110,000 wild coho smolts.

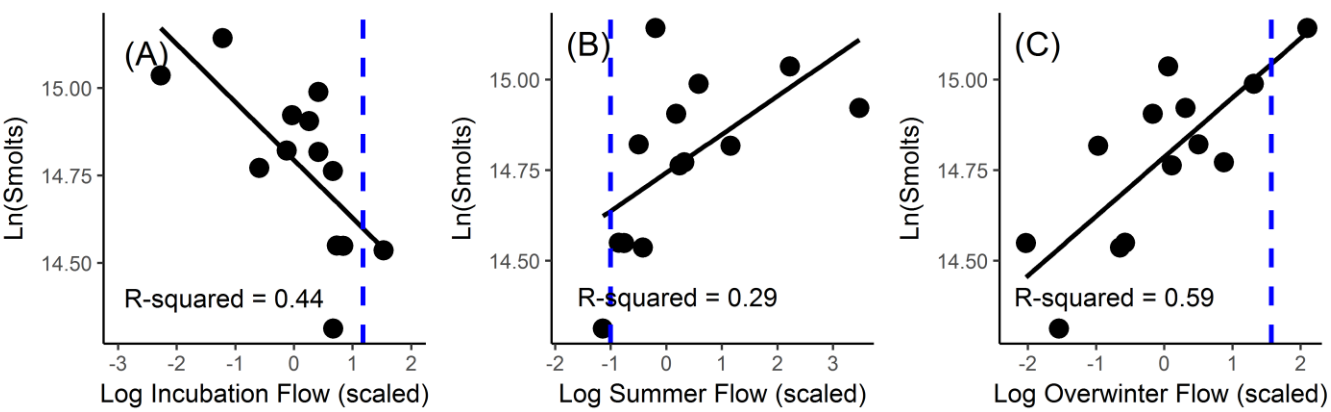


Figure 16. Chehalis River wild coho smolt production as a function of incubation flows (a), summer rearing flows (b), and overwinter rearing flows (c) for ocean entry year 2000-2016 as measured at USGS gage #12027500 in Grand Mound. Incubation flows are the cumulative daily mean flow between December 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 2000, 20004, 2006) because of high leverage on the incubation flow regression. Vertical blue dashed line indicates the conditions associated with the 2017 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 1,413 smolts/mi^2 (2,986,880 smolts per 2,114 mi^2). A total of 262,800 coho smolts are estimated for the tributaries of Grays Harbor (1,413 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 353,250 smolts (1,413 smolts/mi^2*250 mi^2). After summing smolt abundance estimates for all watersheds in the Grays Harbor management unit, total wild coho production was estimated to be 3,603,000 smolts (2,986,880 + 262,800 + 353,250 = 3,602,930).

Willapa Bay

A total of 765,000 coho smolts are estimated to have emigrated from the Willapa Bay basin in 2017 (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 2017 (765,000 smolts) was calculated by applying 900 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 2017, coho smolt abundance was directly monitored in eight watersheds using 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 (Carlson et al. 1998; Bjorkstedt 2005). 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, upper Cowlitz/Cispus rivers, and Coweeman River.

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, Germany Creek, and the Coweeman River. Although these watersheds have no operating coho hatcheries, hatchery coho salmon do stray and spawn in them. In addition, the forecast made use of a historical time series from Cedar Creek, which was not monitored in 2017. 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 2017 estimate of 5,053 natural-origin coho smolts, the coho smolt density was estimated to be 194 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 2017 coho smolt density from these watersheds ranged between 153 and 215 smolts/mi^2 (Table 4). A total of 15,087 natural-origin coho smolts were estimated to have emigrated from all three watersheds in 2017 (Table 5). This included 6,244 smolts from Mill Creek, 4,440 smolts from Abernathy Creek, and 4,403 smolts from Germany Creek. These estimates are preliminary.

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 28,097 natural-origin coho smolts, captured at Swift Dam in 2017, 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 [17,059 = 14,360 yearlings + 2,699 2-year olds] plus the number estimated to pass through the turbine [2,214 = 19,273 – 17,059] multiplied by an assumed 85% survival [18,941 = 17,059 + 2,214 *0.85].

Based on a watershed area of 159 mi^2 and a preliminary 2017 estimate of 19,273 natural-origin smolts emigrating from the Tilton River, coho smolt density was estimated to be 121 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 68,727 smolts produced above Cowlitz Falls, coho smolt density of the Upper Cowlitz River was estimated to be 66 smolts/mi^2 in 2017 (Table 4). The total number of natural-origin coho emigrating from the Upper Cowlitz was the 26,617 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 Coweeman River, a tributary to the Cowlitz River, was monitored with a rotary screw trap trap at river mile 7.5. Based on a watershed area of 119 mi^2 and a 2017 smolt estimate of 4,909 smolts, the coho smolt density from the Coweeman River was estimated to be 41 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 2017. Historically, a juvenile trap was operated at river mile 2 of Cedar Creek and annual smolt abundance averaged 36,000 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 596 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 2017 smolt production was assumed to be the time series average of 36,000 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 102,380 (93,171 – 330,550 95% C.I.) smolts (Table 5). This estimate was derived from an average smolt production density of 127 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 93,171 (65,739 – 120,604 95% C.I.) smolts (Table 5). This estimate was derived from an average smolt production density of 150 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, 331,000 natural-origin coho smolts (rounded from 330,550) are estimated to have emigrated from the Washington Lower Columbia region in 2017 (Table 1). The 95% confidence intervals for this estimate range between 235,317 and 353,195 smolts but are underestimated due to missing variance estimates for upper Cowlitz River smolt densities. On average, the 2017 smolt production in watersheds without hatchery production had a 53% decrease from the 10-year average (2007 to 2016) whereas watersheds with hatchery production had a 27% decrease from the 10-year 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.

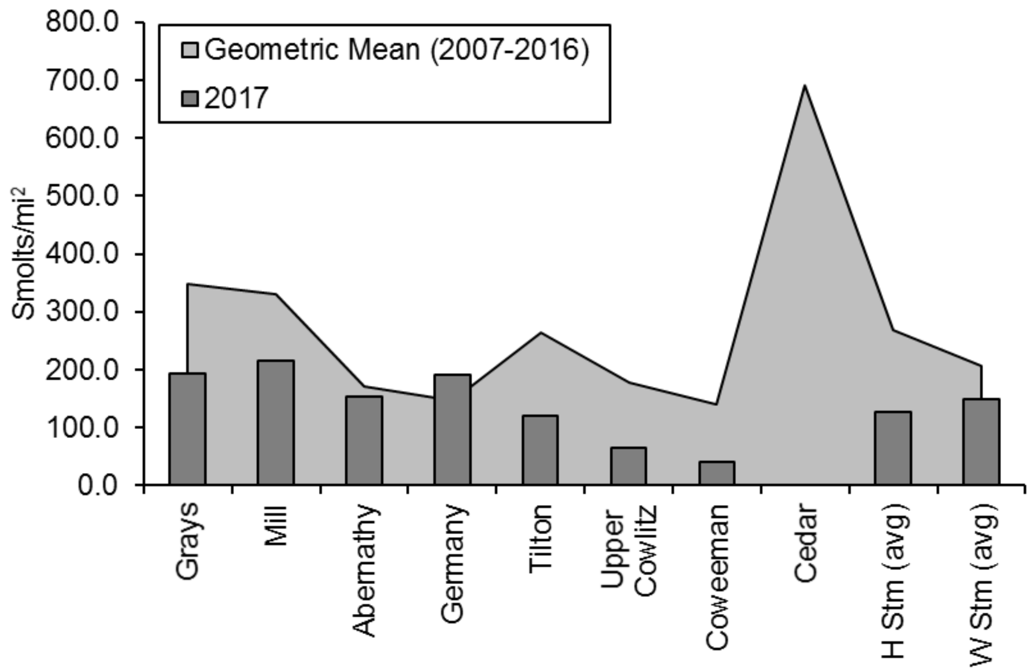


Figure 17. Coho smolt densities (smolts per mile^2 of watershed area) in eight Lower Columbia tributaries in Washington State. Graphs shows the 2017 density (bars) relative to the average smolt abundance from these watersheds (2007-2016).

Table 4. Smolt densities in 2017 from monitored coho salmon streams in the Lower Columbia River ESU. Variance associated with upper Cowlitz River smolt production was not available. No data were collected from Cedar Creek in 2017.

	Density		
Watersheds	N/mi^2	95% Low	95% High
Grays	194.3	111.6	277.1
Mill	215.3	145.1	285.5
Abernathy	153.1	120.6	185.7
Germany	191.4	131.2	251.7
Tilton	121.2	118.5	124.0
Upper Cowlitz	66.0	NA	NA
Coweeman	41.3	27.3	55.3
Cedar	NA	NA	NA
Average Hatchery Streams	127.2	98.7	155.7
Average Wild Streams	150.3	106.0	194.5

Table 5. Coho smolt emigrants in 2017 from the Lower Columbia Evolutionary Significant Unit including monitored streams, non-monitored streams with hatcheries, and non-monitored streams without hatcheries.

Watersheds	N	95% Low	95% High
Grays	5,053	2,901	7,205
Mill	6,244	4,209	8,279
Abernathy	4,440	3,496	5,384
Germany	4,403	3,017	5,789
NF Lewis River (above dams)	28,097	28,097	28,097
Tilton	18,941	18,566	19,316
Upper Cowlitz	26,617	26,617	26,617
Coweeman	4,909	3,244	6,574
Cedar	36,294	NA	NA
Non-monitored Hatchery Streams	102,380	79,431	125,330
Non-monitored Wild Streams	93,171	65,739	120,604
Total Smolt Emigration	330,550	235,317	353,195

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; Zimmerman 2013; Zimmerman 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 (Mantua et al. 1997; Beamish et al. 1999; Beamish et al. 2000) 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 (Nickelson 1986; Ryding and Skalski 1999; Logerwell et al. 2003). 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. In press). 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 (Coronado and Hilborn 1998; Beetz 2009; 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 – 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 – Hood Canal MU, Baker River – Skagit MU, Deschutes River – Deschutes MU, Bingham Creek – 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; however, 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, http://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 (nonmarked hatchery coho since 1996).

In the Juan de Fuca management unit, marine survival was estimated from the smolts and 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. From the 2012 to 2016 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 Larry LeVoy, NOAA Fisheries).

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", I have applied indices provided by NWFSC ocean monitoring research program 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, demonstrated to vary on the order of decades (Mantua et al. 1997). The ONI is based on conditions in equatorial waters that result from the El Niño Southern Oscillation. El Nino 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, I added a third ocean scale indicator. The North Pacific Gyre Oscillation (NPGO) is an indicator of salinity and nutrients in the areas of the North Pacific ocean (DiLorenzo et al. 2009) 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. The ONI was represented by a single time period (January to June) representing the ocean entry year.

At the "Region Scale", I have applied a set of pre-developed indicators to Washington Coast and Lower Columbia management units and have explored potential (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 48N 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", I have explored variables as indicators as they related 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.

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 - 2016 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 (Peterson and Schwing 2003; Overland et al. 2008). 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 significant predictors of survival ($\alpha = 0.10$) were combined into a multiple regression model to forecast survival of smolts for the 2018 return (2017 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 in this forecast (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 2018 return. Predicted marine survival for the 2018 return year (2017 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 Core Team 2017).

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 have ranged between 1% and 2% with very little variability over the past decade (Zimmerman et al. 2015). Based on the available information, a 2% marine survival 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) 6.2% (range 1.1% to 13.9%) between ocean entry years 1991 and 2016 with a declining trend over this time period (Figure 18).

The model selected for forecasting included two variables – PDO index May to September of ocean entry and local marine chlorophyll densities in May of ocean entry (Table 6). Local marine conditions for this analysis came from the Sarasota Passage-East Point sampling station (SAR003) of the Washington Department of Ecology Marine Waters Monitoring Program (see Appendix C). Higher survival was associated with a lower PDO index values and higher local chlorophyll densities. The analysis was limited to OEY 2002 and later (excluding OEY 2007 and 2015) due to lack of chlorophyll data from these years. Marine survival of the Baker River time series is also correlated with NPGO index values in May to September during ocean entry. Because NPGO and PDO values are highly correlated, I evaluated a second model that included NPGO index (May to September) and local chlorophyll density. The multiple regression model including local chlorophyll and PDO rather than NPGO was selected based on model evaluation statistics (Table 6). Of note, all of the evaluated models under-estimated the marine survival of wild coho returning in 2017 (see Figure 18).

The selected multiple regression model predicted 5.9% (2.7% to 10.8%, 95% C.I.) marine survival for the 2018 return year (2017 ocean entry year). The regression model that included NPGO instead of PDO predicted 4.7% marine survival. Based on these results, a 5.9% 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 1998-2016 ocean entry year (OEY). Variables include NPGO.MS (NPGO index May to September of ocean entry), PDO.MS (PDO index May to September of ocean entry) and Chl.Local (chlorophyll densities in May of ocean entry at WA Dept Ecology station SAR003, Sarasota Passage-East Point). **Model selected for 2018 forecast is in blue text.**

Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2017 OEY)
MS ~ NPGO.MS + Chl.Local	-0.0010	0.0239	0.0264	-38.33%	68.17%	0.0474
MS ~ PDO.MS + Chl.Local	0.0007	0.0201	0.0241	-37.21%	65.91%	0.0588

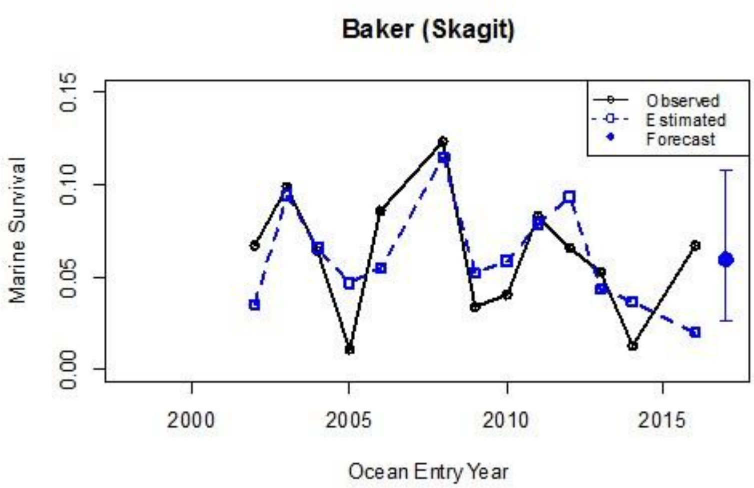


Figure 18. Marine survival of wild coho salmon from the Baker River (Skagit), ocean entry years 2002 to 2016 (excluding 2007 and 2015 for which no local chlorophyll data were available to develop the predictive model). Black solid line are the observed marine survivals. Blue dashed line are the marine survivals estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±95% C.I) for the 2017 ocean entry year (2018 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) 10.9% (ranged 1.8% to 27.6%) between ocean entry years 1978 and 2016 with a declining trend over this time period (Figure 19). Marine survival estimated for the 2016 ocean entry year was the lowest survival in the time series.

The model selected for forecasting included two variables – NPGO index May to September of ocean entry and local marine water clarity (light transmissivity) in May of ocean entry (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 (see Appendix C). Higher survival was associated with higher NPGO index values and higher light transmissivity. The 2015 ocean entry year was not included in the analysis because no light transmissivity data were available for this year.

The selected multiple regression model predicted 4.5% (1.6% to 9.7%, 95% C.I.) marine survival for the 2018 return year (2017 ocean entry year). Based on these results, a 4.5% 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 1998-2016 ocean entry year (OEY). Variables include NPGO.JM (NPGO index January to March prior to ocean entry) and Light.Local (light transmissivity in May of ocean entry measured at WA Dept Ecology station PSS019, Possession Sound-Gedney Island).

Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2017 OEY)
MS ~ NPGO.JM + Light.Local	-0.0004	0.0343	0.0451	-18.47%	43.33%	0.0451

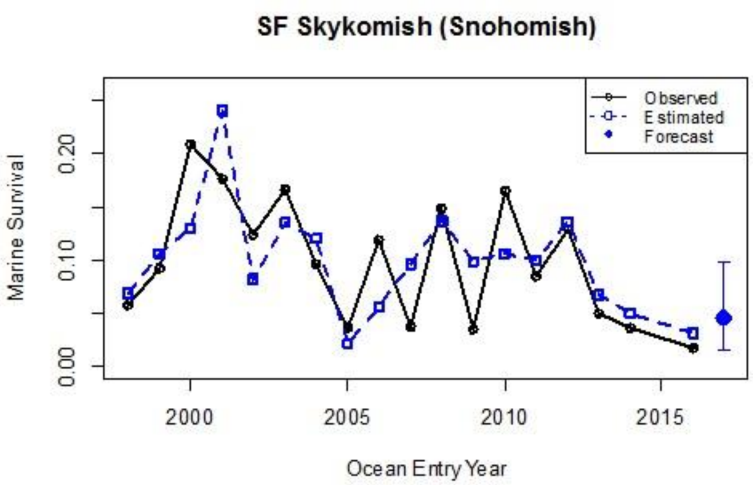


Figure 19. Marine survival of wild coho salmon in the SF Skykomish River, ocean entry year 1998 to 2016. Black solid line are the observed marine survivals. Blue dashed line are the marine survivals estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±95% C.I) for the 2017 ocean entry year (2018 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) 4.7% with a range of 0.7% to 16.9% between the 1977 and 2015 ocean entry years with a declining trend over this time period (Figure 20).

The model selected for forecasting included two variables – NPGO index May to September of ocean entry and water clarity (light transmissivity) in Admiralty Inlet in May of ocean entry (Table 8). Higher survival was associated with a higher NPGO index values and higher light transmissivity values.

The selected regression model predicted a marine survival of 2.6% (0.8% to 6.0%, 95% C.I.) for the 2018 return year (2017 ocean entry year). Based on these results, a marine survival rate of 2.6% 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 – 2016 ocean entry years (OEY). Variables include NPGO.MS (NPGO index May to September of ocean entry) and Light.Regional (light transmissivity measured at WA Dept Ecology station ADM001, Admiralty Inlet-Bush Point).

Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2017 OEY)
MS ~ NPGO.MS + Light.Regional	0.0030	0.0199	0.0260	-39.06%	71.74%	0.0261

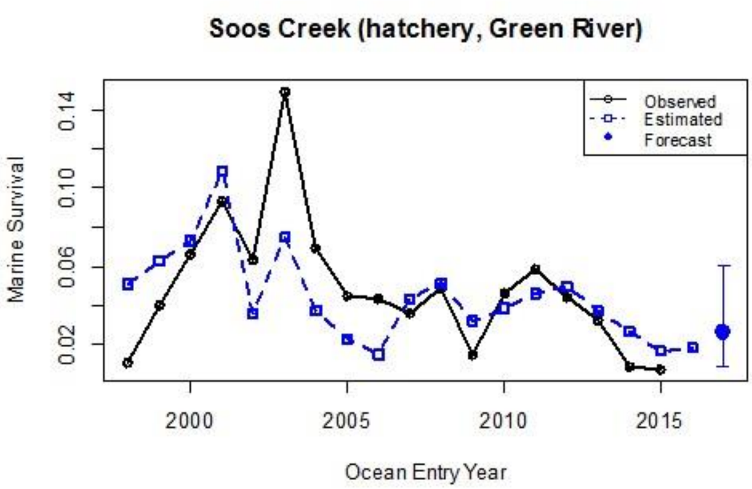


Figure 20. Marine survival of hatchery coho salmon released from Soos Creek hatchery in the Green River, ocean entry year 1998 to 2015. Black solid line are the observed marine survivals. Blue dashed line are the marine survivals estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±95% C.I) for the 2017 ocean entry year (2018 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) 10.0% and ranged from 1.9 to 29.5% between ocean entry year 1979 and 2015 with a declining trend over time (Figure 21).

The model selected for forecasting included two variables – PDO index May to September to ocean entry and the strength of upwelling (upwelling anomaly) at 48˚N April to June of ocean entry (Table 9). Higher survival was associated with a higher PDO index values and stronger upwelling (more positive anomaly). Marine survival in the Deschutes River time series is also correlated with NPGO index values in May to September during ocean entry. Because NPGO and PDO values are highly correlated, I evaluated a second model that included NPGO index (May to September) and upwelling anomaly. The multiple regression model including upwelling anomaly and PDO rather than NPGO was selected based on model evaluation statistics (Table 9).

The selected regression model predicted a 1.3% marine survival (0.7% to 2.1%, 95% C.I.) for the 2018 return year (2017 ocean entry year). Based on these results, a marine survival of 1.3% was applied to the Deschutes as well as South Sound and Nisqually MUs which share the same oceanographic basin as the Deschutes River (Table 1).

Table 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 1998-2016 ocean entry year (OEY); however, only six estimates are available in this time series. Variables include PDO.MS (NPGO index May to September of ocean entry), UI.ANOM.48 (strength of coastal upwelling or Bakun upwelling anomaly at 48˚N April to June of ocean entry), and NPGO.MS (NPGO index May to September of ocean entry). **Model selected for 2018 forecast is in blue text.**

Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2017 OEY)
MS ~ PDO.MS + UI.ANOM.48	-0.0015	0.0188	0.0235	-9.38%	37.07%	0.0126
MS ~ NPGO.MS + UI.ANOM.48	0.0095	0.0243	0.0302	2.63%	49.24%	0.0098

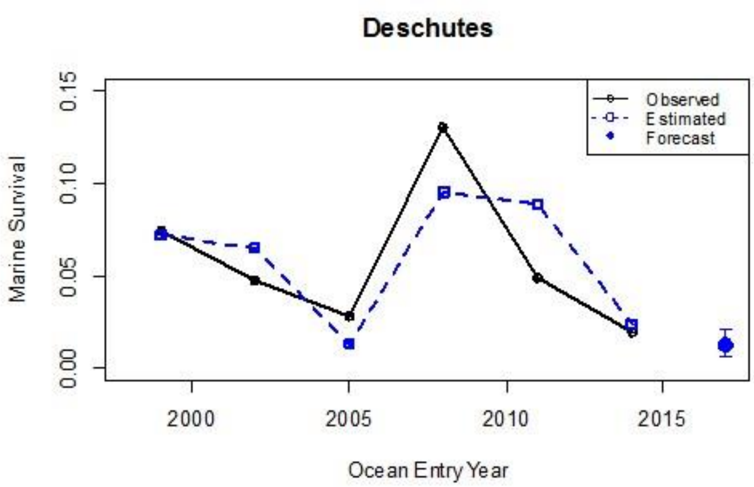


Figure 21. Marine survival of Deschutes River natural coho salmon, ocean entry years 1998 to 2014. Black solid line are the observed marine survivals. Blue dashed line are the marine survivals estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±95% C.I) for the 2017 ocean entry year (2018 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) 12.1% (range 2% to 32%) between ocean entry year 1977 and 2016 with a declining trend over this time period (Figure 22).

The model selected for forecasting included two variables – NPGO index in May to September of ocean entry and sea surface salinity at the Race Rocks light house in April to June of ocean entry (Table 10). Higher survival was associated with higher NPGO index values and higher salinity. The regression model was evaluated with and without 2003, which was identified as an outlier in the individual regressions. The regression model was also evaluated with and without jack survival as a third variable. The multiple regression model fit the data better without the inclusion of 2003 ocean entry year and without the inclusion of jack survival as a variable (Table 10). As a result, the model selected for forecasting included NPGO index (May to September) and sea surface salinity at Race Rocks (April to June), excluding data from the 2003 ocean entry year.

The selected multiple regression model predicted a 7.6% (3.5% to 13.9%, 95% C.I.) marine survival for the 2018 return year (2017 ocean entry year). For the purpose of comparison, regression models including the 2003 ocean year predicted a marine survival of 8.0% and including jack survival predicted a marine survival of 9.0%. Based on these results, a 7.6% marine survival was applied to the entire Hood Canal management unit (Table 1).

Table 10. Model evaluation statistics for multiple regression model used to predict marine survival (MS) of wild coho salmon from Big Beef Creek. Model was developed and evaluated for 1998-2016 ocean entry year (OEY). Variables include NPGO.MS (NPGO index May to September of ocean entry), RR.SSS (sea surface salinity at Race Rocks light house in the strait of Juan de Fuca, April to June of ocean entry), and Jacks (marine survival of Big Beef Creek coho from smolt to age-2). Model evaluation statistics are shown for the regression model with and without the 2003 ocean entry year which was an outlier in most of the individual regressions. **Model selected for the 2018 forecast is in blue text.**

Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2017 OEY)
MS ~ NPGO.MS + RR.SSS + Jacks	-0.0031	0.0384	0.0517	-31.83%	56.02%	0.090
MS ~ NPGO.MS + RR.SSS	-0.0016	0.0405	0.0502	-31.78%	57.84%	0.080
MS ~ NPGO.MS + RR.SSS [without 2003]	-0.0018	0.0357	0.0403	-24.40%	52.04%	0.076

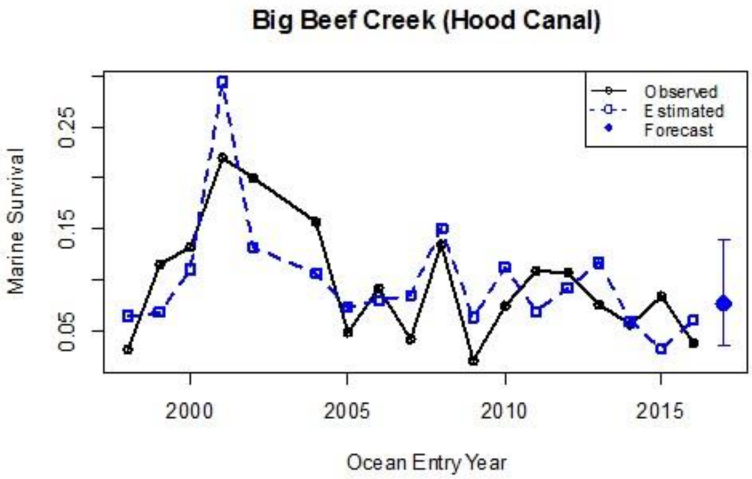


Figure 22. Marine survival of Big Beef Creek wild coho, ocean entry year 1998 to 2016. Black solid line are the observed marine survivals. Blue dashed line are the marine survivals estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±95% C.I) for the 2017 ocean entry year (2018 return year).

Strait of Juan de Fuca

Marine survival in the Juan de Fuca management unit has averaged (geometric mean) 4.8% and ranged between 0.9% to 12.3% between ocean entry year 1998 and 2014 (Figure 23).

The multiple regression model selected for forecasting included three variables – NPGO index January to March prior to ocean entry, winter ichthyoplankton densities the winter prior to ocean entry, and the date of physical transition from downwelling to upwelling conditions on the Pacific coast (Table 11). Higher survival was associated with a higher NPGO index, higher ichthyoplankton densities, and an early physical transition date. The 2007 ocean entry year was an outlier in all of the individual regressions and was removed from the data set to generate the final prediction for the 2017 ocean entry year.

The selected regression model predicted a 4.0% (2.2% to 6.6%, 95% C.I.) marine survival for the 2018 return year (2017 ocean entry year). If 2007 was included in the data set to develop the final regression model, the predicted marine survival for the 2017 ocean entry year was 3.7%. Based on these results, a 4.0% 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 1998-2015 ocean entry year (OEY). Variables include NPGO.JM (NPGO index January to March prior to ocean entry), Wint.Ichthyo (winter ichthoplankton densities in NOAA ocean surveys the winter prior to ocean entry), and Phys.Trans.Date (date of spring transition from down welling to upwelling conditions for coastal waters). Model evaluation statistics are shown with and without the 2007 ocean entry year which was an outlier in most of the individual regressions. **Model selected for the 2018 forecast is in blue text.**

Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2017 OEY)
MS ~ NPGO.JM + Wint.Ichthyo + Phys.Trans. Date	-0.0012	0.0190	0.0270	-29.8 %	51.0%	0.037
MS ~ NPGO.JM + Wint.Ichthyo + Phys.Trans. Date [without 2007]	-0.0006	0.0189	0.0244	-13.6 %	33.6%	0.040

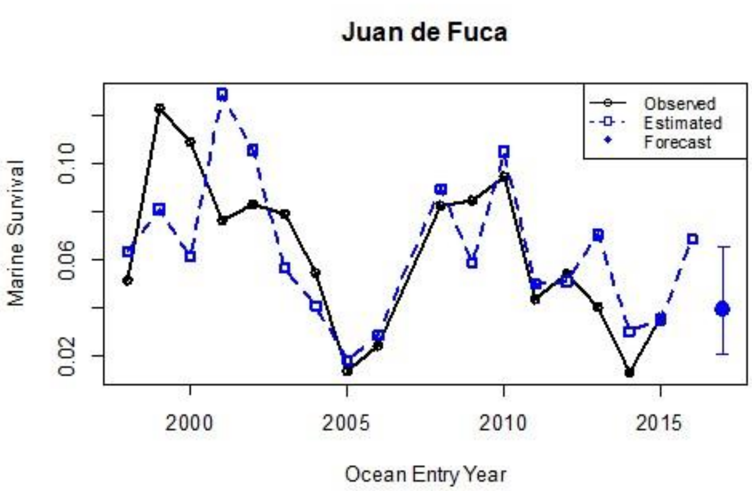


Figure 23. Marine survival of wild coho in the Strait of Juan de Fuca management unit, ocean entry year 1998 to 2016. Black solid line are the observed marine survivals. Blue dashed line are the marine survivals estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±95% C.I) for the 2017 ocean entry year (2018 return year).

Washington Coast

Marine survival of wild coho in the coastal Washington region is measured at Bingham Creek, a tributary to the East Fork Satsop River (a right bank tributary to the Chehalis River). Marine survival of Bingham Creek wild coho has averaged (geometric mean) 4.2% (range 0.6% to 11.7%) between ocean entry year 1982 and 2016 with no apparent trend over this time period (Figure 24).

The model selected for forecasting included three variables – PDO index between May and September of ocean entry, strength of upwelling (anomaly) between April and May of ocean entry, and jack survival (Table 12). Higher survival was associated lower PDO values (i.e., cooler oceanic temperature), stronger upwelling, and higher jack survival. The 2012 ocean entry year was an outlier in the PDO regressions and not used in the final analysis.

The selected multiple regression model predicted a 2.8% (1.5% to 4.6%, 95% C.I.) marine survival for the 2018 return year (2017 ocean entry year). If the 2012 ocean entry year was included in the multiple regression model, the predicted marine survival was 2.7%. Based on these results, a marine survival of 2.8% 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 1998-2016 ocean entry year (OEY). Variables include PDO.MS (PDO index May to September of ocean entry), UI.ANOM.45 (strength of coastal upwelling or Bakun upwelling anomaly at 45˚N April to June of ocean entry), and Jacks (marine survival of Bingham Creek coho from smolt to age-2). Model evaluation statistics are shown for the model with and without the 2012 ocean entry years which was outlier in most of the individual regressions. **Model selected for the 2018 forecast is in blue text.**

Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2017 OEY)
MS ~ PDO.MS + UI.ANOM.45 + Jacks [without 2012]	-0.0004	0.0118	0.0151	-10.5%	28.1%	0.0282
MS ~ MS ~ PDO.MS + UI.ANOM.45 + Jacks [all years, including 2012]	-0.0005	0.0138	0.0170	-14.9%	35.1%	0.0274

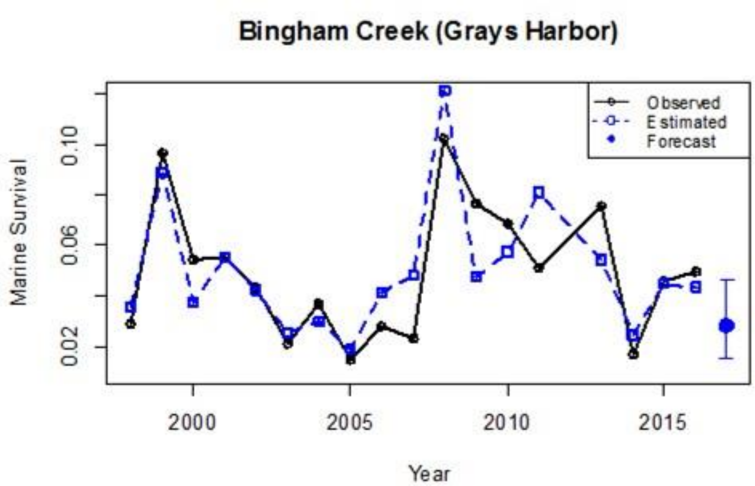


Figure 24. Marine survival of wild coho from Bingham Creek, Washington, ocean entry year 1998 to 2016. 2015 results are preliminary. Black solid line are the observed marine survivals. Blue dashed line are the marine survivals estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±95% C.I) for the 2017 ocean entry year (2018 return year).

Lower Columbia River

Marine survival in the lower Columbia River is measured in the Cowlitz River. Marine survival of natural coho from the Cowlitz River has averaged (geometric mean) 3.3% (range 0.9% to 11.5%) between ocean entry year 2001 and 2016 (Figure 25).

The final model included two variables – average temperature in the upper 20 m at the NH05 buoy (Newport) between May and September of ocean entry and length of upwelling conditions on the Pacific coast during the year of ocean entry (Table 13). Higher marine survival was associated cooler temperatures and longer upwelling seasons. The date of physical transition from down welling to upwelling conditions was also predictive of marine survival; this variable was highly correlated with the length of upwelling conditions and therefore examined in a separate set of models. Model evaluation statistics (Table 13) indicated that the multiple regression model including the length of upwelling was a slighter better fit to the data than the model including the date of physical transition. The 2001 and 2015 ocean entry year were outliers in the individual regressions (potentially due to localized factors in the Cowlitz River) and not used in the final analysis. Variables that correlated with marine survival of Washington natural 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 predicted a 3.9% (2.8% to 5.3%, 95% C.I.) marine survival for the 2018 return year (2017 ocean entry year). If the 2001 and 2015 ocean entry years were included in the multiple regression model, the predicted marine survival was 3.7%. Based on these results, a marine survival of 3.9% 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 form the Cowlitz River. Model was developed and evaluated for 1998-2016 ocean entry year (OEY). Variables include NH05.20.MS (ocean temperature May to September of ocean entry in the upper 20 m at NOAA Buoy 46050, located 22 miles off Newport, OR), Upwell.length (length of upwelling conditions in coastal waters at 45˚N latitude), and Phys.Trans.Date (date of spring transition from down welling to upwelling conditions for coastal waters). Model evaluation statistics are shown for the final model with and without the 2001 and 2015 ocean entry years which were outliers in most of the individual regressions. **Model selected for the 2018 forecast is in blue text.**

Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2017 OEY)
MS ~ NH05.20.MS+Upwell.length [without 2001, 2015]	0.0008	0.0099	0.0138	-3.5 %	21.2 %	0.0392
MS ~ NH05.20.MS+Phys.Trans.Date [without 2001, 2015]	0.0007	0.0130	0.0202	-8.4%	28.9 %	0.0365
MS ~ NH05.20.MS+Upwell.length [include all years]	0.0019	0.0138	0.0197	-30.5%	59.2 %	0.0325
MS ~ NH05.20.MS+Phys.Trans.Date [include all years]	0.0008	0.0170	0.0237	-34.3 %	65.8 %	0.0277

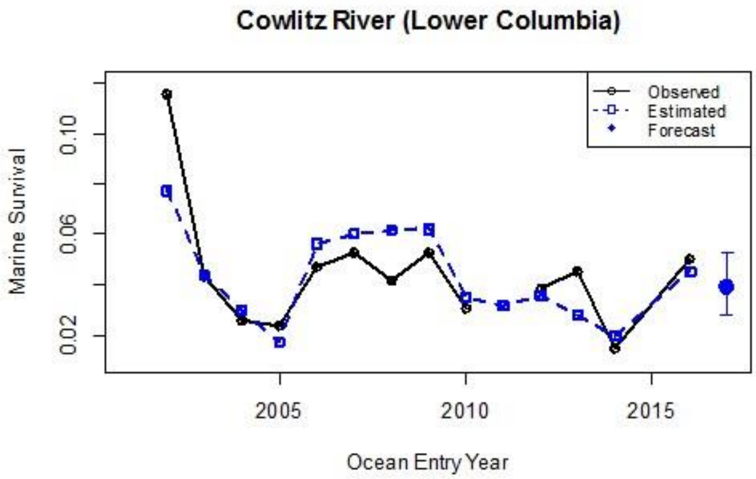


Figure 25. Marine survival of natural origin coho from the Lower Columbia River management unit, ocean entry year 2001 to 2016 (no data available for 2011). Black solid line are the observed marine survivals. Blue dashed line are the marine survivals estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±95% C.I) for the 2017 ocean entry year (2018 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.

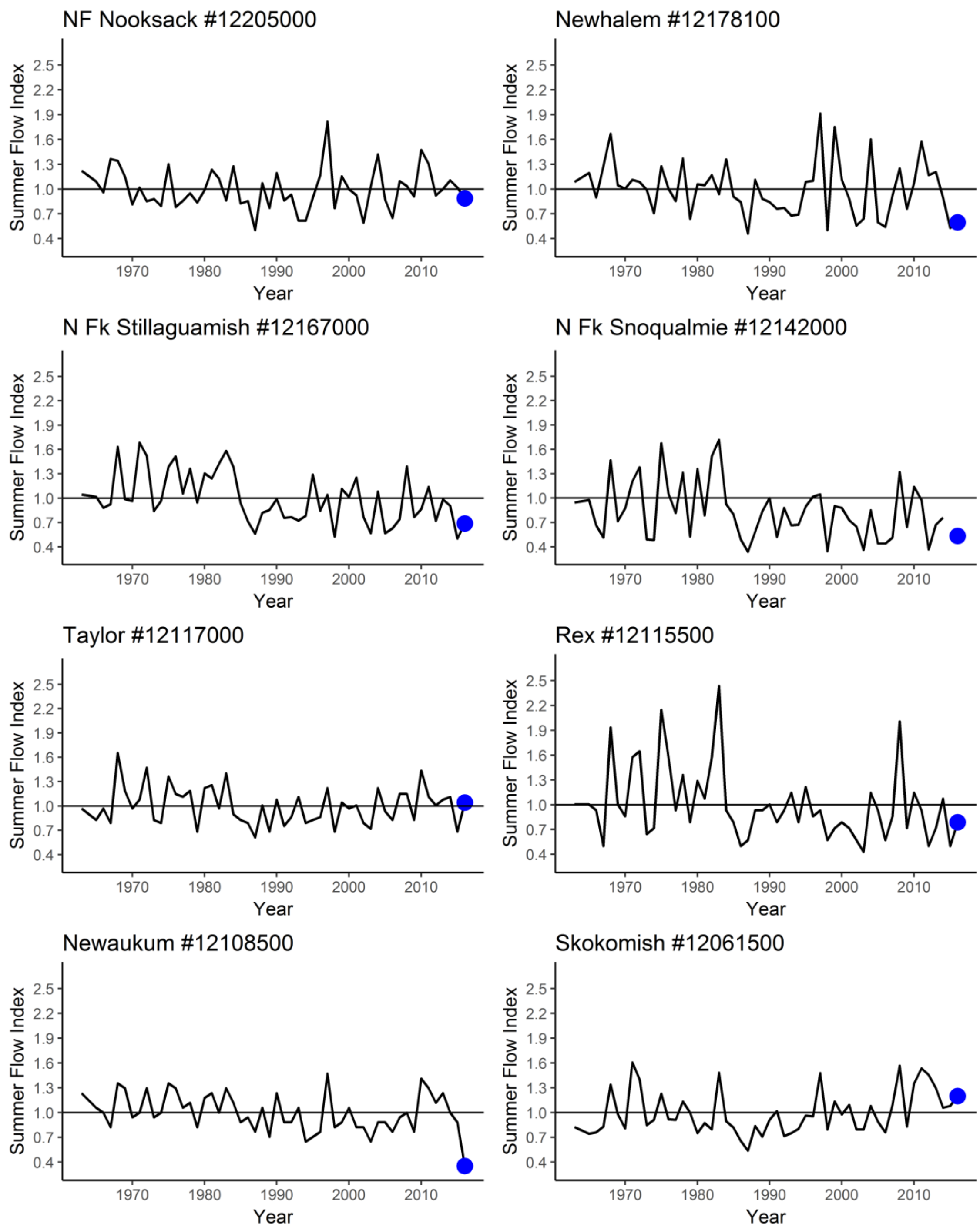
An alternate gage on the Nooksack River (Nooksack at Ferndale, #12213100) was selected beginning with the 2011 wild coho forecast because the previously used gage (South Fork Nooksack gage #12209000) was discontinued as of September 30, 2008. Flows from the Ferndale gage were correlated with those from 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 2016 (including alternate Nooksack gage), the PSSLFI has ranged between 4.4 and 12.6 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 2016 (corresponding to the 2017 outmigration and 2018 returning adults) had an index value of 6.09 or 76% 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 2018 wild coho return shown as blue point in graph.



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	Monitored
Quillayute	629	
Dickey		87
Bogachiel		129
Hoh	299	
Queets (no Clearwater)	310	310
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]
.	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[7]
R/P	Salinity 20 m (Apr-Jun)	ADM001	ADM001	ADM001	ADM001	ADM001	ADM001	---	---	WA ECY-MWMP[7]
R/P	Chlorophyll 20 m (May)	ADM001	ADM001	ADM001	ADM001	ADM001	ADM001	---	---	WA ECY-MWMP[7]
R/P	Light transmission (May)	ADM001	ADM001	ADM001	ADM001	ADM001	ADM001	---	---	WA ECY-MWMP[7]
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]
L/P	Salinity 20 m Apr-Jun	SAR003	PSS019	PSB003	BUD005	HCB003	---	---	---	WA ECY-MWMP[8]
L/B	Chlorophyl 20 m May	SAR003	PSS019	PSB003	BUD005	HCB003	---	---	---	WA ECY-MWMP[8]
L/B	Light transmission May	SAR003	PSS019	PSB003	BUD005	HCB003	---	---	---	WA ECY-MWMP[8]
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/lighthouses-phares/index-eng.htm

[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 Julia Bos, WA Department of Ecology.

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