2016 Wild Coho Forecasts for Puget Sound, Washington Coast, and Lower Columbia

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by
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Contributors: This coho forecast was made possible through funding from numerous federal, state, and local sources and the participation of numerous WDFW, tribal, and PUD biologists. The following WDFW employees, listed in alphabetical order, provided field data used in the 2016 forecast: Pat Hanratty (Bingham Creek), Todd Hillson (Grays River), Trevor Johnson (Mill, Abernathy, and Germany creeks), Clayton Kinsel (Skagit River and Big Beef Creek), Kelly Kiyohara (Lake Washington), Matt Klungle (Nisqually River), John Serl (Cowlitz Falls), Jamie Lamperth (Coweeman River), Pete Topping (Green River, Deschutes River), and John Winkowski (Chehalis River). Smolt data obtained from tribal and PUD biologists and sources of freshwater and freshwater and marine environmental indicators are cited in the document. Dave Seiler, Greg Volkhardt, Dan Rawding, and Thomas Buehrens have contributed to the conceptual approaches used in this forecast.

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 should 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 populations 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 survival from saltwater entry through the ocean rearing phase to the point that harvest begins. Marine survival for a given stock is measured by summing coho harvest and escapement and dividing by smolt production. Harvest of wild coho produced by these watersheds 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 in returning spawners are enumerated at upstream trapping structures. Results from these monitoring stations describe patterns in survival among years and watersheds. These patterns are used to predict marine survival of the wild coho cohort that is currently recruiting into the fisheries.

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, most notable in recent years are modifications to methods used to predict marine survival.

Table 1 summarizes the 2016 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. 2016 wild coho run forecast summary for Puget Sound, Coastal Washington, and Lower Columbia.

	Production X	**Marine Survival =**	**Recruits**	
Production Unit	**Estimated Smolts Spring 2015**	**Predicted Marine Survival**	**Adults (Age 3)**	**Jan. (Age 3)**
Puget Sound				
Primary Units				
Skagit River	665,000	1.8%	11,970	14,743
Stillaguamish River	184,000	3.9%	7,176	8,839
Snohomish River	1,395,000	3.9%	54,405	67,010
Hood Canal	163,000	2.8%	4,564	5,621
Straits of Juan de Fuca	231,000	1.9%	4,389	5,406
Secondary Units				
Nooksack River	514,000	1.8%	9,252	11,396
Strait of Georgia	10,000	1.8%	180	222
Samish River	33,000	1.8%	594	732
Lake Washington	120,000	6.0%	7,200	8,868
Green River	126,000	6.0%	7,560	9,312
East Kitsap	79,000	6.0%	4,740	5,838
Puyallup River	140,000	6.0%	8,400	10,346
Nisqually River	132,000	3.4%	4,488	5,528
Deschutes River	1,400	3.4%	48	59
South Sound	128,000	3.4%	4,352	5,360
Puget Sound Total	3,921,400		129,318	159,279
Coast				
Quillayute River	162,000	1.3%	2,106	2,594
Hoh River	69,000	1.3%	897	1,105
Queets River	156,000	1.3%	2,028	2,498
Quinault River	130,000	1.3%	1,690	2,082
Independent Tributaries	148,000	1.3%	1,924	2,370
Grays Harbor				
Chehalis River	3,128,000	1.3%	40,664	50,086
Humptulips River	340,000	1.3%	4,420	5,444
Willapa Bay	723,000	1.3%	9,399	11,577
Coastal Systems Total	4,856,000		63,128	77,754
Lower Columbia Total	645,000	4.1%	26,445	32,572
GRAND TOTAL	9,422,400		218,891	269,606

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 have 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, we have demonstrated that freshwater productivity (juveniles/female) is a decreasing function of spawner abundance (Figure 1). This density-dependent response in juvenile survival may result from competition for rearing habitat. In most watersheds, overall production of juvenile coho (juveniles/female * # females) rarely limited by spawner abundance, and the majority of variation in juvenile production is the result of environmental effects (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 localized habitat factors such as woody debris, pool habitat, and road densities also impact 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 available for even-year coho salmon cohorts 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 vulnerable to both habitat degradation and low escapements. Density-dependent compensation may not 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).

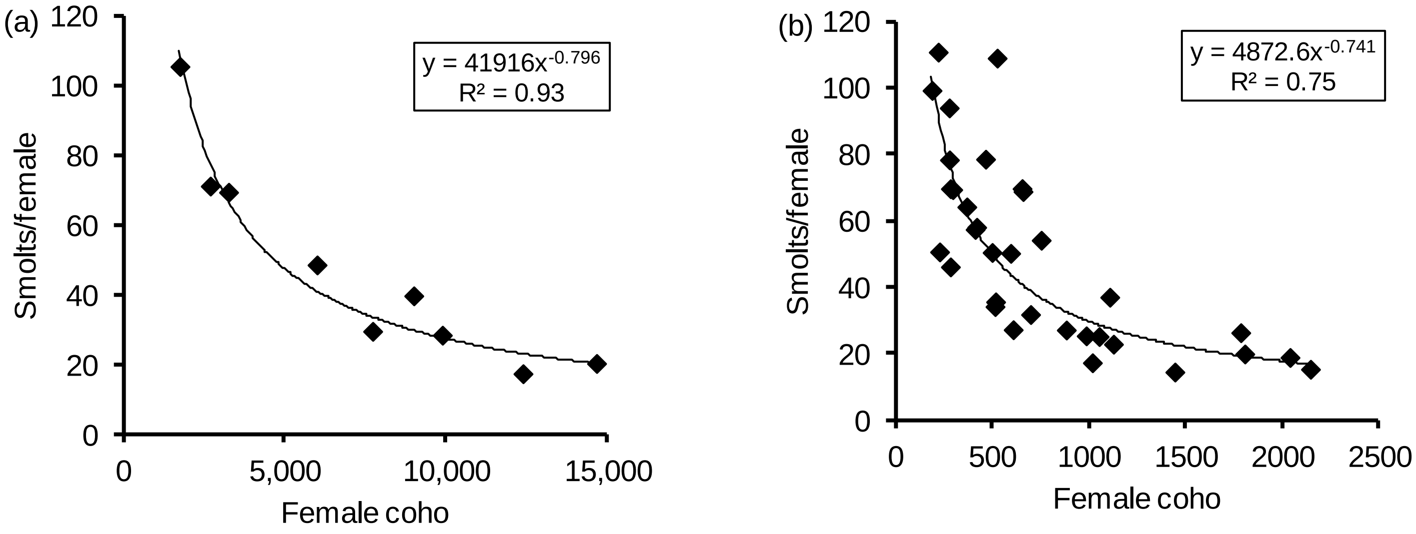

Figure 1. Freshwater productivity (juveniles/female) as a decreasing function of female coho escapement in the South Fork Skykomish (*a*, Sunset Falls, brood year 1976-1984) and Big Beef Creek (*b*, brood year 1978-2009) watersheds.

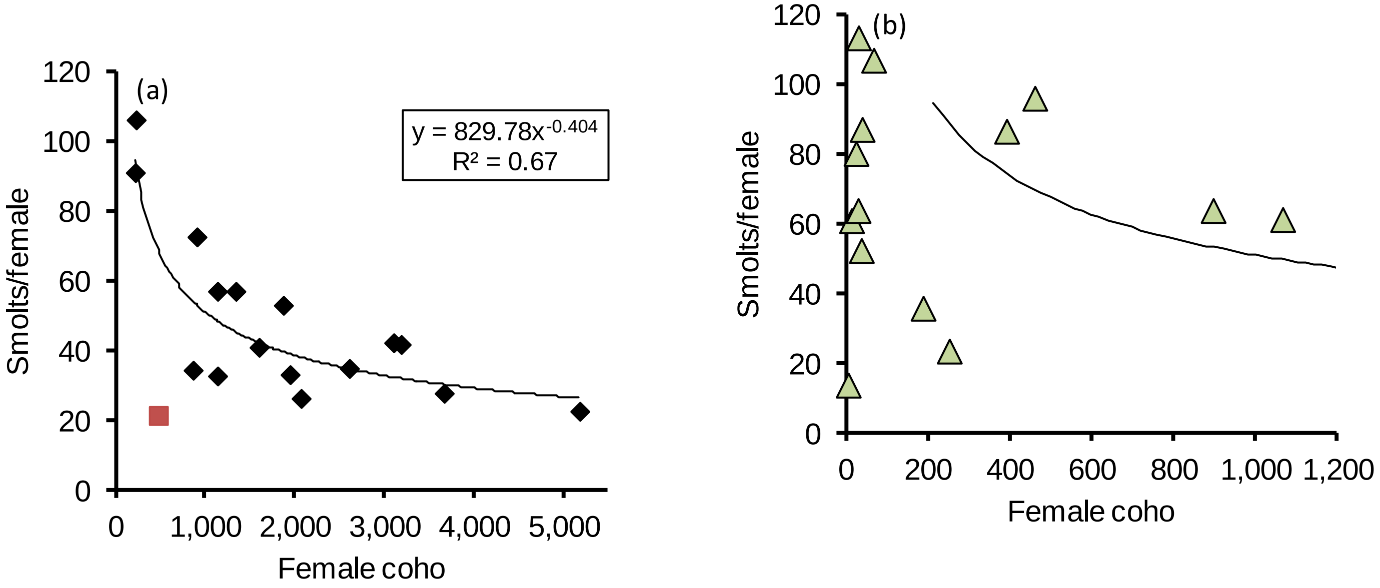

Figure 2. Freshwater productivity (juveniles/female) as a function of female coho spawners in the Deschutes River. For brood year 1978-1994 (*a*), coho productivity was a decreasing function of escapement (black square) with the exception of brood year 1989 (red square). The 1989 brood year corresponded 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 2015, 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 seven additional management units (Nooksack, Juan de Fuca, Stillaguamish, Snohomish, Puyallup, East Kitsap, South Sound) were available due to juvenile monitoring studies conducted by the Lummi, Jamestown, Elwha, Makah, Tulalip, Stillaguamish, Puyallup, Suquamish, and Squaxin Tribes. For watersheds where trapping data were not available in 2015, coho smolt abundance was estimated using several approaches.

One approach was based on the smolt potential predicted for each watershed by Zillges (1977). This approach was used to estimate production from an entire watershed when smolt production is known from at least some portion of that watershed. Zillges (1977) assumed that summer low flows were the primary limiting factor for Puget Sound coho and predicted smolt potential based on the wetted summer habitat of Puget Sound streams. Rearing habitat was estimated for each stream segment defined in the Washington stream catalog (Williams et al. 1975). Coho densities for each segment were estimated based on densities measured in small (Chapman 1965) and large (Lister and Walker 1966) watersheds. Average production estimates for Puget Sound watersheds range between 11% and 134% of the predicted potential production (Table 2). The common metric developed by Zillges (1977) makes his predictions useful for expanding production measured in one portion of the watershed to other areas of the watershed.

A second approach was the use of a Puget Sound Summer Low Flow Index (PSSLFI) or individual flow indices for each of the streams used in the composite index (Appendix A). This index was used to estimate smolts in watersheds where historical estimates were available but current year estimates are not. The PSSLFI index was calculated from a representative series of eight USGS stream flow gages in Puget Sound and was based on the general observation that summer low flows are correlated among Puget Sound watersheds. This approach is 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 low flows in 2014 (corresponding to the 2015 outmigration and 2016 returning adults) had an index value of 7.99 or 100% of the long-term average (Figure 3).

Table 2. Wild coho smolt production 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.

		Smolt production above trap			Zillges (1977) potential above trap		
Stream	No. Years	Average	Min	Max	Average	Min	Max
Hood Canal							
Big Beef	38	27,918	8,115	58,136	72.4%	21.0%	150.7%
Little Anderson	22	672	45	1,969	13.2%	0.9%	38.6%
Seabeck	22	1,346	496	2,725	12.8%	4.7%	26.0%
Stavis	22	5,282	1,549	9,667	105.1%	30.8%	192.3%
Skagit River	26	1,086,355	426,963	1,884,668	79.2%	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	12	64,274	22,671	194,393	28.5%	10.1%	86.2%
Lake Washington							
Cedar River**	17	65,051	13,322	129,666	53.8%	11.0%	107.3%
Bear Creek	17	32,364	12,208	62,970	64.6%	24.4%	125.7%
Nisqually	7	158,143	80,048	228,054	136.9%	69.3%	197.4%
Deschutes***	35	45,496	1,187	133,198	20.7%	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.

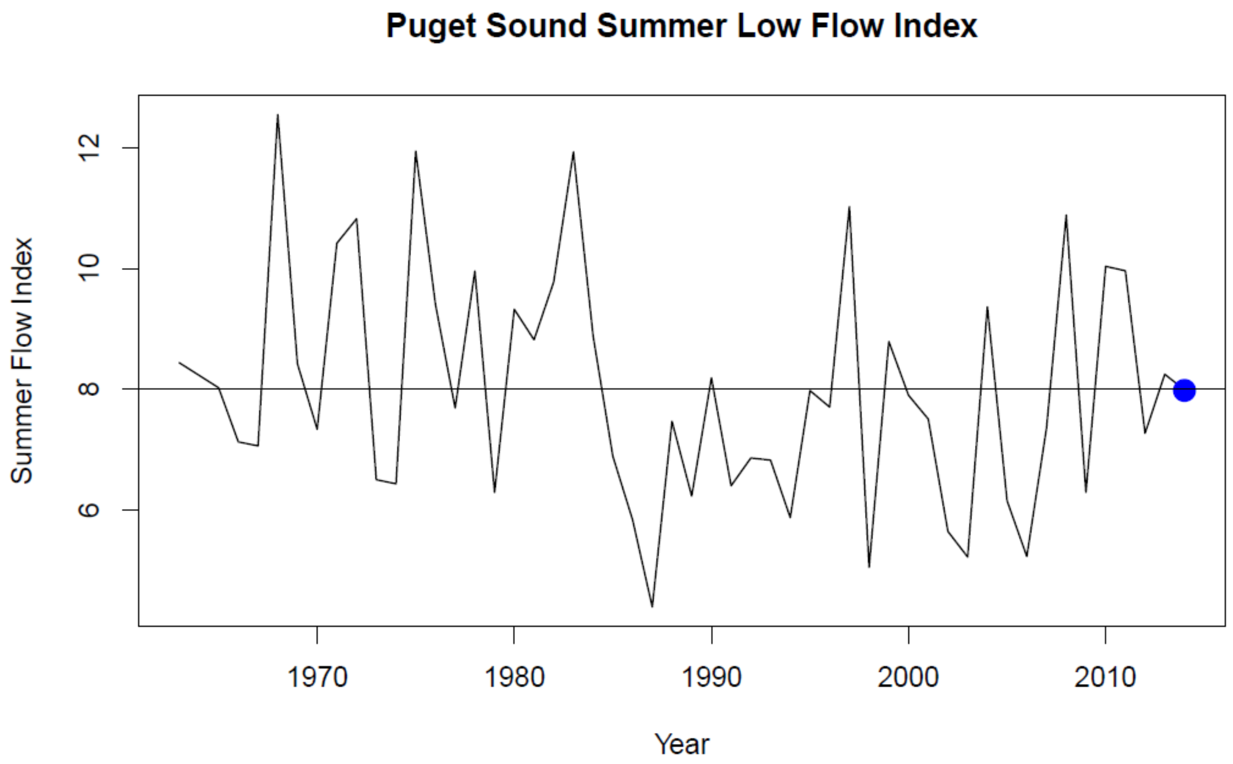

Figure 3. Puget Sound Summer Low Flow Index (PSSLFI) by summer rearing year (return year – 2). PSSLFI is based on 60-day minimum flow averages at eight stream gages in Puget Sound (see Appendix A). The minimum 60-day average flow at each gage is compared to its long-term average (1967 to present) and then summed across all eight gages. Flow index corresponding to the 2016 wild coho return is highlighted in blue.

Puget Sound Primary Units

Skagit River

A total of 665,000 (±240,500, 95% C.I.) wild coho smolts are estimated to have emigrated from the Skagit River in 2015 (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 2015 was 39% decrease from the long-term average of 1,095,000 smolts between the 1990 and 2015 ocean entry years (Table 2, Figure 4).

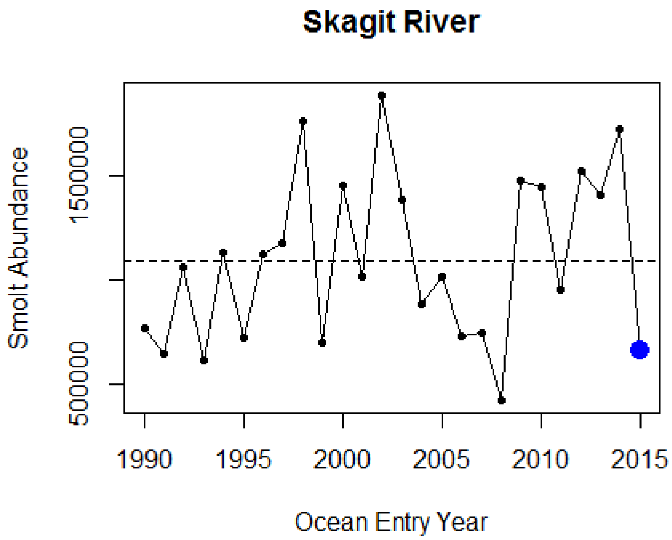

Figure 4. Time series of wild coho smolt outmigration from the Skagit River, ocean entry years 1990 to 2015. Blue point represents current year outmigration and the horizontal line is the time series average.

Stillaguamish River

A total of 184,000 coho smolts are estimated to have emigrated from the Stillaguamish River in 2015 (Table 1). This estimate was based on a CPUE index of abundance for the 2015 outmigration and a relationship between a time series of CPUEs and 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); however, this monitoring effort has not included trap efficiency trials needed to directly expand CPUE to watershed abundance. CPUE provides an index of abundance to the extent that trap efficiency is relatively constant among years. Between 2001 and 2015, CPUE has averaged 5.3 fish/hour (range 0.9 to 13.6). CPUE observed in 2015 was the lowest value (0.9) in the time series. Previous year's forecasts have explored relationships between the CPUE index of smolt abundance and flow metrics. A weak relationship with summer rearing flow was identified but has not retained predictive value over time.

An alternative estimate of smolt abundance for the Stillaguamish River was back-calculated from ocean age-3 run reconstruction and an estimated marine survival rate. Ocean age-3 run size is the estimate of coho 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 2001 and 2012 outmigration averaged 406,000 smolts (range 174,000 to 751,000), bracketing the watershed smolt estimates calculated in 1981-1983.

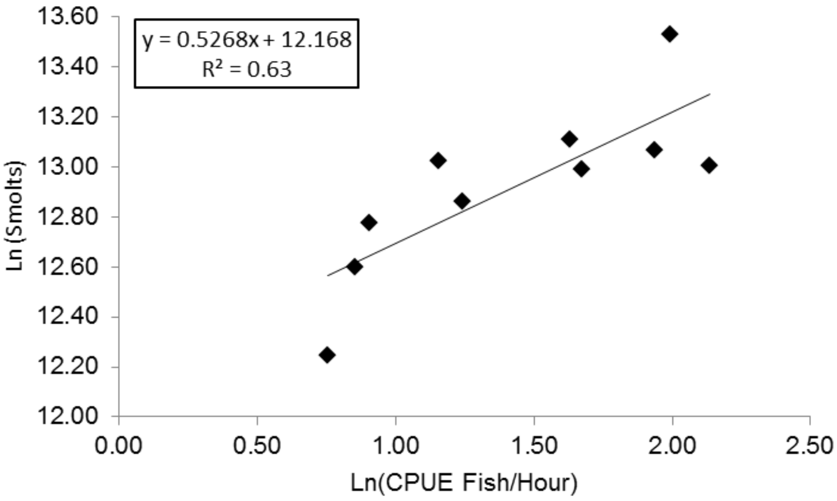

Figure 5. Correlation between CPUE of wild coho smolts in Stillaguamish smolt trap and back-calculated smolt estimates, 2001 to 2012. Two years (2001, 2002) were removed from this analysis because the duration of trap operation was half of that for the remainder of the time series. Smolt trap data were 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 2015 outmigration (0.9 fish/hour) resulting in an estimated outmigration of 184,000 smolts (rounded from 183,978). This estimate has additional uncertainty because the CPUE in 2015 was the lowest observed in the time series (outside the existing predictive relationship).

Snohomish River

A total of 1,395,000 coho smolts are estimated to have emigrated from the Snohomish River in 2015 (Table 1). The 2015 estimate 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). The traps were operated and results provided by the Tulalip Tribes (D. Holmgren, personal communication). Smolt trap estimates for the Skykomish (*n* = 508,449) and Snoqualmie *(n* = 494,039) rivers summed to 1,002,488 wild coho smolts above both traps. These estimates were further expanded for rearing in the Snohomish River below the traps assuming that 71.9% of the rearing habitat was included in the smolt estimates (per Zillges 1977). Coho smolt production from the Snohomish River in 2015 was a 36% decrease from the long-term average of 2,178.917 smolts between the 2001 and 2015 ocean entry years (Figure 6).

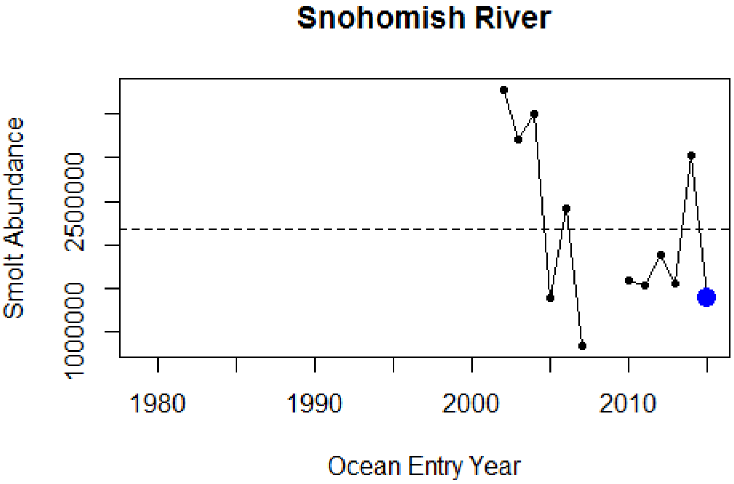

Figure 6. Time series of wild coho smolt outmigration from the Snohomish River, ocean entry years 2002 to 2015. Blue point represents current year outmigration and the horizontal line is the time series average. Data provided by D. Holmgren (Tulalip Tribes).

Hood Canal

A total of 163,000 coho smolts are estimated to have emigrated from Hood Canal tributaries in 2015 (Table 1). This estimate is based on measured smolt abundance in select tributaries expanded to the entire management unit.

In 2015, wild coho smolt abundance was measured in Big Beef Creek (*n* = 8,115*)*, Little Anderson Creek (*n* = 622), Seabeck Creek (*n* = 726*)*, and Stavis Creek (*n* = 2,937). 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 2015 abundance of coho smolts from Big Beef Creek was the lowest observed since monitoring of this creek began in 1978, representing a decrease of 71% from the long-term average between the 1978 and 2015 ocean entry years (Table 2, Figure 7). Coho smolt abundances in neighboring Stavis and Seabeck creeks were a 44%, and 46% decrease from the long-term average in these watersheds. In comparison, the 2015 coho production from Little Anderson, which has received substantial in stream habitat restoration efforts, was decreased just 7.5% from the long-term average smolt abundance (Table 2).

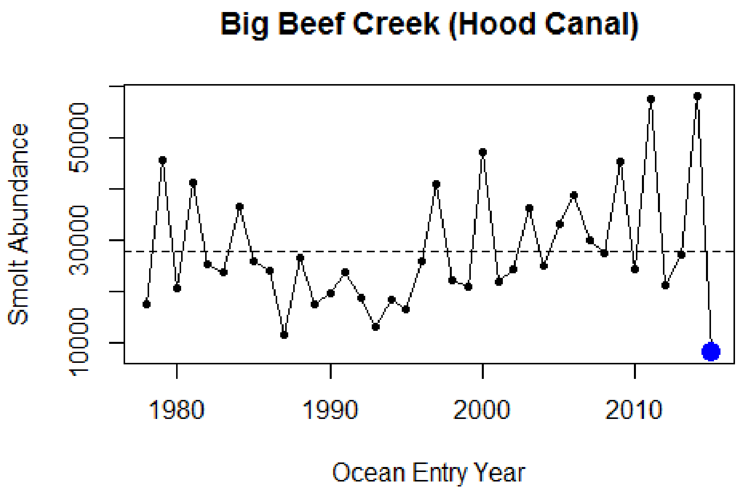

Figure 7. Time series of wild coho smolts from Big Beef Creek, ocean entry years 1978 to 2015. Blue point represents current year outmigration and the horizontal line is the time series average.

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.

The three approaches described above restimated that the 2015 wild coho production in Hood Canal ranged between 163,000 and 210,000 smolts. Using the Zillges approach, the total of 12,400 smolts from the four tributaries were expanded to an estimated 210,169 Hood Canal smolts. Using the second approach (HCJTC 1994 revision), the total of 12,400 smolts from the four tributaries were expanded to 163,158 Hood Canal smolts. The third approach expanded the 8,115 smolts from Big Beef Creek to a total of 177,961 Hood Canal smolts. This forecast is based on the most conservative result, provided by the second approach.

Juan de Fuca

A total of 231,000 coho smolts (rounded from 231,115) are estimated to have emigrated from Juan de Fuca tributaries in 2015 (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 2015 through a collaborative effort by WDFW, Jamestown S'Klallam Tribe, Elwha Tribe, and the Makah Tribe. Monitored tributaries were Jimmy Comelately, Siebert, Bell, McDonald, Ennis, and Snow creeks in the eastern part of the Strait, and Salt, East Twin, West Twin, Deep, and Little Hoko creeks in the western part of the Strait. Measured smolt abundance was extrapolated to all tributaries in the Juan de Fuca management unit based on the proportion of summer rearing habitat represented in the monitored tributaries (calculations provided by Hap Leon, Makah Tribe). The Elwha and Dungeness rivers are managed separately from the Juan de Fuca management unit and are not included in this forecast. Coho smolt production from the Juan de Fuca tributaries in 2015 was 22% decrease from the long-term average of 297,334 smolts between the 1998 and 2015 ocean entry years.

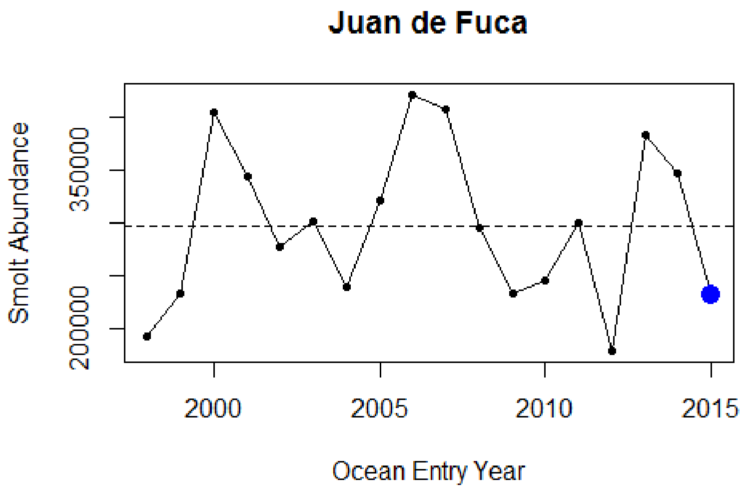

Figure 8. Time series of wild coho smolts from Strait of Juan de Fuca tributaries, ocean entry years 1998 to 2015. Blue point represents current year outmigration and the horizontal line is the time series average. Data provided by Hap Leon.

Puget Sound Secondary Units

Nooksack River

A total of 514,000 coho smolts are estimated to have emigrated from the Nooksack River in 2015 (Table 1). Smolt abundance estimates from the Nooksack River were not available at the time of this forecast. However, smolt trapping conducted by the Lummi Tribe has provided estimates between 2005 and 2014, which averaged 643,000 smolts (range 493,000 to 809,000, data provided by Evelyn Brown). The 2015 value selected for this forecast is 80% of the average value reflecting the lower than average smolt abundance observed throughout Puget Sound in 2015. This value is 114% of the predicted potential of 451,275 smolts (Zillges 1977).

Strait of Georgia

A total of 10,000 coho smolts are estimated to have emigrated from the Straits of Georgia watersheds in 2015 (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. Previous forecasts for the Straits of Georgia have estimated that wild coho production was 20% to 50% of its potential. The 2015 coho production was estimated to be 10,000 smolts (rounded from 10,364), 20% 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 2015 (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 8.7% with an average of 6.1% in the Skagit River (Zimmerman 2012), 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 spawners. Assuming a marine survival rate of 6%, an average of 33,000 smolts will result in a return of 2,000 coho 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 120,000 coho smolts are estimated to have entered Puget Sound from the Lake Washington basin in 2015 (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 2015, coho smolt abundance from the Cedar River was estimated to be 107,874 (±16,827 95% C.I.) smolts. This production was an increase of 65% from the long-term average of 65,051 smolts between the 1999 and 2015 ocean entry years (Figure 9). In comparison, coho smolts from Bear Creek were estimates to be 30,544 (±519 95% C.I.), which was a decrease of 6% from the long-term average of 32,364 smolts between the 1999 and 2015 ocean entry years. Between 1999 and present, coho smolt abundance has not been correlated between the Cedar River and Bear Creek. Among the potential reasons for these differences 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).

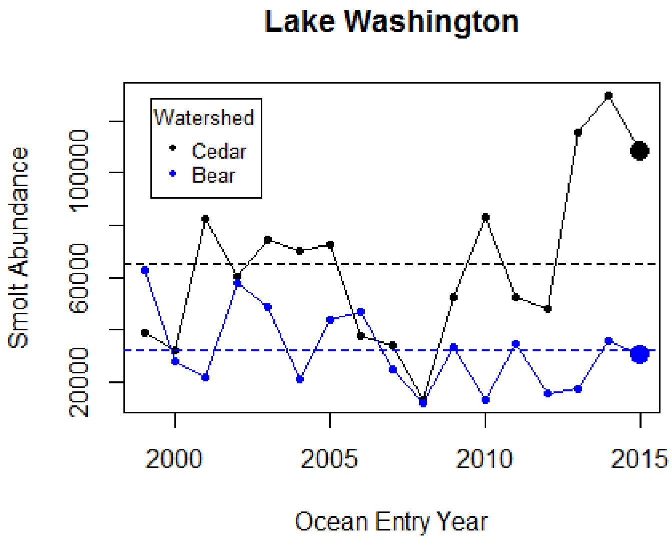

Figure 9. Time series of natural-origin coho smolts from Cedar Creek (black) and Bear Creek (blue), ocean entry years 1999 to 2015. Larger symbol represents current year outmigration. Horizontal lines are the time series average for each watershed.

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 2015 coho production from Issaquah Creek was estimated by scaling the 2000 estimate for this creek (19,812 smolts; Seiler et al. 2002a) by the 2015 to 2000 smolt ratio in Bear Creek. In 2015, coho smolt production in Bear Creek was 108% of that measured in 2000 (30,544/28,142 = 1.08). Therefore, 2015 coho production from Issaquah Creek was estimated to be 21,503 smolts (19,812 * 1.08).

The total coho production of 120,000 smolts (rounded from 119,941) assumed 75% survival through Lake Washington. A total of 159,921 coho smolts were estimated to enter Lake Washington (107,874 Cedar + 30,544 Bear + 21,503 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). However, based on a 2011 release of PIT tagged wild coho smolts from both the Cedar River and Bear Creek traps this estimate of survival through the lake may be high (Kiyohara and Zimmerman 2012).

Green River

A total of 126,000 (rounded from 125,678) natural-origin coho smolts are estimated to have emigrated from the Green River in 2015 (Table 1). This estimate is the sum of 42,564 smolts upstream of the juvenile trap (river mile 34), 24,540 smolts below the juvenile trap, and 58,574 smolts from Big Soos Creek.

In 2015, 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 42,564 (±23,459 95% C.I.) smolts. This production was a decrease of 39% from the long-term average of 69,506 smolts between the 2000 and 2015 ocean entry years (Figure 10).

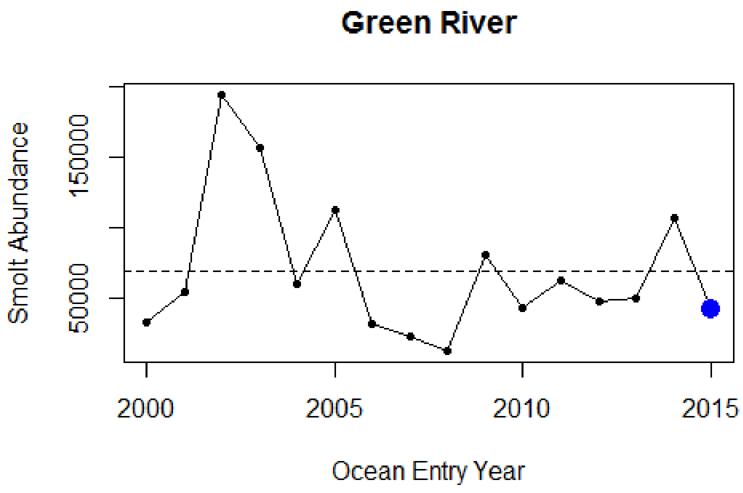

Figure 10. Time series of natural-origin coho smolts from Green River, ocean entry years 2000 to 2015. Blue point represents current year outmigration. Horizontal lines are the time series average.

Coho smolt production from above the juvenile trap represents 19.1% 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 24,540 smolts based 19% of the potential production (128,630) predicted for this portion of the watershed.

Big Soos Creek enters the Green River downstream of the juvenile trap. An indirect estimation method was used to predict the number of coho smolts from this portion of the Green River basin. 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). Big Soos Creek is a low gradient stream and coho production is likely impacted by summer low flows. Therefore, 2015 smolt abundance from this creek was based on the ratio of PSSLFI values associated with the 2015 and 2000 outmigration years (see Appendix A for explanation of PSSLFI). This ratio (8.0/8.0 = 94.3%) converts to an estimated 58,574 smolts (0.943*64,431).

East Kitsap

A total of 79,000 coho smolts (rounded from 79,273) are estimated to have emigrated from East Kitsap tributaries in 2015 (Table 1). In previous years, this estimate has been based on an expansion of measured production in Steele Creek, an East Kitsap tributary which was trapped between 2001 and 2010 (Steele Creek Organization for Resource Enhancement; www.bougan.com/SCORE). 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 began a smolt monitoring study on Lost and Wildcat creeks in 2011 which continued in 2015 (J. Oleyar, Suquamish Tribe, personal communication). Based on a recent assessment of summer rearing habitat conducted by the Suquamish Tribe, the smolt potential above the trap locations is 2,513 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 determined by the Suquamish Tribe biologists (1.7 to 1.9 miles in Lost Creek).

The 2015 coho abundance of 4,793 smolts from Lost (*n* = 1,896) and Wildcat (*n* = 2,897) creeks was 51.1% of the calculated smolt potential. Total coho smolt abundance for the East Kitsap management unit was estimated to be 79,273 smolts based on 51.1% of the 155,269 smolt potential for all watersheds in this management unit.

Puyallup River

A total of 140,000 coho smolts (rounded from 140,097) are estimated to have emigrated from the Puyallup River in 2015 (Table 1). This estimate is based on measured production in the Puyallup River above the juvenile trap (32,112), estimated production from the White River (97,943), and an estimate from the Puyallup River below the Puyallup-White confluence (10,042).

In 2015, the Puyallup Tribe operated a juvenile fish trap on the Puyallup River just upstream of the confluence with the White River. A total of 32,112 coho smolts were estimated to have migrated past the juvenile trap (Berger et al. 2016). This production was a decrease of 57% from the long-term average of 74,730 smolts between the 2005 and 2015 ocean entry years.

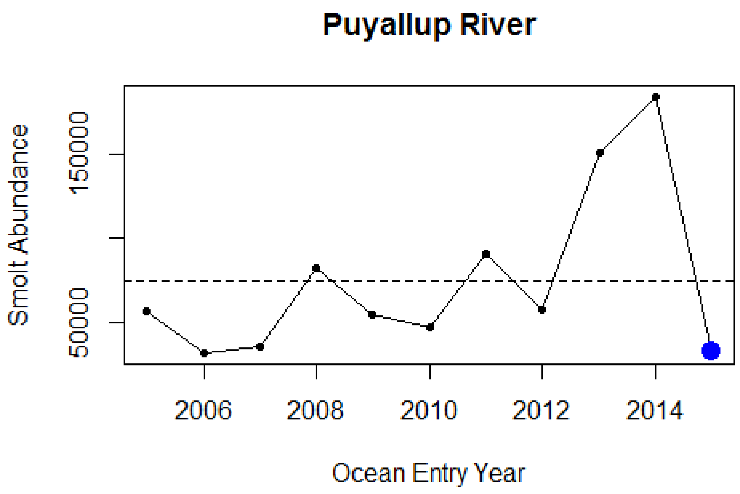

Figure 11. Time series of natural-origin coho smolts from the Puyallup River, ocean entry years 2005 to 2015. Blue point represents current year outmigration. Horizontal lines are the time series average. Data provided by Andrew Berger (Puyallup Tribe).

Coho smolt production above the juvenile trap represents 11.6% 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 2015 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. An additional 10,042 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).

A total of 97,943 coho smolts are estimated to have emigrated from the White River. Coho smolts originating between the Puyallup-White confluence and Buckley Dam were estimated to be 10,133, 10% of the potential production for this portion of the watershed (Zillges 1977). Coho smolts emigrating from above Buckley dam were estimated to be 87,810 smolts based on the number of females passed above Buckley Dam in 2013 (5,854/2 = 2,927) multiplied by 30 smolts per female. Ten to thirty smolts per female is a survival that might be expected in system where spawner escapement fully seeded the watershed (Figure 1).

Nisqually River

A total of 132,000 coho smolts (rounded from 131,756) are estimated to have emigrated from the Nisqually River in 2015 (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 118,580 (±17,714 95% C.I.) smolts. This production was a decrease of 25% from the long-term average of 158,143 smolts between the 2009 and 2015 ocean entry years (Figure 12). This estimate was also 103% of the 115,554 smolt potential predicted by Zillges (1977). Total smolts above and below the trap were estimated to be 131,756 assuming that 10% of coho rearing occurred below the trap.

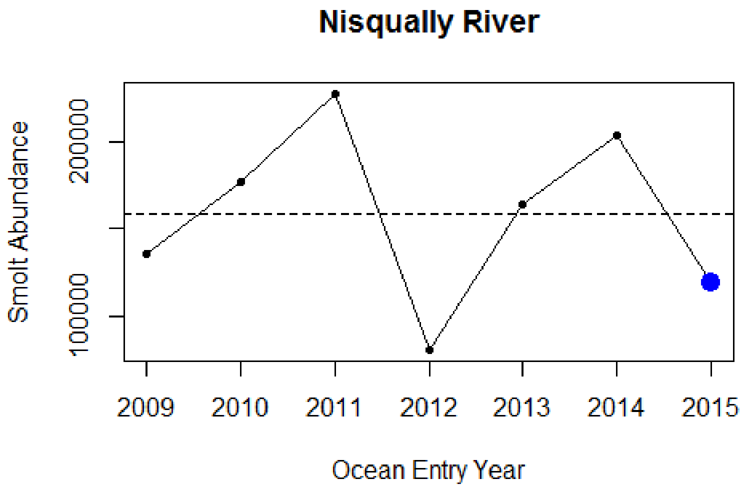

Figure 12. Time series of natural-origin coho smolts from the Nisqually River, ocean entry years 2009 to 2015. Blue point represents current year outmigration. Horizontal lines are the time series average.

Deschutes River

A total of 1,400 natural-origin coho smolts (rounded from 1,363) are estimated to have emigrated from the Deschutes River in 2015 (Table 1). This estimate is based on catch of coho smolts in a juvenile trap operated below Tumwater Falls. A catch of 263 smolts was expanded by a trap efficiency of 19.3%. An additional 860 ad-clipped coho smolts were estimated in the outmigration. These coho do not contribute to this forecast, but are the result of the 100K fry planted in summer of 2014 in an attempt to increase the numbers of spawners returning to the Deschutes River.

The 2015 production represents a decrease of 97% from the long-term average of 44,125 smolts between the 1979 and 2015 ocean entry years (Figure 13) and was just 0.6% (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 14), which has been severely depressed over the past two decades. Two of the three brood lines are virtually extinct. For the 2013 brood, 49 females (20 natural-origin, and 29 hatchery-origin) returned and were released upstream of Tumwater Falls to spawn. Freshwater productivity from this spawner escapement was 28 smolts/female, much lower than productivity expected from typical density-dependent freshwater relationships for coho salmon (Figure 2).

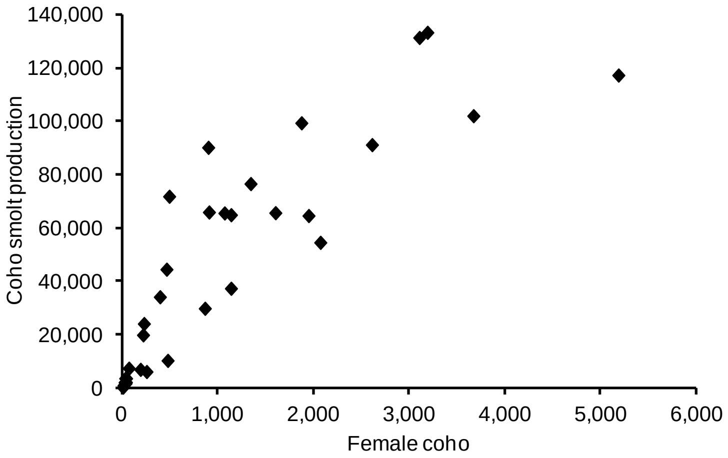

Figure 14. Coho smolt production as a function of female spawners in the Deschutes River, Washington, brood year 1978-2010.

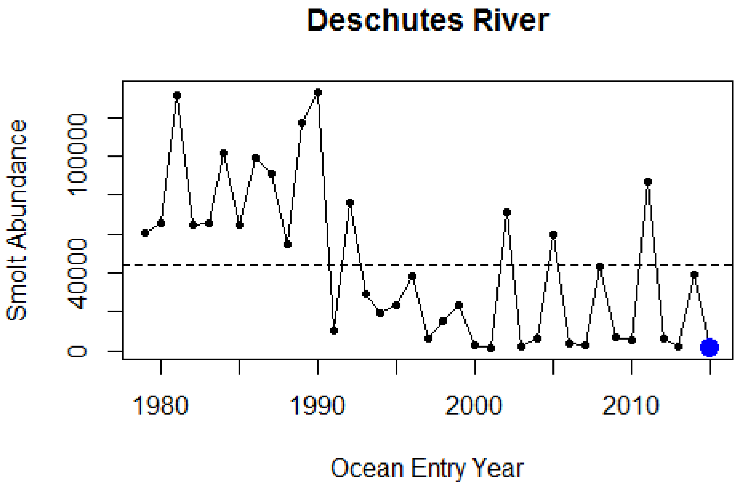

Figure 13. Time series of natural-origin coho smolts from the Deschutes River, ocean entry years 1979 to 2015. Blue point represents current year outmigration. Horizontal lines are the time series average.

South Sound

A total of 128,000 coho smolts are estimated to have emigrated from South Sound tributaries in 2015 (Table 1). This estimate was based on results of smolt monitoring in Cranberry, Mill, Skookum, and Goldsborough creeks conducted by the Squaxin Island Tribe (data provided by Daniel Kuntz, Natural Resources Department, Squaxin Island Tribe). Natural-origin coho smolt estimate for Cranberry Creek was 142 smolts (0.7%), Mill Creek was 1,985 smolts (3.6%), Skookum Creek was 1,310 (4.5%), and Goldsborough Creek was 113,246 smolts (158.1%). Numbers in parentheses represent the proportion of the smolt potential observed (Zillges 1977), which averaged 61.7% when Goldsborough Creek was included but just 2.9% of production potential if Goldsborough Creek numbers were not included. Coho smolt production from Goldsborough Creek in 2015 was a three-fold increase (300%) over the long-term average of 27,870 smolts between 1999 and 2014 ocean entry years. One potential explanation for this increase is a culvert removal on Midway Creek coupled with large wood debris placements that occurred concurrent with the spawning and rearing of the 2015 outmigration year. 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 when the creeks were 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. While promising, the large increase in smolt production from Goldsborough Creek is only one portion of this variability and is not likely to represent current conditions in many of the small creeks in this management unit. Therefore, the 2015 coho production was estimated in two steps – smolt estimate for Goldsborough Creek (113,246) 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 14,562, which was 2.9% applied to the Zillges production potential of 502,142 smolts for these watersheds. The rate of 2.9% represented the 2015 proportion of the overall production potential observed in Cranberry, Mill, and Skookum creeks. Coho production for the entire South Sound management unit was estimated to be 128,000 smolts (127,808 = 113,246 + 14,562), which is 22.2% 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, rivers are low gradient with rain-fed rivers that drain into Grays Harbor and Willapa Bay. 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, is typically higher than high-gradient watersheds, such as the Clearwater (Queets tributary) or Bogachiel (Quillayute tributary) rivers.

In 2015, WDFW operated a juvenile trap to estimate wild coho smolt abundance in the Chehalis River (Grays Harbor management unit). Smolt abundance in the Queets River management unit was available due to a juvenile monitoring program conducted by the Quinault Tribe. 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 2015, 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/mi2		
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)	34	69,294	27,314	134,052	495	195	958
Queets (no Clearwater)	32	198,422	53,473	352,694	640	172	1,138
Chehalis (Grays Harbor)	32	2,084,025	502,918	3,769,789	986	238	1,783

Queets River

A total of 156,000 (rounded from 155,936) wild coho smolts (347 smolts/mi^2) are estimated to have emigrated from the entire Queets River watershed in 2015 (Table 1). This estimate was based on coho smolt data collected and analyzed by the Quinault Tribe (Tyler Jurasin, Quinault Tribe, personal communication) and includes smolts from the Clearwater River. Smolt abundance from the Clearwater River alone was estimated to be 32,297 wild coho smolts (231 smolts/mi^2).

Quillayute River

A total of 162,000 coho smolts are estimated to have emigrated from the Quillayute River system in 2015 (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 2015.

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 2015 Quillayute coho production was based on previously measured smolt abundance adjusted by the ratio of current-year to previously measured smolt abundance in the Clearwater River. An expansion factor of 0.53 was the ratio of Clearwater River production in 2015 (32,297 smolts) to average Clearwater River production in 1992-1994 (32,297/61,000 = 0.53). Because historical smolt densities differed between the Dickey and Bogachiel rivers, separate estimates were developed for two portions of the Quillayute River watershed. The 2015 coho smolt abundance in the Dickey River was estimated to be 46,822 smolts (0.53*88,344 smolts). The 2015 coho smolt abundance in the Quillayute (excluding the Dickey) was estimated to be 115,146 smolts (0.53*217,257 smolts). The total 2015 coho production of 162,000 smolts was the rounded sum of these estimates (46,822 + 115,146 = 161,968).

Hoh River

A total of 69,000 wild coho smolts are estimated to have emigrated from the Hoh River in 2015 (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 231 smolts/mi^2 from the Clearwater River was applied to the 299-mi^2 of the Hoh watershed and resulted in an estimated 69,000 smolts (rounded from 69,069) from the Hoh River system.

Quinault River

A total of 130,000 wild coho smolts are estimated to have emigrated from the Quinault River in 2015 (Table 1). Smolt abundance was not directly measured in this watershed; therefore, the estimate was based on smolt densities in the Queets River system. When compared with the Queets River, coho production rates in the Quinault River are likely limited by additional factors such as higher harvest rates (i.e., low escapement) and degraded habitat. In 2015, a production rate of 300 smolts/mi^2 was applied to the 434-mi^2 Quinault River system, resulting in an estimated 130,000 smolts (rounded from 130,200).

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 2015, 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 3,468,000 wild coho smolts are predicted to have emigrated from the Grays Harbor system in 2015 (Table 1). This estimate was derived in two steps. Wild coho production was first estimated for the Chehalis River (n = 2,875,301). Smolt abundance per unit watershed area of the Chehalis River system was then applied to the southern tributaries (n = 252,960, Hoquaim, Johns, and Elk rivers) and northern tributaries (n = 340,000, Humptulips) to Grays Harbor.

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 in 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 Tribe, 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 using 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 and existing models are statistically weak. The flow model including incubation and rearing flows as predictive variables has been used in recent years and has generated modeled smolt estimates that are reasonably close to the mark-recapture smolt estimate (Figure 15). Based on the flow model, coho smolt production used for the previous year's forecast (2014 outmigation, 2015 forecast) was 2.7 million smolts. Based on the back-calculation of tagged to untagged coho returning in the terminal fishery in 2015, the coho smolt production in 2014 was 2.6 million smolts. Because the terminal fishery was closed for six weeks in fall of 2015 due to concerns over low coho returns, this back-calculated estimate may be biased because the fish were not sampled representatively to their return timing and therefore the success of the model in predicting smolt production should be interpreted with caution.

The 2015 coho smolts were associated with maximum incubation flows of 14,400 cfs and average August rearing flows of 270 cfs. The 2015 smolt production was predicted to be 2,875,301 based on a multiple regression model including these two variables.

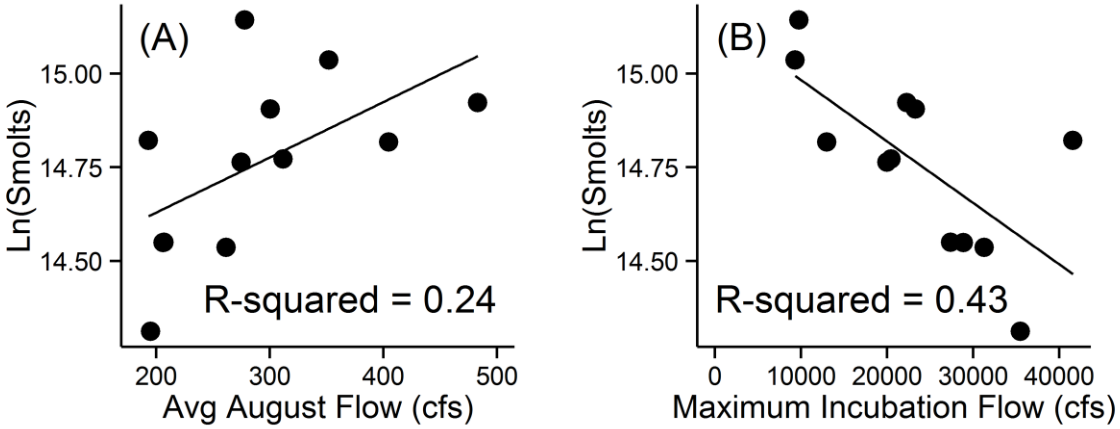

Figure 15. Chehalis River wild coho smolt production as a function of incubation flows (a) and summer rearing flows (b), ocean entry year 2000-2014. Incubation flows are the maximum daily mean flow between December 15 and March 1. Summer rearing flows are average flows during the month of August (USGS gage #12027500, Grand Mound). Three data points were removed (OEY 2000, 20004, 2006) because of high leverage on the incubation flow regression.

Coho smolt abundance in other portions of the Grays Harbor management unit was estimated from the smolt densities for the Chehalis River basin. Abundance per unit area for the Chehalis basin including the Wishkah River was 1,360 smolts/mi^2 (2,875,301 smolts per 2,114 mi^2). A total of 252,960 coho smolts are estimated for the southern tributaries of Grays Harbor (1,360 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 340,000 smolts (1,360 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 3,468,000 smolts (2,875,301 + 252,960 + 340,000 = 3,468,261).

Willapa Bay

A total of 723,000 coho smolts are estimated to have emigrated from the Willapa Bay basin in 2014 (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. Willapa Bay has a presumed high harvest rates (limiting escapement) and somewhat degraded freshwater habitat. Given these impacts, wild coho smolt densities are likely to be somewhat lower than observed in the Chehalis Basin. Wild coho production in 2015 (723,000 smolts) was calculated by applying 850 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. Densities in monitored watersheds (smolts per watershed area) were used to estimate smolt abundance from non-monitored systems. The associated between coho salmon smolt abundance and watershed size is recognized in the peer-reviewed literature (Bradford et al. 2000) as well as observed in statewide WDFW monitoring programs. 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 2015, 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, Tilton River, Upper Cowlitz, Coweeman River, and Cedar Creek.

The smolt monitoring sites were not randomly selected but are believed to be representative of coho production in the Washington portion of the 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 23 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 Cowlitz, and Tilton River, 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. Cedar Creek, also monitored in 2015, was 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 23 mi^2 and a preliminary 2015 estimate of 4,264 natural-origin coho smolts, the coho smolt density was estimated to be 164 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 2015 coho smolt density from these watersheds ranged between 164 and 420 smolts/mi^2 (Table 4). A total of 21,742 natural-origin coho smolts were estimated to have emigrated from all three watersheds in 2015 (Table 5). This included 12,168 smolts from Mill Creek, 5,795 smolts from Abernathy Creek, and 3,779 smolts from Germany Creek.

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 [29,039 = 28,627 yearlings + 412 2-year olds] plus the number estimated to pass through the turbine [3,773 = 32,812 - 29,039] multiplied by an assumed 85% survival [32,246 = 29,039 + 3,773*0.85].

Based on a watershed area of 159 mi^2 and a preliminary 2015 estimate of 32,246 natural-origin smolts emigrating from the Tilton River, coho smolt density was estimated to be 206 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 208,166 smolts produced above Cowlitz Falls, coho smolt density of the Upper Cowlitz River was estimated to be 200 smolts/mi^2 in 2015 (Table 4). The total number of natural-origin coho emigrating from the Upper Cowlitz was the 177,189 smolts captured at Cowlitz Falls Dam and trucked to 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 2015 smolt estimate of 44,141 smolts, coho smolt density from the Coweeman River was estimated to be 371 smolts/mi^2 (Table 4 and Table 5).

Cedar Creek

Coho smolt production from Cedar Creek, a tributary to the NF Lewis, was monitored with a juvenile trap located at river mile 2. The outmigration was estimated to be 33,137 (±2,107 95% C.I.) smolts (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 was estimated to be 625 smolts/mi^2 (Table 4). Cedar Creek coho smolt densities are consistently higher than other Lower Columbia watersheds. These 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.

Wind River

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

Non-monitored “Hatchery” Watersheds

Coho smolt production from non-monitored “hatchery” watersheds was estimated to be 152,889 (131.566 – 174,212 95% C.I.) smolts (Table 5). This estimate was derived from an average smolt production density of 190 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 178,987 (147,075 – 210,899 95% C.I.) smolts (Table 5). This estimate was derived from an average smolt production density of 289 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, 645,000 natural-origin coho smolts (rounded from 644,583) are estimated to have emigrated from the Washington Lower Columbia region in 2015 (Table 1). The 95% confidence intervals for this estimate range between 366,466 and 503,838 smolts. On average, watersheds without hatchery production were slightly higher than the 8-year average and watersheds with hatchery production were slightly lower than the 8-year average (Figure 16). 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.

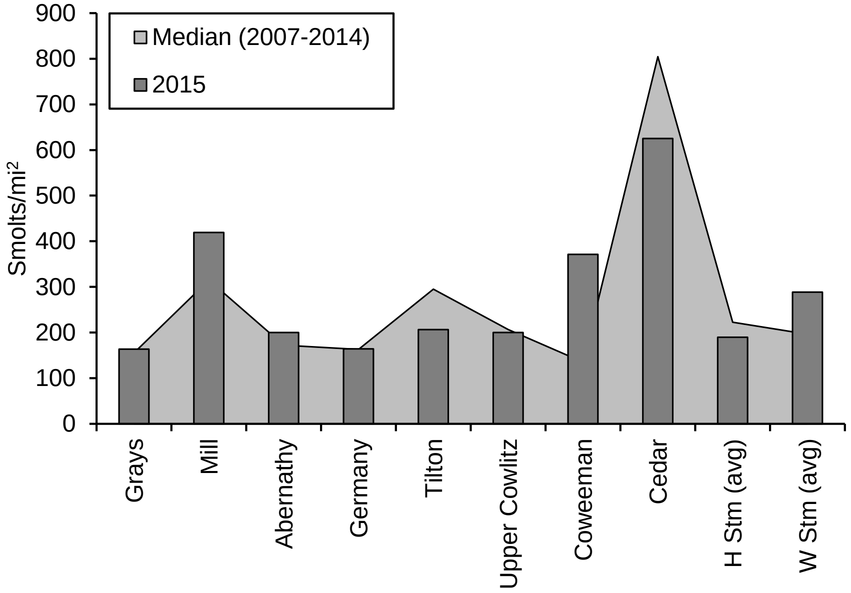

Figure 16. Coho smolt densities (smolts per mile-squared of watershed area) in eight Lower Columbia tributaries in Washington State. Graphs shows the 2015 density (bars) relative to the average smolt abundance from these watersheds (2007-2015).

Table 4. Smolt densities in 2015 from monitored coho salmon streams in the Lower Columbia River ESU. Estimates with asterisks (*) are preliminary and subject to revision.

	Density		
Watersheds	N/mi^2	95% Low	95% High
Grays (*)	163.6	95.0	232.2
Mill	419.5	335.0	504.0
Abernathy	199.9	146.2	253.5
Germany	164.3	159.1	169.5
Tilton	206.4	201.7	211.1
Upper Cowlitz	199.8	193.6	206.0
Coweeman (*)	371.1	308.6	433.5
Cedar (*)	625.2	585.4	664.9
Average Hatchery Streams	189.9	163.4	216.4
Average Wild Streams	288.7	237.2	340.2

Table 5. Coho smolt emigrants in 2015 from the Lower Columbia Evolutionary Significant Unit including monitored streams, non-monitored streams with hatcheries, and non-monitored streams without hatcheries. Estimates with asterisks (*) are preliminary and subject to revision.

Watersheds	N	95% Low	95% High
Grays (*)	4,254	2,471	6,037
Mill	12,168	9,717	14,619
Abernathy	5,795	4,239	7,351
Germany	3,779	3,659	3,899
Tilton	32,243	---	---
Upper Cowlitz	177,189	---	---
Coweeman (*)	44,143	36,710	51,576
Cedar (*)	33,137	31,030	35,244
Non-monitored Hatchery Streams	152,889	131,566	174,212
Non-monitored Wild Streams	178,987	147,075	210,899
Total Smolt Emigration	644,583	366,466	503,838

Marine Survival

Approach

Sibling regressions are a common forecasting tool and were used to predict marine survival in wild coho forecasts produced by WDFW Fish Science since 1996 (Seiler 1996; Zimmerman 2011). Indeed, 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, Bill Peterson and colleagues) and through the Salish Sea Marine Survival project facilitated by Long Live the Kings. Since 2012, forecasts were developed using ecosystem indicators as predictors of marine survival (Zimmerman 2012; Zimmerman 2013; Zimmerman 2014), updating the previous approach based on jack:adult return ratios (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 nine wild coho populations – six in Puget Sound, one in the Strait of Juan de Fuca, one in coastal Washington, and one in the Lower Columbia. Four of the monitored populations (Big Beef Creek, Baker River, Deschutes River, Bingham Creek) are part of the long-term wild coho monitoring program conducted by WDFW Fish Science Division. Marine survival for the remaining five populations (Green/Duwamish, Snohomish River, Strait of Juan de Fuca, Cowlitz River) were calculated 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.

Marine survival for wild populations included in WDFW's long-term coho monitoring program (Big Beef Creek [Hood Canal MU], Baker River [Skagit MU], Deschutes River [Deschutes MU], Bingham Creek [Grays Harbor MU]) was estimated based on the release and recovery of coded-wire tagged coho. 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 (WSPE, 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/).

Identifying an appropriate data source for the MUs in the Puget Sound central basin (Lake Washington, Green River, East Kitsap) has been problematic due to the lack of a life cycle monitoring program for wild coho salmon in watersheds of this sub-basin. The marine survival estimate used for the Lake Washington, Green River, and East Kitsap MUs is based coded-wire tagged coho from Soos Creek hatchery (smolts/[harvest + escapement]). This estimate is likely to be biased low compared to wild coho marine survival. 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.

Marine survival estimate for the Snohomish MU was directly measured using coded-wire tags for brood year 1976 through 1984. For brood year 1985 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).

A time series for natural-origin coho marine survival in the lower Columbia River is from the Cowlitz River. From the 2001 to 2010 ocean entry years, natural coho smolts from the Tilton River were coded-wire tagged prior to outmigration. From the 2012 to 2015 ocean entry years, natural coho smolts from the Upper Cowlitz 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

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 in the Strait of Juan de Fuca (SJDF), physical and biological data from Admiralty Inlet, and an upwelling index at 48N. SJDF 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 index 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.

"Local Scale" variables were explored 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. 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 May, 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. MWMP data from the month of June were not explored as indicators because they would not be available for forecasting predictions made in the month of January. Two additional local variables, river flow (or freshwater inputs) and pink salmon abundance, were also explored as potential indicators. River flows were obtained from the largest river in each sub-basin based on USGS stream flow gages (Appendix C). Pink salmon spawner escapement in the largest river in each sub-basin was used as an index of juvenile pink salmon in the early marine environment the following year.

Statistical Analyses

Linear regression models were used to examine the relationships between marine survival for each population and the variables identified in Appendix C. Linear models were fit using a beta distribution (range 0,1) appropriate for modeling survival data. The analysis was limited to outmigration years 1998 - 2014 to align survival estimates with available 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. Statistically significant individual predictors ($\alpha = 0.05$) were combined into a multiple regression model. When correlations among variables were high ($R > 0.8$), only one of the correlated variables was used in the multiple regression. A backwards stepwise regression process compared nested models (one model compared to the same model with one variable missing) using a likelihood ratio test until the inclusion of all variables significantly improved the prediction of marine survival. Marine survival applied to each MU was based on the multiple regression prediction for the monitored population in that MU. All analyses were completed in the R platform (R Core Team 2014).

Skagit, Strait of Georgia, Samish, and Nooksack Management Units

Marine survival of wild coho from the Baker River was used to represent the Skagit, Nooksack, Strait of Georgia, and Samish management units. Marine survival of wild coho from the Baker River has averaged 7.4% (range 1.1% to 13.9%) between ocean entry years 1991 and 2014 with a declining trend over this time period (Figure 17).

Six of the eighteen ecosystem variables examined were potentially useful indicators of wild coho salmon marine survival in the Skagit River management unit (Table 6). These potential indicators represented ocean, regional, and local scales. At the ocean scale, the NPGO index from January to March during ocean entry explained 35% of the variation and the NPGO index from May to September during ocean entry explained 52% of the variation in marine survival. A higher NPGO index was associated with higher marine survival. The El Nino index (ONI) explained 13% and the PDO index from May to September of ocean entry explained 31% of the variation in marine survival. Higher values of the ONI and PDO indices were associated with lower marine survival. At the regional scale, chlorophyll densities at Admiralty Inlet explained 37% of the variation in marine survival. At the local scale, chlorophyll densities explained 31% of the variation in marine survival. Interestingly, higher chlorophyll densities at the regional scale (Admiralty Inlet) were associated with lower marine survival but higher chlorophyll densities at the local scale (SAR003 buoy) were associated with higher marine survival.

The final regression model includes one variables (NPGO May-September) and explained 52% of the variation in marine survival. Other variables were not included because they were highly correlated (*R* > 0.8) or because they did not add predictive capacity to the model based on likelihood ratio tests. The addition of other potential variables did not improve the predictive ability of the model. Unfortunately, May chlorophyll data for the 2015 ocean entry year were not available at the time of this forecast. The NPGO May-September index for ocean entry year 2015 predicted 1.8% marine survival for the 2016 return year (2015 ocean entry year). Based on these results, a 1.8% marine survival rate was applied to the Skagit management unit as well as the Nooksack, Strait of Georgia, and Samish management units (Table 1).

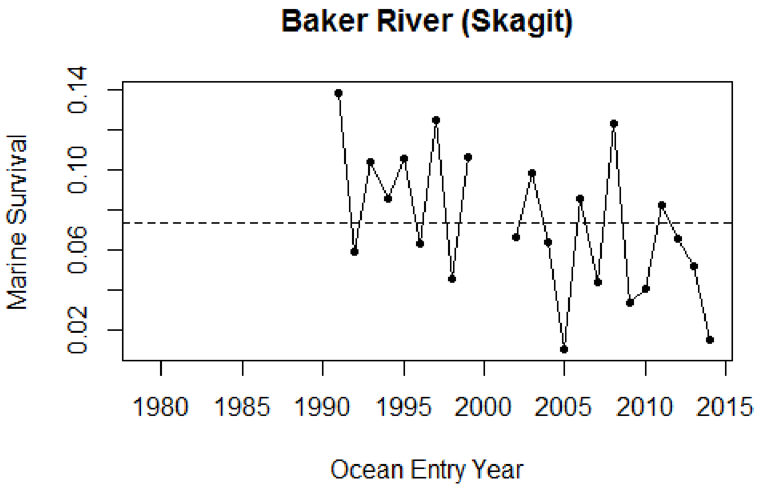

Figure 17. Marine survival of wild coho salmon from the Baker River (Skagit), ocean entry years 1991 to 2014 (excluding 2000 and 2001 when no monitoring was conducted). 2014 survival is preliminary. Horizontal line is average marine survival.

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 13.2% (ranged 2.6% to 27.6%) between ocean entry years 1978 and 2014 with a declining trend over this time period (Figure 18).

Four of the eighteen ecosystem variables examined were potentially useful indicators of wild coho salmon marine survival in the Snohomish River management unit (Table 7). These potential indicators represented ocean and regional scales. At the ocean scale, the average NPGO from January to March prior to ocean entry and May to September during ocean entry explained 44% and 42% of the variation in marine survival respectively. This indices were highly correlated with each other ($R = 0.86$) and a higher NPGO value was associated with higher marine survival. The PDO index between May and September of the ocean entry year explained 22% of the variation in marine survival. Higher PDO values were associated with lower marine survival. At the regional scale, sea surface salinity at the Race Rocks lighthouse in the Strait of Juan de Fuca explained just 20% of the variation in marine survival. Higher salinity was associated with higher survival.

The final regression model including NPGO (January to March) and explained 44% of the variation in marine survival. Other variables were not included because they were highly correlated ($R > 0.8$) or because they did not add predictive capacity to the model based on likelihood ratio tests. The NPGO indicator predicted 3.9% marine survival for the 2016 return year (2015 ocean entry year). Based on these results, a 3.9% marine survival (average of the two NPGO predictions) was applied to the Snohomish and Stillaguamish management units (Table 1).

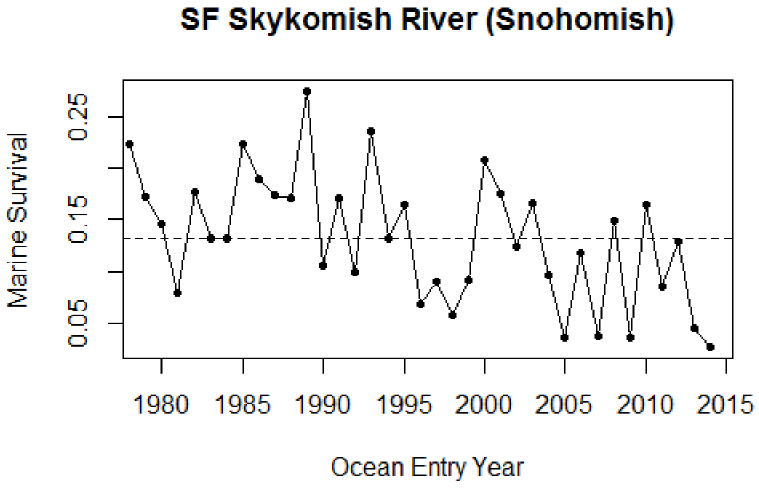

Figure 18. Marine survival of wild coho salmon in the SF Skykomish River, ocean entry year 1978 to 2014. 2013 and 2014 estimates are preliminary. Horizontal line is average survival.

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 ranged between 1.1% and 16.8% between the 1977 and 2012 ocean entry years with a declining trend over this time period (Figure 19).

Four of the eighteen ecosystem variables examined were potentially useful indicators of hatchery coho salmon marine survival in the Green River management unit (Table 8). These potential indicators represented ocean and regional scales. At the ocean scale, the average PDO from December to March prior to ocean entry explained 51% of the variation in marine survival. A higher PDO value was associated with higher marine survival (opposite the pattern observed for juveniles outside of Puget Sound). At the regional scale, light transmission, chlorophyll densities, and temperature at the Admiralty Inlet buoy explained 32% and 39% of the variation in marine survival respectively. More light transmission (clearer water) was associated with lower survival. Higher chlorophyll concentrations were associated with higher survival. Warmer temperatures were associated with lower survival. The three regional indices were highly correlated with each other (*R* > 0.80).

The final multiple regression model included PDO (December to March) and light transmission in Admiralty Inlet and explained 62% of the variation in marine survival. Other variables were not included because they were highly correlated (*R* > 0.8). The multiple regression model predicted a marine survival of 6.0% (3.1% to 10.2%) for the 2016 return year (2015 ocean entry year). These results did not include the 2001 ocean entry year which had exceptionally low marine survival (0.9%) and was an outlier in all analyses. Based on these results, a marine survival rate of 6.0% was applied to the Lake Washington, Green River, Puyallup, and East Kitsap MUs (Table 1).

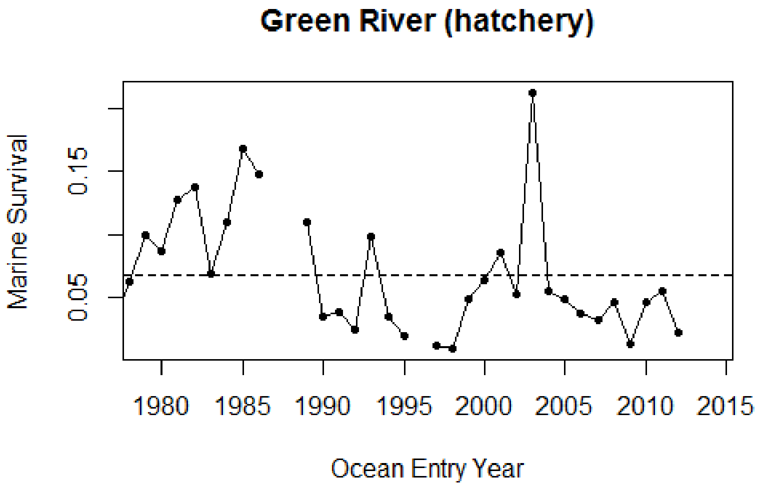

Figure 19. Marine survival of hatchery coho salmon released from Soos Creek hatchery in the Green River, ocean entry year 1977 to 2012. Data missing for 1996 ocean entry year as fish were released early due to a flood. CWT data are not yet available for the 2013 ocean entry year.

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 13.6% (ranged 1.9 to 29.5%) between ocean entry year 1979 and 2014 with a declining trend over time (Figure 20). Since the mid-1990s, two of the three brood classes of coho in the Deschutes River have been severely depressed and not enough smolts are captured in the low brood years to warrant a CWT release group. This has led to gaps in marine survival estimates in recent years.

Four of the eighteen ecosystem variables examined were potentially useful indicators of natural coho salmon marine survival in the Deschutes River management unit (Table 9). These potential indicators represented ocean and regional scales, which was surprising given that this sub-basin is the most geographically distant from the open ocean waters. At the ocean scale, the average PDO from December to March prior to ocean entry and May to September the year of ocean entry explained 59% and 81% of the variation in marine survival respectively. Higher marine survival was associated with a lower PDO value. The NPGO index between May and September of ocean entry explained 68% of the variation in marine survival. Higher survival was associated with a higher NPGO value. At the regional scale, the upwelling anomaly (48 N) between April and June explained 67% of the variation in marine survival. Higher survival was associated with more upwelling. In addition, the sea surface temperature at Race Rocks (Strait of Juan de Fuca) explained 40% of the variation in marine survival. Higher survival was associated with lower temperatures. All of the ocean and regional scale indices were highly correlated with each other (*R* > 0.80).

The final regression model included PDO index in May to September of the ocean entry and explained 81% of the variation in marine survival. The regression model using PDO (May to September of ocean entry) predicted a 3.4% marine survival. Other variables were not included because they were highly correlated (*R* > 0.8). Based on these results, a 3.4% marine survival (average of the PDO and NPGO predictions) was also applied to the South Sound and Nisqually MUs which share the same oceanographic basin as the Deschutes River (Table 1).

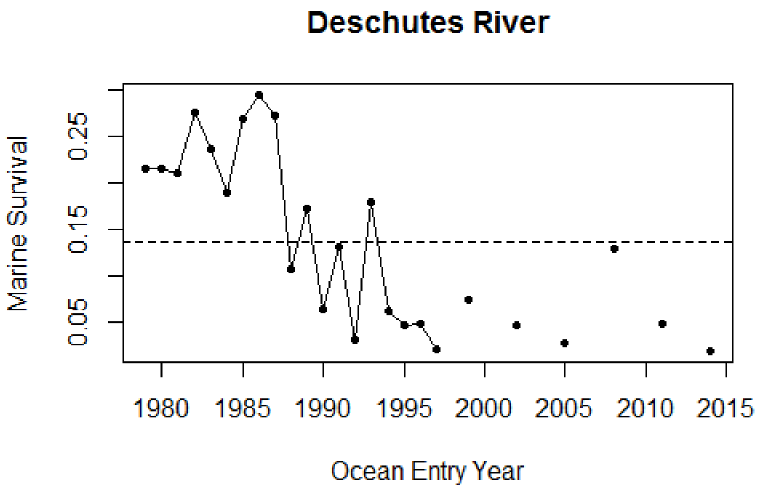

Figure 20. Marine survival of Deschutes River natural coho salmon, ocean entry years 1979 to 2014. 2014 results are preliminary. Since 1998, marine survival estimates are only available for every third year due to too few smolts to tag on the alternate years.

Hood Canal Management Unit

Marine survival in the Hood Canal management unit is measured at Big Beef Creek, a watershed draining westward from the Kitsap peninsula. Marine survival of wild coho in Big Beef Creek (Hood Canal Management Unit) has averaged 14% (range 2% to 32%) between ocean entry year 1977 and 2014 with a declining trend over this time period (Figure 21).

Four of the eighteen ecosystem variables examined were potentially useful indicators of wild coho salmon marine survival in Big Beef Creek (Table 10). These potential indicators represented ocean, regional, and local scales. At the ocean scale, the average NPGO from January to March prior to ocean entry and the average NPGO from May to September during ocean entry explained 30% and 31% of the variation in marine survival respectively. These indicator variables were highly correlated with each other (R = 0.87) and a higher NPGO value was associated with higher survival. At the regional scale, average sea surface salinity at Race Rocks lighthouse between April and June explained 47% of the variation in marine survival. Higher salinity was associated with higher survival. And at the local scale, jack return rates explained 32% of the variation in marine survival. Higher jack return rates were associated with higher survival. Light transmission at the Hood Canal buoy in April and May has been a significant local predictor in past years, but this relationship did remained a stable predictor over time.

The final multiple regression model included NPGO (January to March) and sea surface temperature at Race Rocks lighthouse and explained 66% of the variation in marine survival. Other variables were not included because they were highly correlated (*R* > 0.8) or because they did not add predictive capacity to the model based on likelihood ratio tests. The multiple regression model predicted a 2.8% (0.7% to 7.1%, 95% C.I.) marine survival for the 2016 return year (2015 ocean entry year. This predictive model did not include the 2003 ocean entry year, which was an outlier in the regression. Including the 2003 ocean year in the multiple regression model predicted a marine survival of 3.1%. Based on these results, a 2.8% marine survival was applied to the entire Hood Canal management unit (Table 1).

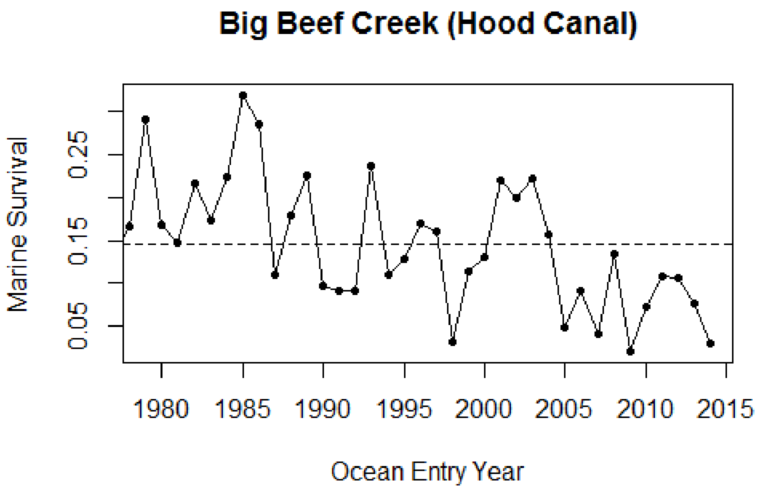

Figure 21. Marine survival of Big Beef Creek wild coho, ocean entry year 1977 to 2014. 2014 results are preliminary. Horizontal line represents average marine survival.

Strait of Juan de Fuca

Marine survival estimates for the Strait of Juan de Fuca were compiled by Hap Leon (Makah Tribe) and provided for the purpose of this forecast document. The estimates are based on smolt and spawner estimates at the scale of the management unit. Spawner estimates are expanded by the pre-terminal exploitation rate of hatchery coho coded-wire tag groups from the Elwha River. Marine survival of wild coho salmon in the Juan de Fuca management unit has averaged 5.3% (range 0.9% to 9.2%) between ocean entry year 1998 and 2012 (Figure 22).

Six of the twenty ecosystem variables examined were potentially useful indicators of wild coho salmon marine survival in the Strait of Juan de Fuca (Table 11). These potential indicators represented ocean and regional scales. At the ocean scale, the average NPGO from January to March prior to ocean entry and May to September during ocean entry explained 63% and 32% of the variation in marine survival respectively. A higher NPGO value was associated with higher survival. At the regional scale, juvenile coho CPUE in September, copepod richness, southern copepod biomass, and copepod community structure index explained 19% to 21% of the variation in marine survival. Higher survival was associated with higher juvenile coho CPUE (September), lower copepod richness, lower southern copepod biomass and a lower value of the copepod community index. Juvenile coho CPUE (September) values were not available as predictors for the 2015 ocean entry year

The multiple regression model including NPGO (January to March prior to ocean entry) and copepod richness explained 62.5% of the variation in marine survival. Other variables were not included because they were highly correlated (R > 0.8) or because they did not add predictive capacity to the model based on likelihood ratio tests. 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 2015 ocean entry year. The regression model predicted a 1.9% (0.8% to 3.7%, 95% C.I.) marine survival for the 2016 return year (2015 ocean entry year). If 2007 was included in the data set to develop the multiple regression model, the predicted marine survival would have been 1.6%. Based on these results, a 1.9% marine survival was applied to the Juan de Fuca management unit (Table 1).

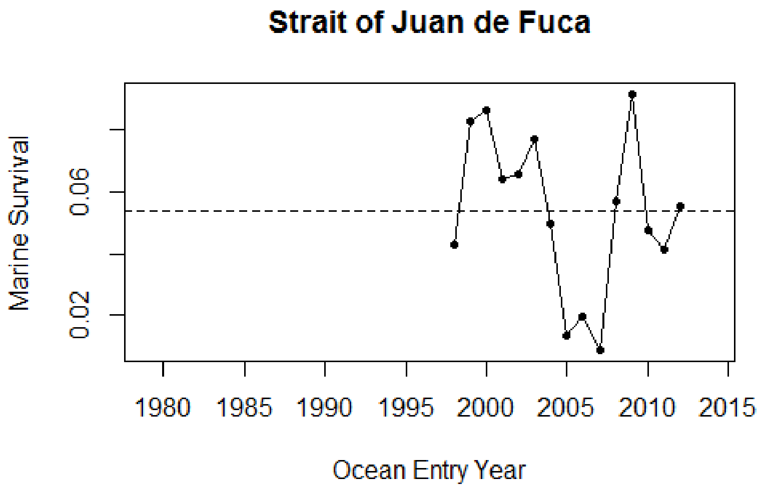

Figure 22. Marine survival of wild coho in the Strait of Juan de Fuca management unit, ocean entry year 1998 to 2012. Horizontal line represents average marine survival

Washington Coast

Marine survival of wild coho in the coastal Washington region is measured at Bingham Creek, a tributary to the East Fork Satsop River (a right bank tributary to the Chehalis River). Marine survival of Bingham Creek wild coho has averaged 4.6% (range 0.6% to 11.7%) between return year 1983 and 2015 with no apparent trend over this time period (Figure 23).

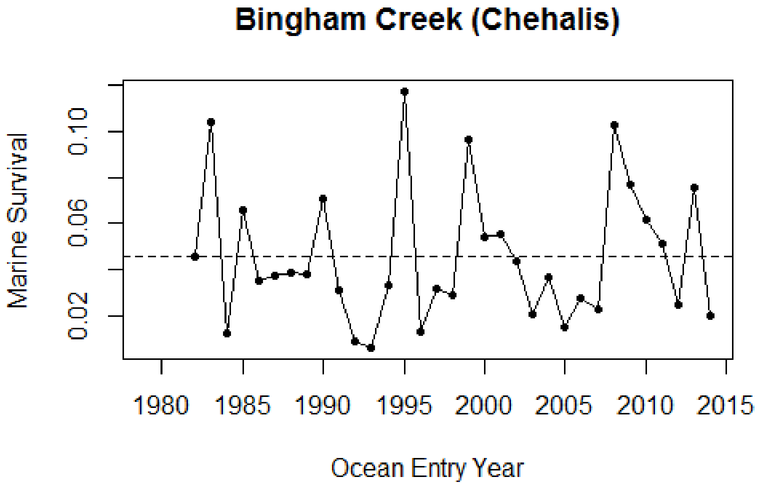

Figure 23. Marine survival of wild coho from Bingham Creek, Washington, ocean entry year 1982 to 2014. 2014 results are preliminary. Horizontal line represents average marine survival.

Thirteen of the twenty-four ecosystem variables examined were potentially useful indicators of wild coho salmon marine survival at Bingham Creek (Table 12). These potential indicators represented ocean, regional, and local scales but provided two very different outlooks on coho marine survival. Two regional scale variables, upwelling strength in April and May and winter ichthyoplankton densities, individually predicted a marine survival between 7% and 10%. The remaining variables predicted a marine survival between 1.3% and 4.6%. At the ocean scale, the average PDO (December to March and May to September), average ONI (January to June), and average NPGO (January to March and May to September) were significant predictors of marine survival and individually explained between 31% and 73% of this variation. Higher survival was associated with lower PDO and ONI values and higher NPGO values. At the regional scale, sea surface temperature, copepod richness, southern copepod biomass, copepod community structure, timing of the biological transition, winter ichthyoplankton, and juvenile Chinook catches in the month of June were significant predictors of marine survival and explained between 18% and 46% of the variation in marine survival. Because the biological transition never occurred in ocean entry year 2015, this variable was not useful as a predictor in further analyses. At the local scale, higher survival was associated with higher jack return rates, which explained just 19% of the variation in marine survival.

The final multiple regression model used to predict marine survival included PDO (May to September), upwelling anomaly, and winter ichthyoplankton. Other variables were not included because they were highly correlated (R > 0.8) or because they did not add predictive capacity to the model based on likelihood ratio tests. The multiple regression model explained 79% of the variation in marine survival and predicted a 3.5% (2.1% to 5.5%, 95% C.I.) marine survival for the 2016 return year (2015 ocean entry year). A regression model based on PDO (May to September) alone explained 72.8%

of the variation in marine survival and predicted a 1.3% (0.4% to 2.9%) marine survival for the 2016 return year (2015 ocean entry year). Both models were developed after removing information from the 2012 ocean entry year, which was an outlier in the PDO regressions. In addition to the statistical model selection, the selection of a marine survival value for the forecast considered the conflicting predictions provided by two individual variables (upwelling, ichthyoplankton) and all other investigated variables. These differences were revealed by the dramatic changes to the ocean environment in the 2014 and 2015 ocean entry years and add uncertainty to the forecasting process. Based on this uncertainty, I have adopted the more conservative prediction of 1.3% marine survival to all management units in the coastal Washington region (Table 1).

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 4.1% (range 0.9% to 11.5%) between ocean entry year 2001 and 2014 (**Error! Reference source not found.**).

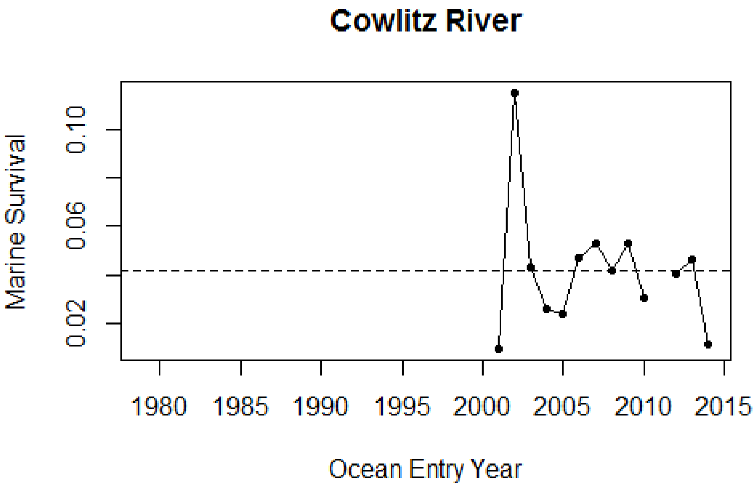

Figure 24. Marine survival of natural origin coho from the Upper Cowlitz River, ocean entry year 2001 to 2014 (excluding 2011). 2014 results are preliminary. Horizontal line is average value.

Three of the twenty-three ecosystem variables examined, all at the regional scale, were potentially useful indicators of natural coho salmon marine survival in the Cowlitz River (Table 13). Upwelling length explained 71% of the variation in marine survival. A longer period of upwelling resulted in higher survival. Temperature (May to September) in the upper 20 m at the NH05 buoy off Newport explained 59% of the variation in marine survival. Lower sea surface temperature resulted in higher survival. Timing of the spring transition explained 37% of the variation in marine survival. Earlier timing resulted in higher survival. 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).

A multiple regression model that included upwelling length and sea surface temperature (upper 20 m) at the NH05 buoy between May and September of the ocean entry year explained 81% of variation in marine survival. The 2001 ocean entry year was an outlier in the individual regressions and not used in the final analysis. Timing of spring transition was highly correlated with upwelling length (R = 0.79) and therefore not used in the multiple regression analysis. The final multiple regression predicted a 4.1% (2.8% to 5.7%, 95% C.I.) marine survival for the 2016 return year (2015 ocean entry year). If the 2001 ocean entry year was included in the multiple regression model the predicted marine survival was 3.7%. Based on these results, a marine survival of 4.1% was applied to the Lower Columbia region (Table 1).

Table 6. Marine indicators of wild coho marine survival from Baker River (Skagit management unit), Washington, ocean entry year 1991 to 2014. A pseudo R^2 value describes the relationship between each variable and marine survival fit with a linear regression and beta distribution. A final multiple regression model built from statistically significant correlations was used to predict marine survival predictions for the 2016 coho returns (2015 ocean entry year).

Indicator	R^2	*p*-value	2016 Predict
Ocean Scale			
PDO.Dec.March	---	*ns*	
PDO.May.Sept	0.31	0.005	4.3%
ONI.Jan.June	0.13	0.04	2.5%
NPGO.Jan.March	0.35	0.02	3.2%
NPGO.May.Sept	0.52	<0.001	1.9%
Regional Scale (Physical)			
Race Rocks SST AJ	---	*ns*	
Race Rocks SSS AJ	---	*ns*	
Upwelling 48° N Apr-Jun	---	*ns*	
Admiralty Temp 20 m Apr-May	---	*ns*	
Admiralty Salinity 20 m Apr-May	---	*ns*	
Regional Scale (Biological)			
Admiralty Chlorophyll 20 m Apr-May	0.37	0.009	3.4%
Admiralty Light Trans. 20 m Apr-May	---	*ns*	
Local Scale (Physical)			
Temp 20 m Apr-May	---	*ns*	
Salinity 20 m Apr-May	---	*ns*	
Flow Apr-June	---	*ns*	
Local Scale (Biological)			
Chlorophyll 20 m May	0.31	0.002	NA
Light Transmission 20 m May	---	*ns*	
Juvenile Pinks	---	*ns*	

Table 7. Marine indicators of wild coho marine survival from SF Skykomish River (Snohomish management unit), Washington, ocean entry years 1998 to 2014. A pseudo R^2 value describes the relationship between each variable and marine survival fit with a linear regression and beta distribution. A final multiple regression model built from statistically significant correlations was used to predict marine survival predictions for the 2016 coho returns (2015 ocean entry year).

Indicator	R^2	p-value	2016 Predict
Ocean Scale			
PDO.Dec.March	---	*ns*	---
PDO.May.September	0.21	0.04	7.2%
ONI.Jan.June	---	*ns*	---
NPGO.Jan.March	0.44	<0.001	3.9%
NPGO.May.Sept	0.42	<0.001	2.6%
Regional Scale (Physical)			
Upwelling 48° N Apr-Jun	---	*ns*	---
Race Rocks SSS Apr-Jun	0.20	0.03	6.7%
Race Rocks SST Apr-Jun	---	*ns*	---
Admiralty Salinity 20 m Apr-Jun	---	*ns*	---
Admiralty Temp 20 m Apr-Jun	---	*ns*	---
Regional Scale (Biological)			
Admiralty Chlorophyll 20 m May	---	*ns*	---
Local Scale (Physical)			
Salinity 20 m Apr-Jun	---	*ns*	---
Temp 20 m Apr-Jun	---	*ns*	---
River Flows Apr-Jun	---	*ns*	---
Local Scale (Biological)			
Chlorophyll 20 m May	---	*ns*	---
Light transmission May	---	*ns*	---
Pink Salmon abundance	---	*ns*	---

Table 8. Marine indicators of hatchery coho marine survival to Soos Creek hatchery in the Green River management unit, ocean entry years 1998 to 2012. A pseudo R^2 value describes the relationship between each variable and marine survival fit with a linear regression and beta distribution. A final multiple regression model built from statistically significant correlations was used to predict marine survival predictions for the 2016 coho returns (2015 ocean entry year).

Indicator	R^2	p-value	2016 Predict
Ocean Scale			
PDO.Dec.March	0.51	<0.001	7.4%
PDO.May.September	---	*ns*	---
ONI.Jan.June	---	*ns*	---
NPGO.Jan.March	---	*ns*	---
NPGO.May.Sept	---	*ns*	---
Regional Scale (Physical)			
Upwelling 48° N Apr-Jun	---	*ns*	---
Race Rocks SSS Apr-Jun	---	*ns*	---
Race Rocks SST Apr-Jun	---	*ns*	---
Admiralty Salinity 20 m Apr-Jun	---	*ns*	---
Admiralty Temp 20 m Apr-Jun	0.31	0.03	7.6%
Regional Scale (Biological)			
Admiralty Light 20 m May	0.39	0.01	9.5%
Admiralty Chlorophyll 20 m May	0.35	0.04	9.5%
Local Scale (Physical)			
Salinity 20 m Apr-Jun	---	*ns*	---
Temp 20 m Apr-Jun	---	*ns*	---
River Flows Apr-Jun	---	*ns*	---
Local Scale (Biological)			
Chlorophyll 20 m May	---	*ns*	---
Light transmission May	---	*ns*	---
Pink Salmon abundance	---	*ns*	---

Table 9. Marine indicators of natural coho marine survival from Deschutes River, ocean entry year 1990 to 2014. A pseudo R^2 value describes the relationship between each variable and marine survival fit with a linear regression and beta distribution. A final multiple regression model built from statistically significant correlations was used to predict marine survival predictions for the 2016 coho returns (2015 ocean entry year).

Indicator	R^2	p-value	2016 Predict
Ocean Scale			
PDO.Dec.March	0.59	0.03	2.5%
PDO.May.September	0.82	<0.001	3.4%
ONI.Jan.June	---	*ns*	---
NPGO.Jan.March	---	*ns*	---
NPGO.May.Sept	0.68	<0.001	1.4%
Regional Scale (Physical)			
Upwelling 48° N Apr-Jun	0.78	<0.001	NA
Race Rocks SSS Apr-Jun	---	*ns*	---
Race Rocks SST Apr-Jun	0.40	0.01	2.4%
Admiralty Salinity 20 m Apr-Jun	---	*ns*	---
AdmiraltyTemp 20 m Apr-Jun	---	*ns*	---
Regional Scale (Biological)			
Admiralty Light 20 m May	---	*ns*	---
Admiralty Chlorophyll 20 m May	---	*ns*	---
Local Scale (Physical)			
Salinity 20 m Apr-Jun	---	*ns*	---
Temp 20 m Apr-Jun	---	*ns*	---
River Flows Apr-Jun	---	*ns*	---
Local Scale (Biological)			
Chlorophyll 20 m May	---	*ns*	---
Light transmission May	---	*ns*	---
Pink Salmon abundance	---	*ns*	---

Table 10. Marine indicators of wild coho marine survival from Big Beef Creek (Hood Canal management unit), ocean entry year 1998 to 2014. A pseudo R^2 value describes the relationship between each variable and marine survival fit with a linear regression and beta distribution. A final multiple regression model built from statistically significant correlations was used to predict marine survival predictions for the 2016 coho returns (2015 ocean entry year).

Indicator	R^2	p-value	2016 Predict
Ocean Scale			
PDO.Dec.March	---	*ns*	--
PDO.May.September	---	*ns*	--
ONI.Jan.June	---	*ns*	--
NPGO.Jan.March	0.30	0.002	4.0%
NPGO.May.Sept	0.31	0.004	2.7%
Regional Scale (Physical)			
Upwelling 48° N Apr-Jun	---	*ns*	--
Race Rocks SSS Apr-Jun	0.47	<0.001	5.1%
Race Rocks SST Apr-Jun	---	*ns*	--
Admiralty Salinity 20 m Apr-Jun	---	*ns*	--
AdmiraltyTemp 20 m Apr-Jun	---	*ns*	--
Regional Scale (Biological)			
Admiralty Light 20 m May	---	*ns*	--
Admiralty Chlorophyll 20 m May	---	*ns*	--
Local Scale (Physical)			
Salinity 20 m Apr-Jun	---	*ns*	--
Temp 20 m Apr-Jun	---	*ns*	--
River Flows Apr-Jun	---	*ns*	--
Local Scale (Biological)			
Chlorophyll 20 m May	---	*ns*	--
Light transmission May	---	*ns*	--
Jack return rate	0.32	0.014	16.0%

Table 11. Marine indicators of wild coho marine survival from Strait of Juan de Fuca tributaries, Washington, ocean entry year 1998 to 2012. A pseudo R^2 value describes the relationship between each variable and marine survival fit with a linear regression and beta distribution. A final multiple regression model built from statistically significant correlations was used to predict marine survival predictions for the 2016 coho returns (2015 ocean entry year).

Indicator	R^2	p-value	2016 Predict
Ocean Scale			
PDO.Dec.March	---	*ns*	---
PDO.May.September	---	*ns*	---
ONI.Jan.June	---	*ns*	---
NPGO.Jan.March	0.63	<0.001	2.1%
NPGO.May.Sept	0.32	0.022	2.2%
Regional Scale (Physical)			
Race Rocks SSS Apr-Jun	---	*ns*	---
Race Rocks SST Apr-Jun	---	*ns*	---
Phys.Spr.Trans	---	*ns*	---
Upwell.April.May	---	*ns*	---
Upwell Length	---	*ns*	---
Fraser River Flows Apr-Jun	---	*ns*	---
Length.Upwell	---	*ns*	---
Regional Scale (Biological)			
Copepod.Rich.May.Sept	0.19	0.04	2.0%
N.Cop.May.Sept	---	*ns*	---
S.Cop.May.Sept	0.20	0.04	3.1%
Bio.Trans	---	*ns*	---
Winter.Ichth	---	*ns*	---
Chk.Juv.June	---	*ns*	---
Coho.Juv.Sept	0.21	0.009	NA
Cop.Comm.Structure	0.20	0.05	2.7%

Table 12. Marine indicators of wild coho marine survival from Bingham Creek (Grays Harbor management unit), Washington, ocean entry year 1998 to 2012. A pseudo R^2 value describes the relationship between each variable and marine survival fit with a linear regression and beta distribution. A final multiple regression model built from statistically significant correlations was used to predict marine survival predictions for the 2016 coho returns (2015 ocean entry year).

Indicator	R^2	p-value	2016 Predict
Ocean Scale			
PDO.Dec.March	0.43	0.001	1.5%
PDO.May.September	0.73	<0.001	1.3%
ONI.Jan.June	0.31	0.002	2.7%
NPGO.Jan.March	0.38	0.018	2.7%
NPGO.May.Sept	0.25	0.033	10.6%
Regional Scale (Physical)			
SST.46050.May.Sept	0.19	0.057	7.1%
NH.05.20.T.Nov.Mar	---	*ns*	---
NH.05.20.May.Sept	---	*ns*	---
NH05.Deep.Temp	---	*ns*	---
NH05.DeepSal	---	*ns*	---
Phys.Spr.Trans	---	*ns*	---
Upwell.April.May	---	*ns*	---
Length.Upwell	---	*ns*	---
NH05.SST.May.Sept	---	*ns*	---
Regional Scale (Biological)			
Copepod.Rich.May.Sept	0.33	0.01	1.6%
N.Cop.May.Sept	---	*ns*	---
S.Cop.May.Sept	0.40	0.002	2.2%
Bio.Trans	0.34	0.005	NA
Winter.Ichth	0.41	0.001	7.1%
Chk.Juv.June	0.44	<0.001	3.7%
Coho.Juv.Sept	---	*ns*	---
Cop.Comm.Structure	0.46	0.001	1.8%
Local Scale (Physical)			
River Flows Apr-Jun	---	*ns*	---
Local Scale (Biological)			
Jack Return Rate	0.19	0.03	4.6%

Table 13. Marine indicators of wild coho marine survival from Cowlitz River, Washington, ocean entry year 2001 to 2013. A pseudo R^2 value describes the relationship between each variable and marine survival fit with a linear regression and beta distribution. A final multiple regression model built from statistically significant correlations was used to predict marine survival predictions for the 2016 coho returns (2015 ocean entry year).

Indicator	R^2	p-value	2016 Predict
Ocean Scale			
PDO.Dec.March	---	*ns*	---
PDO.May.September	---	*ns*	---
ONI.Jan.June	---	*ns*	---
NPGO.Jan.March	---	*ns*	---
NPGO.May.Sept	---	*ns*	---
Regional Scale (Physical)			
SST.46050.May.Sept	---	*ns*	---
NH.05.20.T.Nov.Mar	---	*ns*	---
NH.05.20.May.Sept	0.59	0.02	4.2%
NH05.Deep.Temp	---	*ns*	---
NH05.DeepSal	---	*ns*	---
Phys.Spr.Trans	0.37	0.02	4.9%
Upwell.April.May	---	*ns*	---
Length.Upwell	0.71	0.02	4.0%
NH05.SST.May.Sept	---	*ns*	---
Regional Scale (Biological)			
Copepod.Rich.May.Sept	---	*ns*	---
N.Cop.May.Sept	---	*ns*	---
S.Cop.May.Sept	---	*ns*	---
Bio.Trans	---	*ns*	---
Winter.Ichth	---	*ns*	---
Chk.Juv.June	---	*ns*	---
Coho.Juv.Sept	---	*ns*	---
Cop.Comm.Structure	---	*ns*	---
Local Scale (Physical)			
River Flows Apr-Jun	---	*ns*	---

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. 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). 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.

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 occur 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 long-term average. This index was calculated based on flow data from 1967 to present (forecasts based on the discontinued Nooksack gage were based on flow data from 1963 to 2008). The PSSLFI was the sum of all eight watershed indices.

Based on flow data compiled between 1967 and 2013 (including alternate Nooksack gage), the PSSLFI has ranged between 4.3 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 2014 (corresponding to the 2015 outmigration and 2016 returning adults) had an index value of 7.99 or 100% of the long-term average.

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 wild coho salmon marine survival in Puget Sound, Coastal Washington, and Lower Columbia.

Scale /Type	Indicator	JDF	PUGET SOUND SKGT	SNOH	CENT	SSND	HC	COAST	LC	Data Source
O/P	PDO Dec-Mar	▨	▨	▨	▨	▨	▨	▨	▨	NOAA-NWFSC[1]
O/P	PDO May-Sept	▨	▨	▨	▨	▨	▨	▨	▨	NOAA-NWFSC[1]
O/P	ONI Jan-Jun	▨	▨	▨	▨	▨	▨	▨	▨	NOAA-NWFSC[1]
O/P	NPGO Jan-Mar	▨	▨	▨	▨	▨	▨	▨	▨	E. Di Lorenzo[2]
O/P	NPGO May-Sept	▨	▨	▨	▨	▨	▨	▨	▨	E. Di Lorenzo[2]
R/P	River Flow Apr-Jun	08MF005								Environment Canada[3]
R/P	Race Rocks SST Apr-Jun	▨	▨	▨	▨	▨	▨			DFO[4]
R/P	Race Rocks SSS Apr-Jun	▨	▨	▨	▨	▨	▨			DFO [4]
R/P	Upwelling 48° N Apr-Jun	▨	▨	▨	▨	▨	▨			NOAA-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								▨	NOAA-NWFSC[1]
R/P	NH05.Upper.20mT.NovMar								▨	NOAA-NWFSC[1]
R/P	NH05.Upper.20mT.MaySept								▨	NOAA-NWFSC[1]
R/P	NH05.DeepT.MaySept								▨	NOAA-NWFSC[1]
R/P	NH05DeepS.MaySept								▨	NOAA-NWFSC[1]
R/P	Phys. Spring Transition Date								▨	NOAA-NWFSC[1]
R/P	Upwelling Apr-May								▨	NOAA-NWFSC[1]
R/P	Length Upwelling								▨	NOAA-NWFSC[1]
R/P	SST NH05 Summer								▨	NOAA-NWFSC[1]
R/B	Copepod Richness May Sept								▨	NOAA-NWFSC[1]
R/B	N Copepod Biomass May Sept								▨	NOAA-NWFSC[1]
R/B	S Copepod Biomass May Sept								▨	NOAA-NWFSC[1]
R/B	Biological Transition								▨	NOAA-NWFSC[1]
R/B	Winter Ichthyoplankton								▨	NOAA-NWFSC[1]
R/B	June Chinook								▨	NOAA-NWFSC[1]
R/B	September Coho								▨	NOAA-NWFSC[1]
R/B	Copepod Community Struct								▨	NOAA-NWFSC[1]

L/P	River Flow Apr-Jun		12200500	12200500	12113000	12089500	12061500		USGS[6]
L/P	Temp 20 m Apr-Jun		SAR003	PSS019	PSB003	BUD005	HCB003		WA ECY-MWMP[7]
L/P	Salinity 20 m Apr-Jun		SAR003	PSS019	PSB003	BUD005	HCB003		WA ECY-MWMP[7]
L/B	Chlorophyl 20 m May		SAR003	PSS019	PSB003	BUD005	HCB003		WA ECY-MWMP[7]
L/B	Light transmission May		SAR003	PSS019	PSB003	BUD005	HCB003		WA ECY-MWMP[7]
L/B	Percent Jack Return								WDFW Fish Science

[1] Ocean indicator data for the Pacific coast continental shelf were from ocean monitoring program conducted by Bill Peterson and colleagues at the Northwest Fisheries Science Center in Newport, OR. Data and their descriptions are available at: http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/a-ecinhome.cfm

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

[3] Fraser River flows was daily average flow measured at Hope (08MF005) were obtained from Environment Canada. Data are available at: http://wateroffice.ec.gc.ca/search/searchRealTime_e.html

[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 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] 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 are available at http://www.ecy.wa.gov/apps/eap/marinewq/mwdataset.asp.

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