2014 Wild Coho Forecasts for Puget Sound, Washington Coast, and Lower Columbia

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by
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Introduction

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

Wild coho run sizes (adult ocean recruits) have been predicted using various approaches across Washington’s coho producing systems. Methods that rely on the relationship between adult escapement and resulting run sizes are problematic due to inaccurate escapement estimates and difficulty allocating catch in mixed stock fisheries. In addition, escapement-based coho forecasts often have no predictive value because watersheds become fully seeded at low spawner abundances (Bradford et al. 2000). Furthermore, different variables in the freshwater (Sharma and Hilborn 2001; Lawson et al. 2004) and marine environments (Nickelson 1986; Ryding and Skalski 1999; Logerwell et al. 2003) influence coho survival and recruitment to the next life stage. Therefore, the accuracy of coho run size forecasts 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 2014 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). December age-2 recruits, which have been included in this table in previous years, are not provided as they are no longer used by fisheries managers. The following sections describe the approach used to derive smolt production and predict marine survival.

Table 1. 2014 wild coho run forecast summary for Puget Sound, Coastal Washington, and Lower Columbia.

	Production X	**Marine Survival =**	**Recruits**	
Production Unit	**Estimated Smolts Spring 2012**	**Predicted Marine Survival**	**Adults (Age 3)**	**Jan. (Age 3)**
Puget Sound				
Primary Units				
Skagit River	1,409,000	7.0%	98,630	121,482
Stillaguamish River	237,000	11.0%	26,070	32,110
Snohomish River	750,000	11.0%	82,500	101,615
Hood Canal	490,000	10.0%	49,000	60,353
Straits of Juan de Fuca	**see note below**			
Secondary Units				
Nooksack River	158,000	7.0%	11,060	13,623
Strait of Georgia	18,000	7.0%	1,260	1,552
Samish River	33,000	7.0%	2,310	2,845
Lake Washington	109,000	6.0%	6,540	8,055
Green River	132,000	6.0%	7,920	9,755
East Kitsap	92,000	6.0%	5,520	6,799
Puyallup River	295,000	8.0%	23,600	29,068
Nisqually River	183,000	8.0%	14,640	18,032
Deschutes River	1,500	8.0%	120	148
South Sound	177,000	8.0%	14,160	17,441
Puget Sound Total	4,084,500		343,330	422,877
Coast				
Quillayute River	464,000	6.0%	27,840	34,290
Hoh River	203,000	6.0%	12,180	15,002
Queets River	379,090	6.0%	22,745	28,015
Quinault River	217,000	6.0%	13,020	16,037
Independent Tributaries	254,000	6.0%	15,240	18,771
Grays Harbor				
Chehalis River	2,322,000	6.0%	139,320	171,599
Humptulips River	252,500	6.0%	15,150	18,660
Willapa Bay	595,000	6.0%	35,700	43,971
Coastal Systems Total	4,686,590	6.0%	281,195	346,346
Lower Columbia Total	724,000	3.0%	21,720	26,752
GRAND TOTAL	9,495,090		646,245	795,975

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 conducted by WDFW. 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. Analysis 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. As a result, overall production of juvenile coho (juveniles/female * # females) in healthy watersheds is rarely limited by spawner abundance, and the majority of variation in juvenile production is generated by 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 that rear in freshwater in odd years.

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 is not observed when habitat degradation is severe or when escapements fall below critical thresholds. For example, chronically low coho returns to the Deschutes River, beginning in the mid-1990s, have resulted in much lower freshwater survival (juveniles/female) than would be predicted from productivity curves derived from earlier years in the Deschutes (Figure 2a) or from other watersheds (Figure 1).

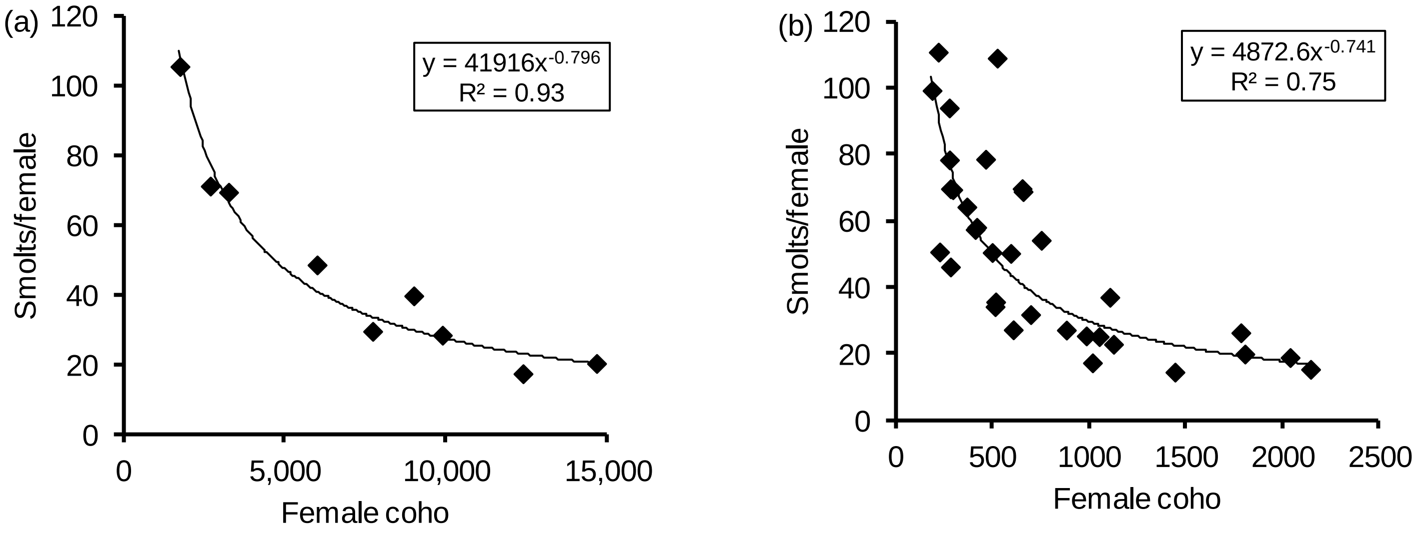

Figure 1. Freshwater productivity (juveniles/female) as a decreasing function of female coho escapement in the South Fork Skykomish (*a*, Sunset Falls, brood year 1976-1984) and Big Beef Creek (*b*, brood year 1978-2009) watersheds.

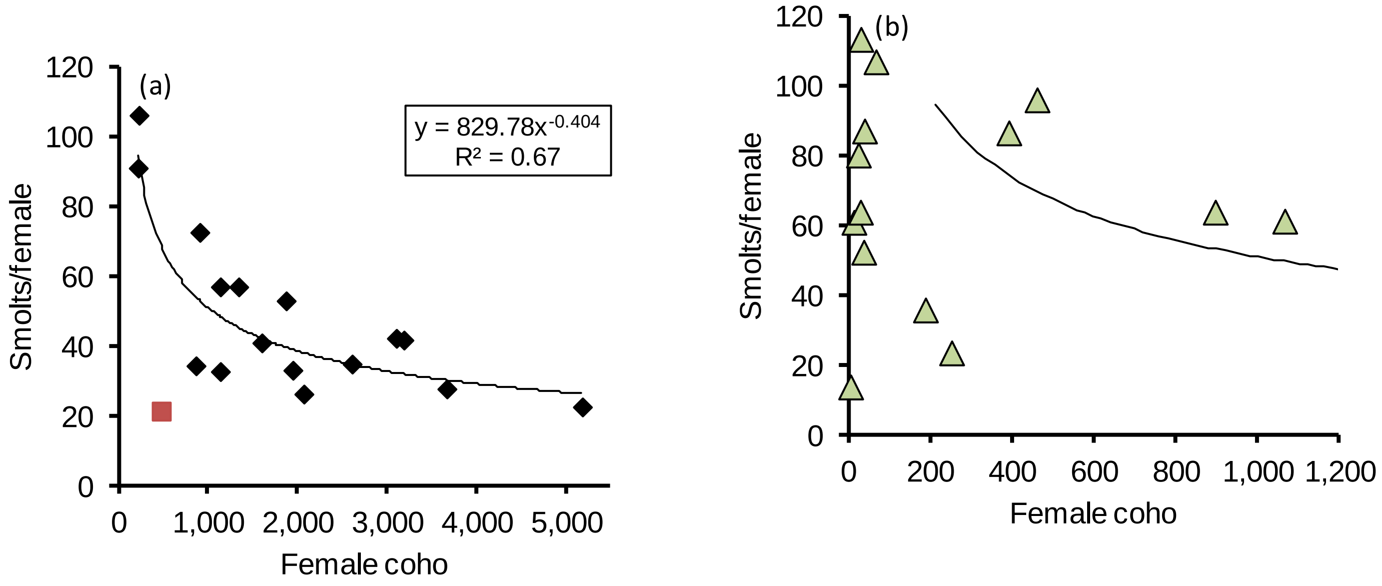

Figure 2. Freshwater productivity (juveniles/female) as a function of female coho escapement in the Deschutes River. For brood year 1978-1994 (*a*), coho productivity was a decreasing function of escapement (black square) with the exception of brood year 1989 (red square). The 1989 brood year corresponded 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 2013, 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 three additional management units (Stillaguamish, Puyallup, East Kitsap, and South Sound) were available due to juvenile monitoring studies conducted by the Stillaguamish, Puyallup, Suquamish, and Squaxin Tribes. For watersheds where trapping data were not available in 2013, 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. Use of this approach assumes that summer low flows are the key variable influencing freshwater survival of coho and that smolt abundance from one year can be predicted by applying the ratio of summer low flows to smolt production from another year. Summer low flows in 2012 (corresponding to the 2013 outmigration and 2014 returning adults) had an index value of 7.2 or 90% of the long-term average (Figure 3).

A third consideration when estimating coho smolts was based on marine derived nutrients provided by pink salmon. All major river systems in the Whidbey, Central and South basins of Puget Sound have experienced recent increases in odd-year pink salmon escapements to levels unprecedented in recent history. Of these river basins, a correlation between coho smolt production and pink salmon escapement has been evident in the Skagit River but not the Green, Puyallup, or Nisqually rivers (Zimmerman 2013). As the 2013 smolts did not overwinter with pink salmon, the addition of marine nutrients is not considered to be important contributor to the 2013 estimates.

Table 2. Wild coho 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	36	27,617	11,510	57,271	71.6%	29.8%	148.5%
Little Anderson	20	616	45	1,969	12.1%	0.9%	38.6%
Seabeck	20	1,369	496	2,725	13.0%	4.7%	26.0%
Stavis	20	5,359	1,549	9,667	106.6%	30.8%	192.3%
Skagit River	24	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	10	62,236	22,671	194,393	27.6%	10.1%	86.2%
Lake Washington							
Cedar River**	15	57,888	13,322	115,185	47.9%	11.0%	95.3%
Bear Creek	15	32,234	12,208	62,970	64.4%	24.4%	125.7%
Nisqually	5	156,918	80,048	228,054	135.8%	69.3%	197.4%
Deschutes***	34	46,741	1,187	133,198	21.3%	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.

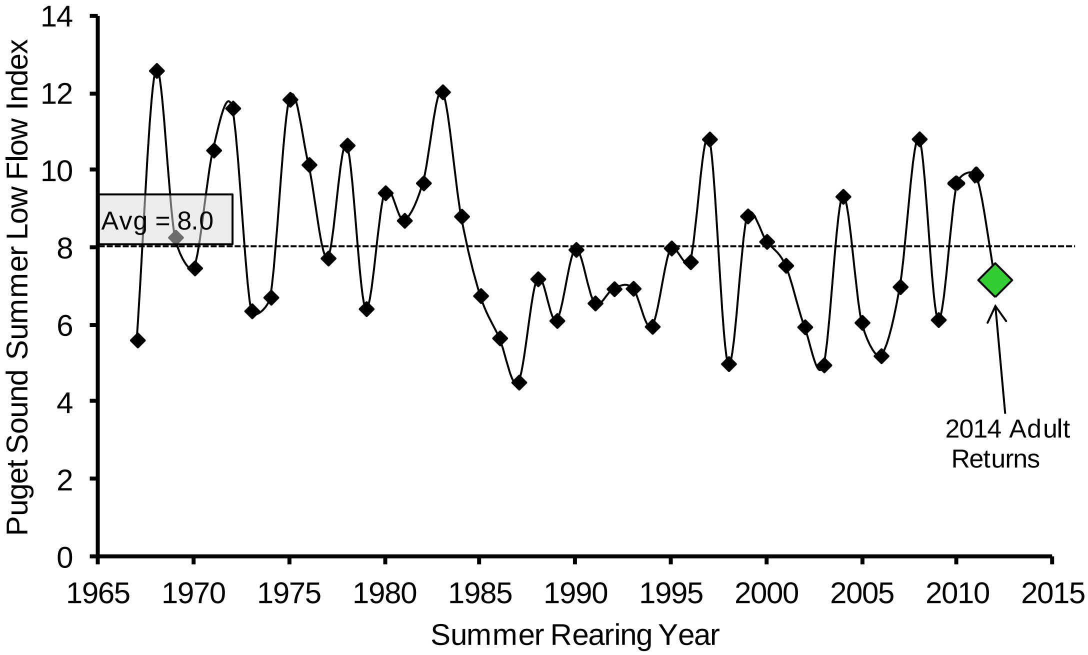

Figure 3. Puget Sound Summer Low Flow Index (PSSLFI) by summer rearing year (return year – 2). PSSLFI is based on 60-day minimum flow averages at eight stream gages in Puget Sound (see Appendix A). The minimum 60-day average flow at each gage is compared to its long-term average (1967 to present) and then summed across all eight gages. Flow index corresponding to the 2014 wild coho return is highlighted in green.

Puget Sound Primary Units

Skagit River

A total of 1,409,000 (±219,000, 95% C.I.) wild coho smolts are estimated to have emigrated from the Skagit River in 2013 (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). Coho abundance was calculated using a Petersen estimator with Chapman modification (Seber 1973; Volkhardt et al. 2007). The 2013 smolt production was slightly higher than the long-term average of 1,086,000 smolts (Table 2).

Coho smolt production from the Skagit River in 2013 was 130% of its long-term average abundance of 1,086,000 smolts. The relationship between river flows and smolts abundance was explored using a principal component regression in order to improve extrapolation to the neighboring Stillaguamish and Snohomish watersheds, where smolt estimates are not currently available. Multivariate descriptors of river flows were derived from a principal component analysis which included cumulative, minimum, and maximum spawning flows (November 1 – December 15), cumulative, minimum, and maximum incubation flows (December 16 – March 1), and summer low flows (60-day average between June 1 and October 31). Flow measures were obtained from the Newhalem Creek gage (USGS #12178100) which should be representative of tributary habitat used for spawning and rearing. Of the seven principal components that best explained overall variation in river flows, smolt abundance was most likely to be explained by the fourth component (AIC comparison, $R^2 = 0.43$, $p < 0.001$). The flow metrics represented in this principal component (loadings) included all flow metrics but was heavily loaded by minimum and maximum incubation flow and summer rearing flows (Figure 4). This multivariate flow metric was a better predictor of smolt abundance than the best individual variable (summer low flow, $R^2 = 0.30$).

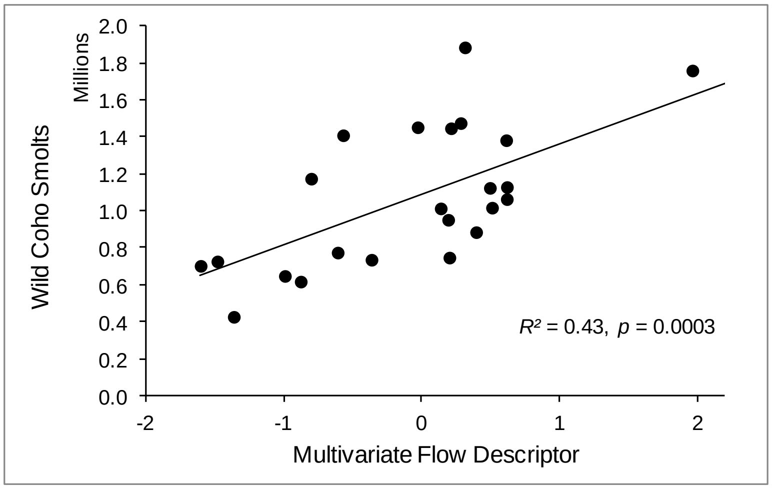

Figure 4. Coho smolt abundance as a function of a multivariate descriptor of summer and winter flows in the Skagit River at the Newhalem Creek gage (USGS#12178100). Data are coho smolt years 1990-2013.

Stillaguamish River

A total of 237,000 coho smolts are estimated to have emigrated from the Stillaguamish River in 2013 (Table 1). This estimate was based on an adjustment of historical smolt estimates based on correlation of current catch rates in a mainstem juvenile trap with summer low flows and the ratio in summer low flows between current and historical trapping years.

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 based on smolts emigrating from above the trap expanded 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). The WDFW trap operation provided total estimates of abundance under the river conditions in these years, but was not a long enough data set to develop a quantitative approach to extrapolate historical estimates to current river conditions. From 2001 to present, smolt catch per unit effort (CPUE) estimates have resulted from a juvenile trap study conducted by the Stillaguamish Tribe near R.M. 6 (J. Griffith, Stillaguamish Natural Resources, personal communication). This study has provided a range of CPUEs which can be used to explore predictive relationships with environmental variables, but has not included trap efficiency trials needed to directly expand CPUE to a total watershed estimate of abundance. In this forecast, I combine the information from both datasets in an attempt to develop a quantitative prediction of smolt abundance from river flow conditions.

Flow predictors of coho smolt CPUE can be examined in the Stillaguamish River if one accepts that CPUE of coho smolts from the juvenile trap is truly an indicator of smolt abundance and minimally influenced by inter-annual variation in trap efficiency. Of the seven flow predictors described above for the Skagit River, only one (summer rearing flows) was significantly correlated with Stillaguamish coho smolt CPUE (Figure 5). This correlation – although weak – provides a quantitative way to adjust historically measured smolt abundances based on differences in summer low flows.

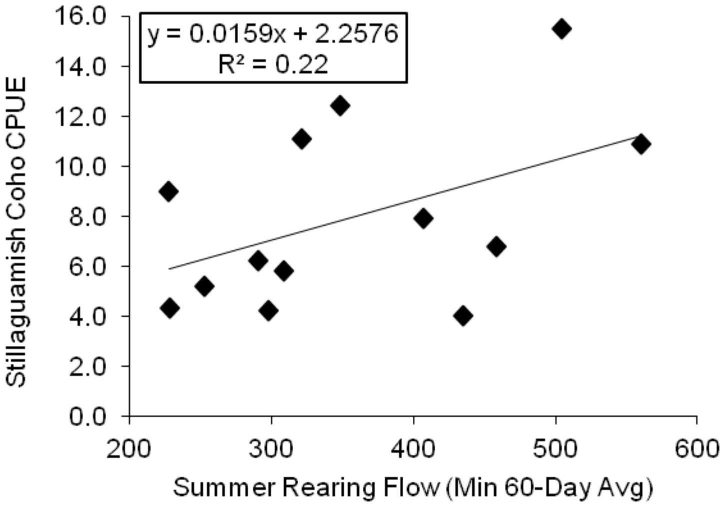

Figure 5. Correlation between CPUE of wild coho smolts in Stillaguamish smolt trap, 2001 to 2013 (data provided by J. Griffith, Stillaguamish Natural Resources) and summer rearing flows (minimum of 60-day average, NF Stillaguamish gage ##12167000).

The 2013 Stillaguamish coho production was estimated to be 237,000 smolts, 64% of that measured in 1981-1983. The average smolt abundance between 1981 and 1983 was adjusted based on summer flow comparisons between 1981-1983 and 2013. For smolts emigrating between 1981 and 1983, the average summer low flow metric (minimum of 60-day average) for the N.F. Stillaguamish gage (USGS #12167000) averaged 532 cfs and was similar among years. Based on the flow-CPUE regression equation in Figure 5, a summer low flow of 532 cfs (1981-1983 average) corresponds to a 10.7 CPUE and a 290 cfs (2013 value) corresponds to a 6.9 CPUE. The 2013 CPUE prediction (6.9) was reasonably close to the 6.2 CPUE index actually measured in 2013. Based on these calculations, the 55% reduction in a summer low flow from 532 cfs to 290 cfs corresponds to an 0.64 ratio of smolt CPUE (0.64 = 6.9/10.7). Assuming that CPUE and smolt abundance are correlated 1:1, this provides a quantitative method for predicting the change in smolts related to summer low flows and the total coho smolt abundance in 2013 is estimated to be 237,000 (370,000*0.64).

Snohomish River

A total of 750,000 coho smolts are estimated to have emigrated from the Snohomish River in 2013 (Table 1). The 2013 estimate is based on historical measures of smolt production in the South Fork Skykomish River expanded to the entire Snohomish watershed and the assumption that freshwater drivers of smolt abundance were similar to those observed in the Skagit River, where smolt production was measured. A juvenile trap was operated on the Skykomish and Snoqualmie rivers by the Tulalip Tribe in 2013; however, analyses of these data will not be completed until later in the year.

Between 1978 and 1986, WDFW operated a juvenile trap below Sunset Falls on the South Fork Skykomish River. Details of these estimates are available in previous forecasts (Seiler 1996; Zimmerman 2013). Between 1978 and 1983, average production was 276,000 smolts (range = 212,000 to 354,000 smolts) and inter-annual variation in smolt production was not correlated with spawner abundance. Between 1982 and 1984 (corresponding to the 1984 to 1986 outmigration), escapement was experimentally reduced in order to determine whether smolt production could be limited by lower escapements. For these three years, limited escapement (1,000 to 3,000 females) reduced coho production to an average of 198,000 smolts.

A basin-wide estimate for years when smolts are not limited by spawner escapement was derived by expanding average coho abundance in the South Fork Skykomish by 20.7%, the portion of the Snohomish system’s drainage area represented by the South Fork Skykomish sub-basin. With this method, average coho abundance for the Snohomish basin is 1,333,000 smolts (Seiler 1996). This estimate was subsequently reduced to 1,000,000 smolts to account for the portions of the watershed that are not accessible to anadromous fish (i.e., 450 mi^2 or 26%; Seiler 1999).

Smolt production in 2013 is estimated to be 500,000 smolts. This estimate assumes that summer low flows limited Snohomish coho smolts in 2013, similar to correlations derived for the Skagit and Stillaguamish Rivers. Summer low flows in the Snohomish River that correspond to the 2013 outmigration were lower than the years when the WDFW estimates were derived. Specifically, the 2012 summer low flow index from the North Fork Snoqualmie gage (USGS # 12142000) was just 35% (51 cfs/146 cfs, minimum 60-day average flow between June and November) the average summer low flow index between 1977 and 1983 (corresponding to the 1978 to 1984 smolt estimates). Missing from this calculation is the rate at which smolt abundance would be reduced according to the lower summer flow conditions. Assuming that this rate is lower than a direct 1:1 ratio, the 2013 coho smolt abundance is estimated to be 750,000, 75% of the watershed average during the years of WDFW trap operations. This estimate also assumes that the 2011 coho escapement to the Snohomish system was assumed to adequately seed the watershed. Returns to Sunset Falls in 2011 (27,916 adults, ~14,000 females) were at a level previously demonstrated to maximize smolt production from the South Fork Skykomish (Seiler 1996).

Hood Canal

A total of 490,000 coho smolts are estimated to have emigrated from Hood Canal tributaries in 2013 (Table 1). Production was not directly measured in all tributaries; therefore this estimate is based on an expansion of the measured production.

In 2013, wild coho smolt abundance was measured in Big Beef Creek (*n* = 27,246*)*, Little Anderson Creek (*n* = 1,507), Seabeck Creek (*n* = 1,368*)*, and Stavis Creek (*n* = 4,327*)*. 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 extrapolation was less than 5% of each estimate.

The 2013 abundance of coho smolts from Big Beef Creek, Seabeck, and Stavis Creeks were 98%, 100%, and 81% the long-term average production measured in these watersheds (Table 2). The 27,246 Big Beef Creek smolts were produced by 343 female spawners passed upstream of the weir in 2011 and represented a freshwater productivity of 79 smolts/female. Freshwater productivity measures in this range are generally the result of density-dependent increases in juvenile survival based on low spawning escapements (Figure 1). In comparison, the 2013 coho production from Little Anderson, which has received substantial in stream habitat restoration efforts, was 244% the long-term average production (Table 2).

Three approaches have been used to expand measured wild coho smolt abundance to the entire the Hood Canal management unit. The first approach assumes that coho abundance from 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 estimated that the 2013 wild coho production in Hood Canal ranged between 490,000 and 631,000 smolts. Using the Zillges approach, the total of 37,226 smolts from the four tributaries were expanded to an estimated 630,949 Hood Canal smolts. Using the second approach (HCJTC 1994 revision), the total of 37,226 smolts from the four tributaries were expanded to 489,816 Hood Canal smolts. The third approach expanded the 27,246 smolts from Big Beef Creek to a total of 597,500 Hood Canal smolts. This forecast is based on the most conservative result, provided by the second approach.

Puget Sound Secondary Units

Nooksack River

A total of 158,000 coho smolts are estimated to have emigrated from the Nooksack River in 2013 (Table 1). Smolt abundance estimates from the Nooksack were not available in 2013. Therefore, coho production in this watershed was estimated by applying a proportion of the Zillges (1977) production potential.

Previous forecasts have estimated the Nooksack River wild coho amolt abundance to be 20% and 50% of its predicted potential of 451,275 smolts (Zillges 1977). This range was due, in part, to the assumption that high harvest rates and habitat degradation were limiting coho smolts in the Nooksack River (Seiler 1996). Summer low flows in 2012 were slightly below average in the Nooksack River and for the Puget Sound index (Figure 3) and were assumed to constrain the abundance of smolts emigrating in 2013. Based on these assumptions, the 2013 abundance of Nooksack wild coho smolts was estimated to be 158,000 (35% of potential production).

Strait of Georgia

A total of 18,000 coho smolts are estimated to have emigrated from the Straits of Georgia watersheds in 2013 (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 assumption that 2012 summer low flows constrained the 2013 smolt production from this management unit. Previous forecasts for the Straits of Georgia have estimated that wild coho production was 20% to 50% of its potential. The 2013 coho production was estimated to be 18,000 smolts, 35% 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 2013 (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 1980s, when hatchery supplementation for coho ended, Samish River coho continued a self-sustaining run of nearly 10,000 spawners. Under conditions favorable to survival, juvenile production of at least 100,000 smolts (20 smolts/female) are needed to produce this number of spawners (i.e., 20% marine survival and 50% harvest; Seiler 1996). Under conditions of lower marine survival, the number of smolts needed to support this level of returns would have been even higher.

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 marine survival in closest geographic proximity to the Samish. During this time period, natural coho returns to the Samish River have averaged ~2,000 spawners, far below the sustained 10,000 spawners observed in the 1980s. Therefore, one might expect that current smolt abundance from this basin would be less than the 100,000 smolts previously estimated.

A total of 1,442 coho spawners are estimated to have contributed to the 2013 smolts from the Samish River, consistent with the spawning escapement observed over the past decade. 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 109,000 coho smolts are estimated to have entered Puget Sound from the Lake Washington basin in 2013 (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 (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 such 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 2013, coho smolt abundance from the Cedar River was estimated to be 115,185 (±24,497 95% C.I.) smolts, the highest smolt abundance since 1999. In comparison, coho smolts from Bear Creek were estimates to be 17,752 (±7,766 95% C.I., K. Kiyohara, personal communication). 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 spawning and rearing habitat between Landsburg and Cedar Falls. Coho returns to this portion of the watershed have steadily increased over time, and natural productivity appears to be contributing substantially to this trend (Anderson 2011). For this reason, coho smolts estimated for Issaquah Creek (in the Sammamish sub basin) was based on monitoring data from the neighboring Bear Creek and not the Cedar River.

The 2013 coho production from Issaquah Creek was estimated by scaling the 2000 estimate for this creek (19,812 smolts; Seiler et al. 2002a) by the 2013 to 2000 smolt ratios in Bear Creek. Both watersheds should be influenced by returns of natural and hatchery coho and summer low flows. In 2013, coho smolt production in Bear Creek was 63% of that measured in 2000 (17,752/28,142 = 63%). Therefore, 2013 coho production from Issaquah Creek was estimated to be 12,482 smolts (19,812 * 0.63).

The total coho production of 109,000 smolts assumed 75% survival through Lake Washington. Coho abundance estimated to enter Lake Washington was 145,419 smolts (115,185 Cedar + 17,752 Bear + 12,482 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 132,000 natural-origin coho smolts are estimated to have emigrated from the Green River in 2013 (Table 1). This estimate is the sum of 50,642 smolts upstream of the juvenile trap (river mile 34), 29,197 smolts below the juvenile trap, and 51,984 smolts from Big Soos Creek.

In 2013, coho smolts emigrating from above river mile 34 were estimated with a partial-capture juvenile trap. The juvenile trap was calibrated based on recapture rates of marked wild coho. Production above the trap was estimated to be 50,642 (±20,646 95% C.I.) smolts (P. Topping, personal communication). This represents 23% 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 29,197 smolts based 23% 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. Although a smolt monitoring study on Big Soos Creek was conducted by the Muckleshoot Tribe in 2013, the results from this work were not available to apply to this forecast. Therefore, 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, 2013 smolt abundance from this creek was based on the ratio of PSSLFI values associated with the 2013 and 2000 outmigration years (see Appendix A for explanation of PSSLFI). This ratio (7.2/8.8 = 80.9%) converts to an estimated 51,984 smolts (0.809*64,341).

East Kitsap

A total of 92,000 coho smolts are estimated to have emigrated from East Kitsap tributaries in 2013 (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 2013 (J. Oleyar, Suquamish Tribe, personal communication). Based on Zillges (1977) calculations of summer rearing habitat, the smolt potential above the trap locations is 2,513 smolts on Lost Creek and 6,875 smolts on Wildcat Creek (J. Oleyar, Suquamish Tribe). More recent measures of summer rearing habitat (Baranski 1989; J. Oleyar, Suquamish Tribe, personal comm.) suggest that current summer rearing habitat may be less than that reported in Zillges et al. (1977).

The 2013 coho abundance of 5,592 smolts from Lost (*n* = 2,046) and Wildcat (*n* = 3546) creeks was 59.5% of the smolt potential calculated by Zillges. Total coho smolt abundance for the East Kitsap management unit was estimated to be 92,000 smolts based on 59.5% of the 154,973 smolt potential for all watersheds in this management unit predicted by Zillges (1977).

Puyallup River

A total of 295,000 coho smolts are estimated to have emigrated from the Puyallup River in 2013 (Table 1). This estimate is based on measured production in the Puyallup River above the juvenile trap (151,198), an estimated production from the White River (134,049), and an estimate from the Puyallup River below the Puyallup-White confluence (10,042).

In 2013, the Puyallup Tribe operated a juvenile fish trap on the Puyallup River just upstream of the confluence with the White River. A total of 151,198 coho smolts were estimated to have migrated past the juvenile trap, the largest number since 2005 (A. Berger, Puyallup Tribe, personal communication). These coho smolts represent 54.8% of the smolt potential for the watershed between the Puyallup-White confluence and Electron dam (Zillges 1977). However, the actual rate is lower than this percentage as the 2013 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 15% of potential production applied to the 66,943 potential production of the lower Puyallup (Zillges 1977).

A total of 134,049 coho smolts were estimated to have emigrated from the White River. Coho smolts originating between the Puyallup-White confluence and Buckley Dam were estimated to be 15,199, 15% of the potential production for this portion of the watershed (Zillges 1977). Coho smolts emigrating from above Buckley dam were estimated to be 118,850 smolts based on the number of females passed above Buckley Dam in 2011 (23,770/2 = 11,885) multiplied by 10 smolts per female. Ten 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 183,000 coho smolts are estimated to have emigrated from the Nisqually River in 2013 (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 (Carlson et al. 1998; Volkhardt et al. 2007).

Wild coho smolts emigrating from above the trap (river mile 12) was estimated to be 164,400 (±14,797 95% C.I.) smolts, 142% of the 115,554 smolt potential predicted by Zillges (1977). Total smolts above and below the trap were estimated to be 182,667 assuming that 10% of coho reared below the trap.

Deschutes River

A total of 1,500 natural-origin coho smolts are estimated to have emigrated from the Deschutes River in 2013 (Table 1), representing 0.7% (1,500/219,574) of the smolt potential estimated by Zillges (1977). This estimate is based on catch of coho smolts in a juvenile trap operated below Tumwater Falls. A catch of 360 smolts was expanded by a trap efficiency of 24.7%.

Production of coho smolts in the Deschutes River is primarily limited by escapement (Figure 6), and coho escapement in the Deschutes River has been severely depressed over the past two decades. Two of the three brood lines are virtually extinct. For the 2011 brood, one of the week brood years, just 32 females returned to spawn. The 2013 outmigration was supplemented by an estimated 2,884 hatchery smolts (adipose clipped) which were planted in the Deschutes River as fry. Both natural-origin and hatchery smolts will contribute to the 2014 spawner escapement.

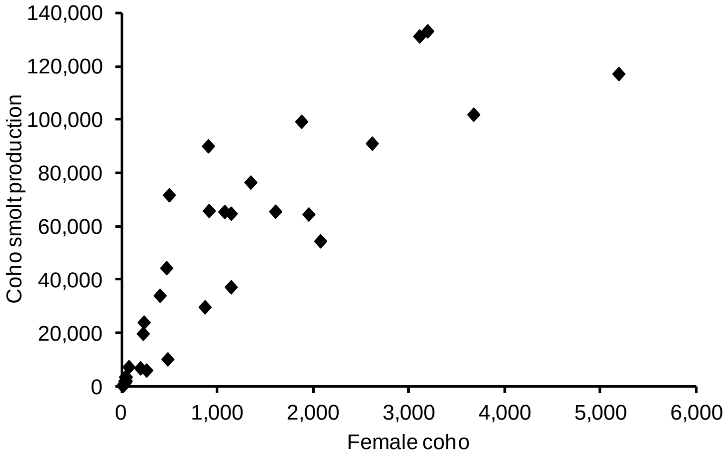

Figure 6. Coho smolt production as a function of female spawners in the Deschutes River, Washington, brood year 1978-2010.

South Sound

A total of 177,000 coho smolts are estimated to have emigrated from South Sound tributaries in 2013 (Table 1). This estimate was based on results of juvenile monitoring studies in Cranberry, Mill, Skookum, and Goldsborough creeks conducted by the Squaxin Island Tribe. Natural-origin coho smolt estimate for Cranberry Creek was 253 smolts (1.2%), Mill Creek was 114 smolts (0.2%), Skookum Creek was 144 smolts (0.5%), and Goldsborough Creek was 54,033 smolts (75.4%, Joseph Peters, Natural Resources Department, Squaxin Island Tribe, personal communication). Numbers in parentheses represent the proportion of the smolt potential observed (Zillges 1977). Low and variable smolt abundances in South Sound tributaries is likely to be driven by a combination of low spawner returns to South Sound (as observed in the Deschutes River) and degraded habitat conditions in this region. Coho production for the entire South Sound management unit was estimated to be 177,000 smolts based on 30.8% 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 from the high-gradient north coast rivers draining west off the Olympic Mountains to the low-gradient, rain-fed southwest rivers of Grays Harbor and Willapa Bay. 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 density 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 2013, WDFW operated a juvenile trap to estimate wild coho smolt abundance in the Chehalis River watershed. Smolt abundance in the Queets management unit was available due to juvenile monitoring study 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 2013, wild coho smolt abundance was estimated by applying a smolt density (smolts/mi^2) from monitored watersheds to the non-monitored watersheds (drainage areas in Appendix B). Among the factors considered when applying a smolt density to each watershed were baseline data (historical smolt estimates), watershed 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 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)	32	70,306	27,314	134,052	502	195	958
Queets (no Clearwater)	30	202,142	53,473	352,694	652	172	1,138
Chehalis (Grays Harbor)	30	2,050,306	502,918	3,769,789	970	238	1,783

Queets River

A total of 379,090 wild coho smolts (842 smolts/mi^2) are estimated to have emigrated from the entire Queets watershed in 2013 (Table 1). This estimate was based on coho smolt monitoring study conducted 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 95,128 wild coho smolts (679 smolts/mi^2).

Quillayute River

A total of 464,000 coho smolts are estimated to have emigrated from the Quillayute River system in 2013 (Table 1). This estimate is based on historical measures of smolt abundance in two sub-basins of the Quillayute River and a comparison with smolt abundance in the Clearwater River, where smolt abundance was measured in 2013.

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 conclusion is further supported by the relatively high smolt densities observed in the low-gradient Chehalis River (Table 3) and Cedar Creek (NF Lewis River, Figure 8). 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 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 2013 Quillayute coho production was based on previously measured smolt abundance adjusted by the ratio of current to previous measured smolt abundance in the Clearwater River. Because of the differences in smolt densities in the Dickey and Bogachiel rivers, the two regions of the watershed were estimated separately. The 2013 coho smolt abundance in the Dickey River was estimated to be 137,817 smolts (1.56*88,344 smolts). The 1.56 expansion factor was the ratio of Clearwater River production in 2013 (95,128 smolts) to average Clearwater River production in 1992-1994 (95,128/61,000 = 1.56). The 2013 coho smolt abundance in the Quillayute (excluding the Dickey) was estimated to be 325,886 smolts (1.50*217,257 smolts). The 1.50 expansion factor was the ratio of Clearwater River coho smolt production in 2013 to average Clearwater River smolt production in 1987, 1988, and 1990 (95,128/63,333 = 1.50). The total 2013 coho production of 464,000 smolts was the rounded sum of these estimates (137,817 + 325,886).

Hoh River

A total of 203,000 wild coho smolts are estimated to have emigrated from the Hoh River in 2013 (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 679 smolts/mi^2 from the Queets River was applied to the 299-mi^2 of the Hoh watershed and resulted in an estimated 203,000 smolts from the Hoh River system.

Quinault River

A total of 217,000 wild coho smolts are estimated to have emigrated from the Quinault River in 2013 (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 high harvest rates (i.e., low escapement) and degraded habitat. In 2013, a production rate of 500 smolts/mi^2 was applied to the 434-mi^2 Quinault River system, resulting in an estimated 217,000 smolts.

Independent Tributaries

A total of 254,000 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 2013, an average production rate of 600 smolts/mi^2 was applied to the total watershed area (424 mi^2; Appendix B), resulting in an estimated 254,000 smolts.

Grays Harbor

A total of 2,574,500 coho smolts are predicted to have emigrated from the Grays Harbor system in 2013 (Table 1). This estimate was derived in two steps. Wild coho production was first estimated for the Chehalis River (n = 2,134,405). Smolt abundance per unit drainage area of the Chehalis River system was then applied to the southern (n = 187,860, Hoquaim, Johns, and Elk rivers) and northern (n = 252,500, Humptulips) tributaries 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 were expanded to a basin-wide smolt abundance based on the recapture 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, a preliminary estimate is used for the run size forecasts. In order to derive a preliminary estimate of the 2013 smolt production, flow variables were examined for their predictive value. Variables were spawning flows (cumulative, minimum, maximum; November 1 to December 15), incubation flow (cumulative, minimum, maximum; December 16 to March 1), and summer rearing flows (minimum of 60-day average, March 1 to November 1). The analysis was limited to a 13 year data set (smolt year 2000 to 2012) in order to minimize temporal changes in land use or watershed condition while using a data set with enough variation that patterns could be identified. Over the past decade, Chehalis smolt production was positively correlated with summer low flows and negatively correlated with incubation flows (Figure 7). Neither minimum nor maximum spawning flows were correlated with coho smolt production during this time period and individual correlations were not improved by combining the variables into multiple regression models (AIC model comparison). Based on a model average of the incubation and summer low flow models, the 2012 smolt abundance was predicted to be 2,415,000 smolts. This prediction was lower but reasonably close to the 2,973,000 smolts estimated following the 2013 tag returns.

The 2013 coho smolt abundance was associated with incubation (20,500 cfs maximum) and rearing (216 cfs 60-day average) flows that were slightly lower than average. The 2013 smolt production was predicted to be 2,134,405 based on model averaging of the incubation and summer rearing flow regressions. Although this preliminary estimate is used for forecasting purposes, note that the 95% confidence intervals for this estimate range between 1.4 and 2.8 million smolts.

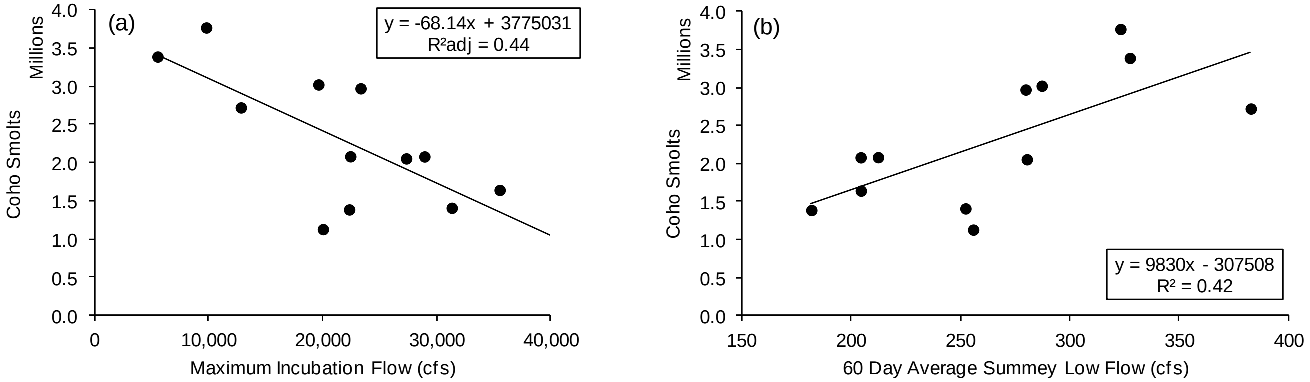

Figure 7. Chehalis River wild coho smolt production as a function of incubation flows (a) and summer rearing flows (b), spawn year 1998-2009. Incubation flows are the maximum daily mean flow between December 15 and March 1. Summer rearing flows are the minimum of the 60-day average flow between March 1 and Nov 1 (USGS gage ##12027500, Grand Mound). One data point (2008 spawn year) was removed 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 1,010 smolts/mi^2 (2,134,405 smolts per 2,114 mi^2). A total of 187,860 coho smolts are estimated for the southern tributaries of Grays Harbor (1,010 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 252,500 smolts (1,010 smolts/mi^2*250 mi^2). After summing smolt abundance estimated for all watersheds in the Grays Harbor management unit, total wild coho production was estimated to be 2,575,000 smolts (2,134,405 + 187,860 + 252,500).

Willapa Bay

A total of 595,000 coho smolts are estimated to have emigrated from the Willapa Bay basin in 2012 (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 a somewhat degraded freshwater habitat. Given these impacts, wild coho smolt density is likely to be somewhat lower than observed in the Chehalis Basin. Wild coho production in 2013 (595,000 smolts) was calculated by applying 700 smolts/mi^2 production rate to the total basin area (850 mi^2).

Lower Columbia Smolt Abundance

Approach

Coho smolt abundance is monitored in a subset of Lower Columbia watersheds. 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 long-term WDFW monitoring studies statewide. The extrapolation to non-monitored watersheds was done separately for systems with primarily wild spawners versus those influenced by hatchery programs, as described below.

In 2013, 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 1973; Volkhardt et al. 2007). Monitored watersheds include Grays River, Mill Creek, Abernathy Creek, Germany Creek, Tilton River, Upper Cowlitz, Coweeman River, and Cedar Creek. In the case of the Upper Cowlitz and Tilton rivers, coho smolts are actively transported around the dam-reservoir systems.

The smolt monitoring sites were not randomly chosen 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, where high levels of hatchery coho occur in the spawning population due to hatchery production in the watershed (i.e., Grays, Upper Cowlitz) or deliberate releases of hatchery coho into the watershed (i.e., Tilton). "Wild monitored" populations were Mill Creek, Abernathy Creek, Germany Creek, and the Coweeman River. These watersheds have no operating coho hatcheries; however, hatchery coho salmon do stray and spawn in them. Cedar Creek, also monitored in 2013, 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 2013).

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, the 2013 coho smolt density was estimated to be 250 smolts/mi^2 (Table 4). A total of 6,501 natural-origin coho smolts are estimated to have emigrated from the Grays River in 2013 (Table 5).

Mill, Abernathy, and Germany Creeks

Juvenile traps on Mill, Abernathy, and Germany creeks are located near the mouth of each creek. The 2013 coho smolt production density of these watersheds ranged between 98 and 434 smolts/mi^2 (Table 4). A total of 18,162 natural-origin coho smolts were estimated to have emigrated from all three watersheds in 2013 (Table 5). This included 12,581 smolts from Mill Creek, 3,319 smolts from Abernathy Creek, and 2,262 smolts from Germany Creek.

Tilton River

The Tilton River juvenile trap is located at Mayfield Dam in the Cowlitz watershed. A 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) When estimating the 2013 smolt production, a release of 1,000 smolts and a recapture of 885 were assumed in order to expand the Mayfield Dam catch to a total smolt abundance estimate for the Tilton River.

Based on a watershed area of 159 mi^2, the 2013 coho smolt density of the Tilton River was estimated to be 373 smolts/mi^2 (Table 4). The total number of natural-origin coho emigrating from the Tilton was 58,257 (Table 5) smolts, this included the 52,468 coho smolts captured at the Mayfield juvenile trap plus the number estimated to pass through the turbine multiplied by an assumed 85% survival.

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 above Cowlitz Falls, coho salmon production density of the Upper Cowlitz River was estimated to be 316 smolts/mi^2 in 2013 (Table 4). The total number of natural-origin coho emigrating from the Upper Cowlitz was the 212,738 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 juvenile trap at river mile 7.5. Based on a watershed area of 119 mi^2, the coho smolt abundance density from the Coweeman River was estimated to be 112 smolts/mi^2 in 2013 (Table 4). The total number of natural-origin coho emigrating from the Coweeman River in 2013 was estimated to be 13,354 smolts (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 total 2013 coho smolt emigration from the Cedar River was estimated to be 52,656 smolts and included naturally produced smolts and remote-site incubation supplementation (Table 5). Remote Site Incubation (RSI) program 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 993 smolts/mi^2 (Table 4). Historically, Cedar Creek coho smolt densities are unusually high with respect to Lower Columbia watersheds. These densities may be due to 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 251,937 (232,661 – 271,213 95% C.I.) smolts (Table 5). This estimate was derived from an average smolt production density of 313 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 117,621 (96,322 – 138,919 95% C.I.) smolts (Table 5). This estimate was derived from an average smolt production density of 190 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, 724,000 natural-origin coho smolts are estimated to have emigrated from the Washington Lower Columbia region in 2013 (Table 1). The 95% confidence intervals for this estimate range between 397,390 and 509,244 smolts. The density of smolts emigrating from each Washington Lower Columbia watershed in 2013 was very close to the 6-year (Figure 8). The total number of smolts in 2013 is ~200,000 smolts greater than 2012 primarily due to improved collection efficiency at Cowlitz Falls Collection Facility. 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 will contribute to natural production in subsequent years.

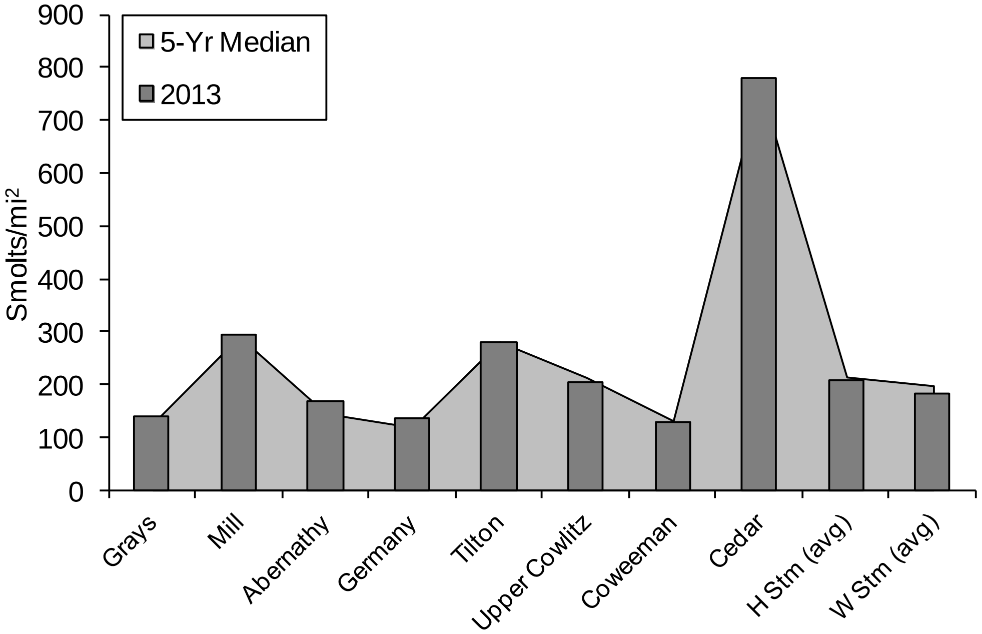

Figure 8. Coho smolt densities (smolts per mile-squared of watershed area) in eight Lower Columbia tributaries in Washington State. Graphs shows the 2013 production (bars) relative to the 6-year average smolt abundance from these watersheds (2007-2012).

Table 4. Estimated smolt densities in from monitored coho salmon streams in the Lower Columbia River ESU during 2013. Estimates are preliminary and subject to revision.

	Density		
Watersheds	N/mi^2	95% Low	95% High
Grays	250.0	197.3	302.7
Mill	433.8	373.6	493.9
Abernathy	114.5	69.2	159.7
Germany	98.3	86.5	110.2
Tilton	372.9	364.5	381.3
Upper Cowlitz	316.0	305.2	326.7
Coweeman	112.3	92.1	132.4
Cedar	993.4	814.2	1172.7
Average Hatchery Streams	313.0	289.0	336.9
Average Wild Streams	189.7	155.4	224.1

Table 5. Estimated number of coho smolt emigrants in 2013 from the Lower Columbia Evolutionary Significant Unit including monitored streams, streams with hatcheries, and streams without hatcheries. Estimates are preliminary and subject to revision.

Watersheds	N	95% Low	95% High
Grays	6,501	5,131	7,871
Mill	12,581	10,836	14,326
Abernathy	3,319	2,006	4,632
Germany	2,262	1,990	2,534
Tilton	58,257	---	---
Upper Cowlitz	212,738	---	---
Coweeman	13,354	10,954	15,754
Cedar	45,742	37,489	53,995
Non-monitored Hatchery Streams	251,937	232,661	271,213
Non-monitored Wild Streams	117,621	96,322	138,919
Total Smolt Emigration	724,312	397,390	509,244

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 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. Both the 2012 and 2013 forecasts were developed using ecosystem indicators as predictors of marine survival (Zimmerman 2012; Zimmerman 2013), 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 ocean conditions (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 (Mueter et al. 2002; Shaul et al. 2007; Beetz 2009). 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). The Puget Sound region was further broken into “Local Scale” indicators associated with each of its oceanographic basins (Babson et al. 2006; Moore et al. 2008b). Local indicators were selected based on the variables (local air temperatures, freshwater inflows, bathymetry, and Strait of Juan de Fuca salinity) 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 ten wild coho populations – five in Puget Sound, one in coastal Washington, and four 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 six populations (Snohomish River, Lake Washington, Abernathy Creek, Coweeman River, Cowlitz/Tilton rivers, Cedar Creek [NF Lewis]) 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/).

The marine survival estimate used for the Lake Washington MU is a based on smolt estimate and terminal run reconstruction compiled by state and tribal co-managers in the basin. The smolt estimate assumes a smolt survival rate of 75% from tributary traps through Lake Washington and does not include pre-terminal harvest.

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 (276,000 smolts), adult coho escapement at the Sunset Falls trap, and coded-wire tag groups from Wallace hatchery (CWT/non-mark since 1996). This estimate assumes that average smolt production has not changed and that harvest rates of hatchery and wild coho are comparable (nonmarked hatchery coho since 1996).

Marine survival of naturally produced coho in the Lower Columbia (Washington watersheds) was represented by a data series of coded-wire and blank-wire tagged natural coho released from Mayfield Dam between 2001 and 2010 (data provided by M. LaRiviere, Tacoma Power). Because the range of marine survival for Lower Columbia coho is largely unknown, a smolt-to-adult return (SAR) estimate was derived for the 2010 and 2011 return years in five watersheds where smolt abundance and spawners are concurrently estimated (Abernathy Creek, Coweeman River, Upper Cowlitz/Tilton River, Cedar Creek [NF Lewis]). SAR values are a proxy for but not the same as marine survival because SAR values do not include exploitation rates. SAR estimates are the total returns of unmarked adult coho spawners divided by the natural-origin smolt production from each watershed.

Indicator Selection

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. The time period used for these indicators (May through September) represents conditions following ocean entry of wild coho smolts.

At the “Region Scale”, I have applied one set of for the Oregon Coast and Columbia River to the Washington Coast and Lower Columbia management units and have derived comparable indicators for Puget Sound (Appendix C). The Washington Coast and Lower Columbia indicators 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 is fully described on the NWFSC website (http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/g-forecast.cfm). The Puget Sound indicators include temperature and salinity data in the Strait of Juan de Fuca (SJDF) and upwelling index at 48N. SJDF temperature and salinity data were compiled and derived from the Race Rocks lighthouse data set, selected to represent water exchange into and out of Puget Sound (Babson et al. 2006). The Bakun upwelling index at 48°N was selected to represent the amount of nutrient rich deep sea water available for transport into Puget Sound. Skagit River flows were selected as a proxy for freshwater input into Puget Sound as this river is responsible for more than 50% of the annual freshwater inflow (Moore et al. 2008a). The time period selected for these indicators (April to June) represents conditions when wild coho salmon enter the marine environment.

The “Local Scale” was applied to oceanographic regions (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 indicators at the local scale included freshwater inflow (river flows during outmigration period) and temperature and salinity in the upper 20 m of marine waters near each river mouth. Biological indicators 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 if a plankton sampling program becomes established in Puget Sound). A depth of 20 m was consistent with temperature indicators used by the NWFSC ocean monitoring research program and with observed swimming depths of juvenile coho salmon (Beamish et al. 2012). Temperature and salinity data were averaged between April and June, the time period that wild coho smolts enter marine waters. Chlorophyll and light transmission values were selected for the month of May, representing conditions at the peak of the wild coho outmigration into marine waters.

Statistical Analyses

Linear regression models were used to examine the relationships between each indicator and marine survival for each population identified in Appendix C. The analysis was limited to outmigration years 1999 - 2011 to align survival estimates with available indicator datasets. This date range also corresponds to the ocean regime following the regime shift identified to have occurred in the northeast Pacific ecosystem in 1998 (Peterson and Schwing 2003). Predicted survival of smolts entering the ocean in 2013 were calculated for all statistically significant ecological predictors ($\alpha = 0.10$). Marine survival applied to each MU was based on the model average calculated from all significant regressions for the monitored population in that MU (AICcmodavg version 1.26 in R).

Skagit River

Marine survival of wild coho from Baker River has ranged between 1.1% and 13.9% between return year 1992 and 2012 with no apparent trend over this time period (Figure 9). Marine survival of Skagit River wild coho was correlated with indicators at the Ocean and Regional scales but not the Local scale indicators (Table 6). Marine survival was higher when the ONI index was lower (cooler). Marine survival was also higher in years with more upwelling during the April to June period.

These indicators predicted marine survival to be between 7.4% and 10.7%. Model averaging resulted in a predicted marine survival rate of 7% (±1%, 95% C.I.). A 7% marine survival rate was therefore applied to the Skagit management unit as well as the three management units in North Sound (Nooksack, Strait of Georgia, and Samish) for which no wild coho marine survival data are available.

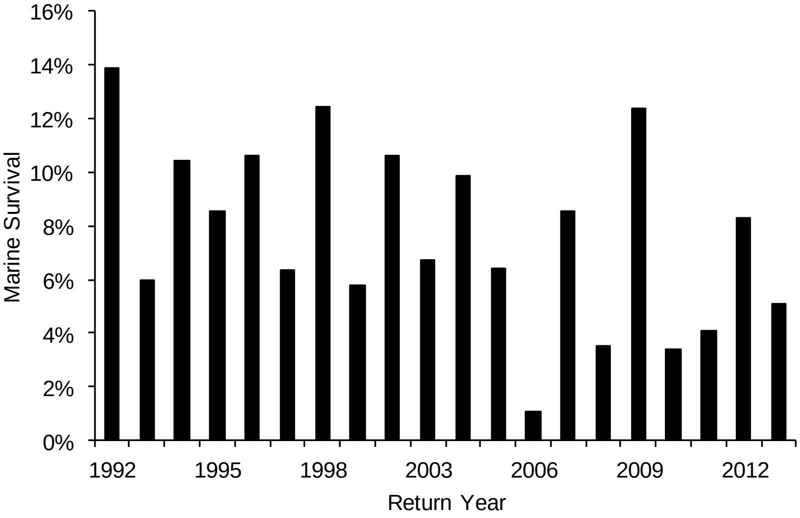

Figure 9. Marine survival of wild coho salmon form the Baker River (Skagit), return years 1992 to 2013. 2013 survival is preliminary.

Snohomish River

Marine survival of wild coho in the Snohomish River has ranged from 3.5% to 28.6% between return year 1979 and 2013 with no apparent trend over this time period (Figure 10). Marine survival of Snohomish River wild coho was weakly correlated with four indicators – one at the Region scale and three at the Local scale. Marine survival increased in years when sea surface salinity was higher in the Strait of Juan de Fuca (Race Rocks lighthouse, April – June of ocean entry year). Marine survival also increased in years when water density, salinity, and chlorophyll were higher at the local WA Ecology buoy (April – June of ocean entry year). Together, these indicators predicted that marine survival would range between 7% and 13%. Based on the weak correlations, however, the confidence intervals in these predictions were wide. Model averaging predicted a marine survival of 11% (± 2%, 95% C.I.), which was the marine survival applied to the Snohomish and Stillaguamish management units.

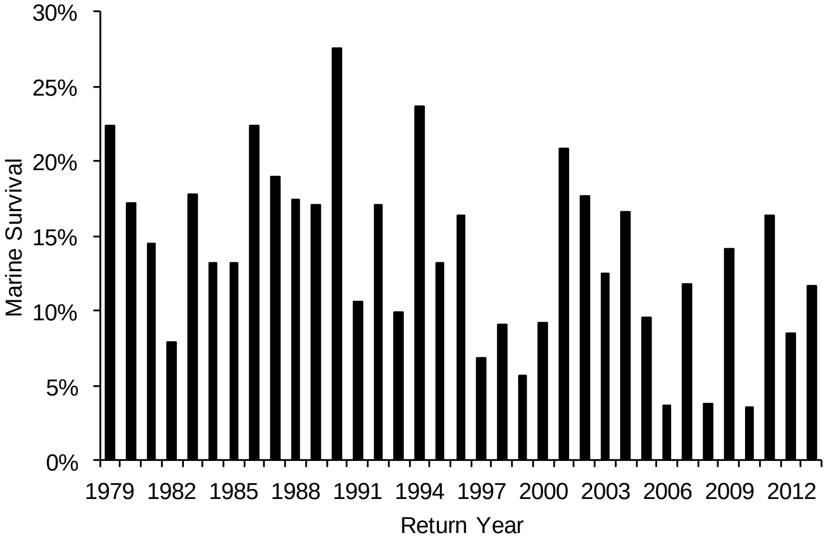

Figure 10. Marine survival of wild coho salmon in the SF Skykomish River, return years 1979 to 2013. 2013 estimate is preliminary.

Lake Washington

Marine survival for natural coho in Lake Washington has ranged between 0.5% and 14.4% between the 2003 and 2011 return years. These estimates do not currently include pre-terminal (ocean) exploitation and are thus not directly comparable to the other values provided in this document.

Of all the indicators explored for the Central basin, the ONI index was the only indicator correlated with marine survival of Lake Washington natural coho and this correlation was relatively weak (Table 8). Based on this index, smolt-to-adult return for the 2014 returns is predicted to be 6% for the Lake Washington MU. However the confidence intervals on this prediction range between 3% and 10% reflecting a high uncertainty in the selected value. Risk associated with the uncertainty of this survival rate may be buffered by pre-terminal exploitation, which was not included in the predictive model. A survival of 6% was applied to the Lake Washington, Green River, and East Kitsap MUs.

Deschutes River

Marine survival of Deschutes River natural coho has ranged between 1.1 and 29.5% with a declining trend over time (Figure 11). 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.

In order to increase the number of years used in the Deschutes analysis, we extended the dataset back to the 1990 ocean entry year (1991 return year). Two ocean scale, two regional scale and one local predictor were significant predictors of Deschutes coho marine survival (Table 9). This result was interesting in that this sub-basin is the furthest from the ocean of all Puget Sound sub-basins and might be expected to be more heavily influenced by local than ocean or regional predictors. Warmer temperatures at ocean scale (PDO prior to and during ocean entry), regional scale (Race Rocks lighthouse), and local scale (South Sound) were all associated with poorer survival. Upwelling along the coast at the inlet to the Strait of Juan de Fuca (48°N) was positively associated with Deschutes coho survival.

Based on the individual regressions, marine survival for the 2014 return year was predicted to range between 5.8% and 11.6%. Based on these predictions, a 8.0% marine survival rate was applied to the

Deschutes management unit. An 8.0% marine survival was also applied to the South Sound and Nisqually, and Puyallup MUs which share the same oceanographic basin as the Deschutes River (Babson et al. 2006).

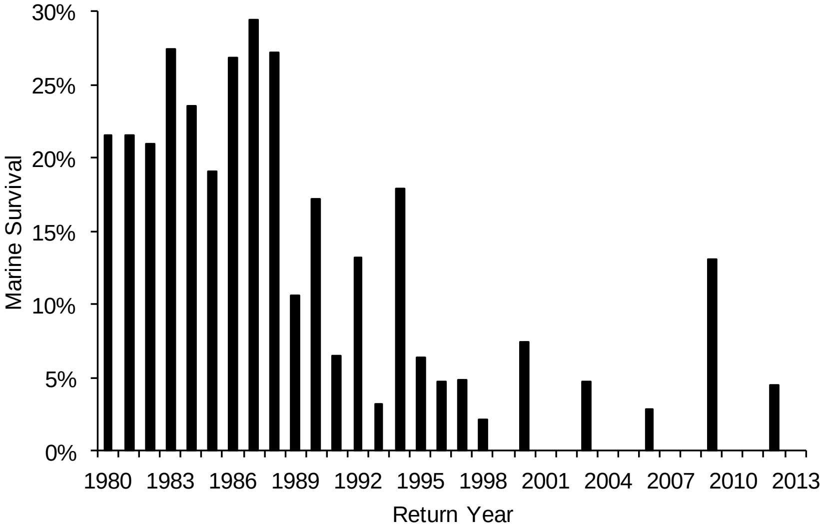

Figure 11. Marine survival of Deschutes River natural coho salmon, return years 1980 to 2013. Since 1998, marine survival estimates are only available for every third year due to too few smolts to tag on the alternate years.

Hood Canal

Marine survival of wild coho in Hood Canal is measured at Big Beef Creek and extrapolated to the management unit. Big Beef Creek is a low gradient system flowing off the Kitsap Peninsula into Hood Canal. Marine survival of Big Beef Creek wild coho has ranged from 2% to 32% between return year 1978 and 2013 with no apparent trend over this time period (Figure 12). The adult-to-jack survival ratio has varied widely over this time period (range 6 to 49 adults per jack coho).

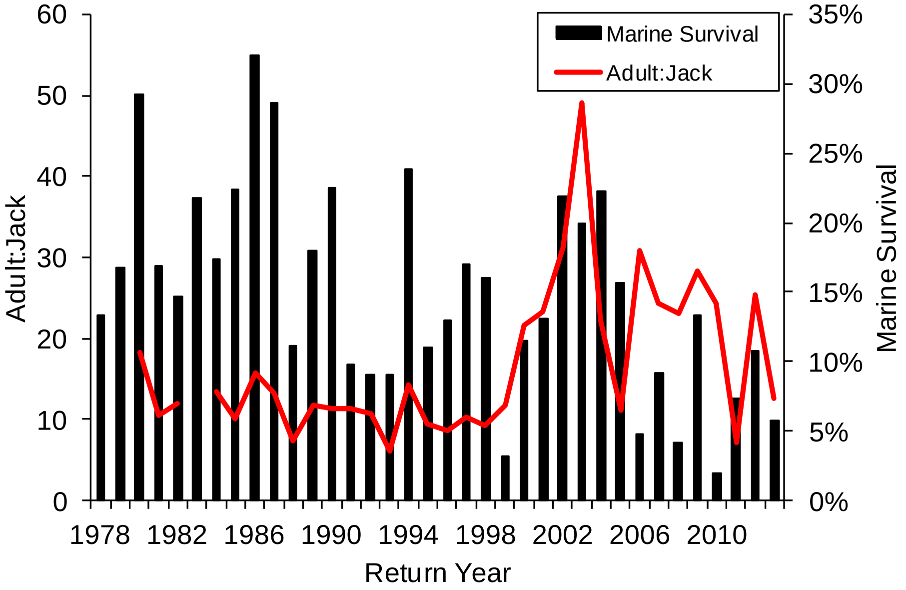

Figure 12. Marine survival and adult (age-3) per jack (age-2) ratio for Big Beef Creek wild coho, return year 1978 to 2013. 2013 results are preliminary.

Marine survival of Big Beef Creek wild coho was correlated with indicators at the Region and Local scales but not at the Ocean scale (Table 10). Marine survival was higher when salinity in the Strait of

Juan de Fuca (Race Rocks light house) was high and when light transmission was lower (water more opaque). Although most sets of ecological indicators predict similar survival rates, the two indicators correlated with Big Beef Creek coho predict very different marine survival rates. The preliminary estimate from the 2013 returns (5.3% marine survival with nonexpanded coded-wire tags) was much closer to the prediction based on Race Rocks salinity (2013 prediction = 7.5%) than local light transmission (2013 prediction = 17.9%) in the 2013 forecast. The regression was updated for the 2014 with an additional year of data and, similar to last year, these two regressions predicted very different marine survival rates for the 2014 return year (Race Rocks salinity predicts 13.7% and local light transmission predicts 3.4%). Furthermore, the relationship between marine survival and light transmission appears may be more appropriately fit with a step function than a linear regression (Figure 13). If the relationship between light transmission and marine survival is considered as a step function, a prediction of 13% marine survival for the 2014 return year appears reasonable. However, based on the uncertainty of this prediction, a rate of 10% is applied to the Hood Canal management unit (Table 1).

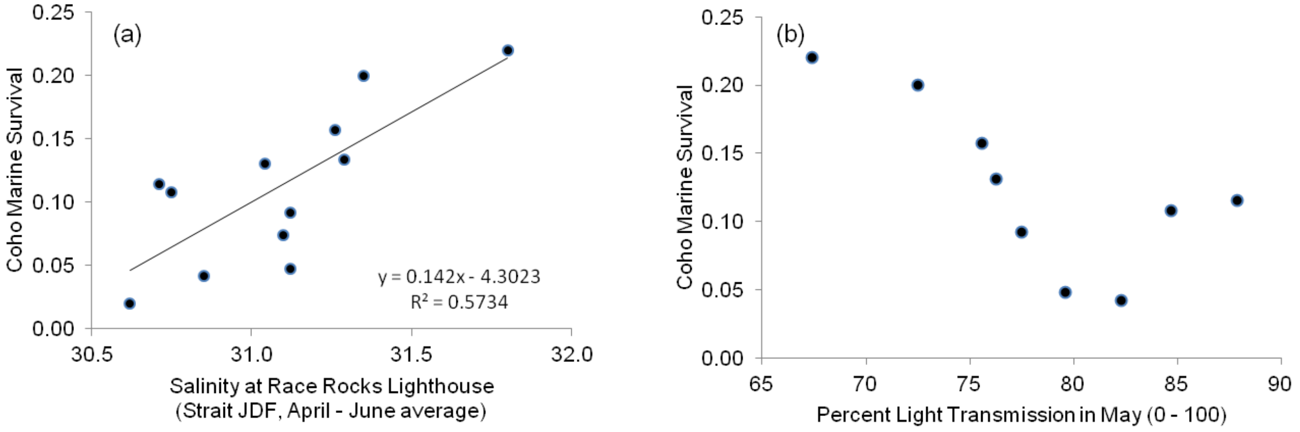

Figure 13. Relationships between marine survival of wild coho from Big Beef Creek (2000-2013 return years) and two ecological indicators. The percent light transmission at the Washington Department of Ecology buoy appears to be more of a step function than a linear relationship. Environmental conditions for the 2014 return year were 31.3 (salinity) and 90.4 (light transmission).

Coastal WA

Marine survival of wild coho in the coastal Washington region is measured at Bingham Creek and extrapolated to other regions of the coast. Bingham Creek is a tributary to the East Fork Satsop River, a right bank tributary to the Chehalis River. Marine survival of Bingham Creek wild coho has ranged from 0.6% to 11.7% between return year 1983 and 2013 with no apparent trend over this time period (Figure 14). The adult-to-jack survival ratio has varied widely over this time period (range 8 to 153 adults per jack coho).

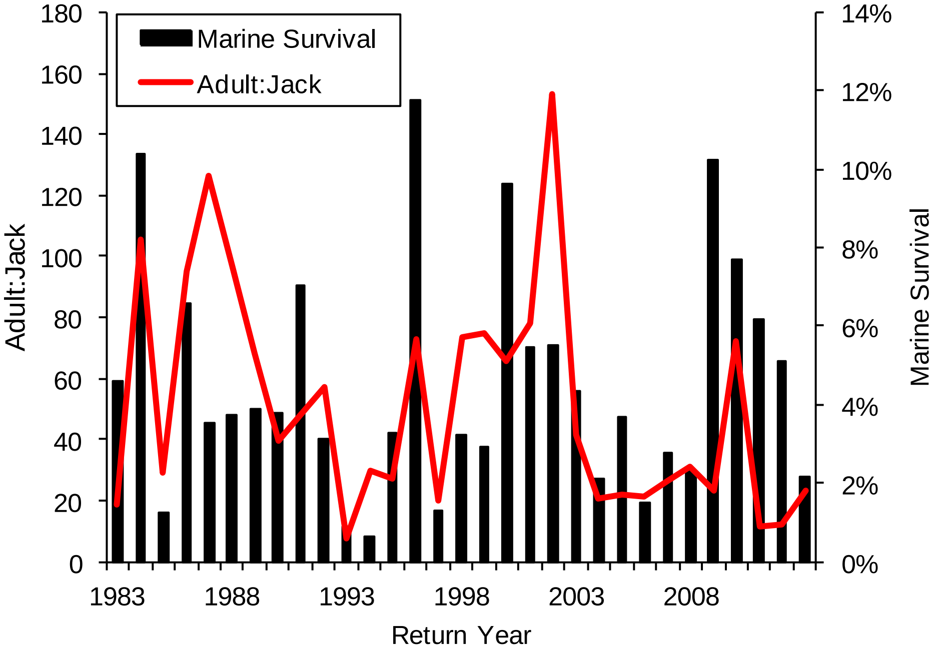

Figure 14. Marine survival and adult (age-3) per jack (age-2) return ratio of wild coho to Bingham Creek, Washington, return year 1983 to 2013. 2013 results are preliminary.

Marine survival of Bingham Creek wild coho was correlated with ten of the selected indicators at both the "Ocean" and "Region" scales (Table 11). The strongest predictors were the PDO index between May and September of the outmigration year and juvenile Chinook densities. Marine survival was lower under higher (warmer) PDO and ONI index values. Marine survival was also lower under higher copepod richness and southern copepod biomass values and was lower when biological transition dates were later. Marine survival was positively correlated with winter ichthyoplankton biomass and June catches of juvenile Chinook salmon. For the time series examined, marine survival of Bingham Creek wild coho was not correlated with physical indicators at the regional scale, except upwelling (more upwelling = better survival).

Individual regression equations predict that marine survival for the 2014 return will be between 4.9 and 6.9% (Table 11). Model averaging of these regressions predicted a 6% (±2%, 95% C.I.) marine survival. Therefore, a marine survival of 6.0% was applied to all management units in the coastal Washington region (Table 1).

Table 6. Marine indicators of wild coho marine survival from Baker River (Skagit), Washington, return year 1999 to 2012. Marine survival predictions for the 2014 coho returns were based on statistically significant correlations.

Indicator	Regression	AICc	Adj R^2	p-value	2014 Predict
Ocean Scale					
PDO.Dec.March	---	-39.37	---	*n.s.*	---
PDO.May.September	---	-41.27	---	*n.s.*	---
ONI.Jan.June	MS = 0.0597 - 0.0371x	-45.74	0.35	0.02	7.38%
Regional Scale (Physical)					
Race Rocks SST Apr-Jun	---	-41.21	---	*n.s.*	---
Race Rocks SSS Apr-Jun	---	-39.48	---	*n.s.*	---
Upwelling 48° N Apr-Jun	MS = 0.0789 + 0.0031x	-43.07	0.19	0.08	5.82%
Local Scale (Physical)					
Temp 20 m Apr-Jun	---	-7.17	---	*n.s.*	---
Density 20 m Apr-Jun	---	-9.43	---	*n.s.*	---
Salinity 20 m Apr-Jun	---	-8.8	---	*n.s.*	---
Local Scale (Biological)					
Chlorophyll 20 m May	---	Inf	---	*n.s.*	---
Light transmission May	---	2.56	---	*n.s.*	---

Table 7. Marine indicators of wild coho marine survival from SF Skykomish River, Washington, return year 1999 to 2012. Marine survival predictions for the 2014 coho returns were based on statistically significant correlations.

Indicator	Regression	AICc	Adj R^2	p-value	2014 Predict
Ocean Scale					
PDO.Dec.March	---	-30.61	---	*n.s.*	---
PDO.May.September	---	-31.46	---	*n.s.*	---
ONI.Jan.June	---	-30.5	---	*n.s.*	---
Regional Scale (Physical)					
Race Rocks SST Apr-Jun	---	-30.08	---	*n.s.*	---
Race Rocks SSS Apr-Jun	MS = -2.6159 + 0.0879x	-33.69	0.17	0.08	13.19%
Upwelling 48° N Apr-Jun	---	-30.39	---	*n.s.*	---
Local Scale (Physical)					
Temp 20 m Apr-Jun	---	-30.27	---	*n.s.*	---
Density 20 m Apr-Jun	MS = -0.978 + 0.0521x	-33.84	0.18	0.08	10.20%
Salinity 20 m Apr-Jun	MS = -0.8987 + 0.037x	-33.53	0.16	0.09	10.40%
Local Scale (Biological)					
Chlorophyll 20 m May	MS = 0.0643 + 0.0052x	-22.61	0.23	0.1	6.87%
Light transmission May	---	-31.13	---	*n.s.*	---

Table 8. Marine indicators of wild coho smolt-to-adult (SAR) return to the Lake Washington basin, return year 2003 to 2011. S ARdoes not include pre-terminal exploitaiton rates. SAR predictions for the 2014 coho returns were based on statistically significant correlations.

Indicator	Regression	AICc	$adjR^2$	P Value	2014 Predict
Ocean Scale					
PDO Dec-Mar	---	60.79	---	*n.s.*	---
PDO May-Sept	---	58.57	---	*n.s.*	---
ONI Jan-Jun	MS = 0.04208 - 0.05341x	56.24	0.35	0.05	6.24%
Region Scale (Physical)					
Race Rocks SST Apr-Jun	---	59.84	---	*n.s.*	---
Race Rocks SSS Apr-Jun	---	59.34	---	*n.s.*	---
Upwelling 48° N Apr-Jun	---	60.81	---	*n.s.*	---
Local Scale (Physical)					
Temp 20 m Apr-Jun	---	60.86	---	*n.s.*	---
Density 20 m Apr-Jun	---	61.11	---	*n.s.*	---
Salinity 20 m Apr-Jun	---	61.31	---	*n.s.*	---
Local Scale (Biological)					
Chlorophyll 20 m May	---	57.62	---	*n.s.*	---
Light transmission May	---	57.19	---	*n.s.*	---

Table 9. Marine indicators of natural coho marine survival from Deschutes River, return year 1991 to 2012. Marine survival predictions for the 2014 coho returns were based on statistically significant correlations.

Indicator	Regression	AICc	$adjR^2$	P-value	2014 Predict
Ocean Scale					
PDO Dec-Mar	MS = 0.0554 - 0.0326x	-44.66	0.38	0.02	6.90%
PDO May-Sept	MS = 0.0654 - 0.0199x	-44.15	0.35	0.02	7.92%
ONI Jan-Jun	---	-39.70	---	*n.s.*	---
Region Scale (Physical)					
Race Rocks SST Apr-Jun	MS = 0.7186 - 0.0669x	-48.82	0.56	0.003	11.58%
Race Rocks SSS Apr-Jun	---	-38.90	---	*n.s.*	---
Upwelling 48° N Apr-Jun	MS = 0.0719 + 0.0021x	-41.59	0.20	0.08	5.79%
Local Scale (Physical)					
Temp 20 m Apr-Jun	MS = 0.2717 - 0.0192x	-41.98	0.23	0.06	6.86%
Density 20 m Apr-Jun	---	-39.16	---	*n.s.*	---
Salinity 20 m Apr-Jun	---	-37.90	---	*n.s.*	---
Local Scale (Biological)					
Light transmission May	---	-33.34	---	*n.s.*	---
Chlorophyll 20 m May	---	Inf	---	*n.s.*	---

Table 10. Marine indicators of wild coho marine survival from Big Beef Creek, return year 1999 to 2012. Marine survival predictions for the 2014 coho returns were based on statistically significant correlations.

Indicator	Regression	AICc	adjR^2	P-value	2014 Predict
Ocean Scale					
PDO Dec-Mar	---	-28.00	---	*n.s.*	---
PDO May-Sept	---	-26.02	---	*n.s.*	---
ONI Jan-Jun	---	-26.03	---	*n.s.*	---
Region Scale (Physical)					
Race Rocks SST Apr-Jun	---	-26.09	---	*n.s.*	---
Race Rocks SSS Apr-Jun	MS = -4.3023 + 0.142x	-31.56	0.57	0.03	13.66%
Upwelling 48° N Apr-Jun	---	-26.28	---	*n.s.*	---
Local Scale (Physical)					
Skokomish River Flow Apr-Jun	---	-17.21	---	*n.s.*	---
Temp 20 m Apr-Jun	---	-17.73	---	*n.s.*	---
Salinity 20 m Apr-Jun	---	-17.98	---	*n.s.*	---
Local Scale (Biological)					
Light transmission May	MS = 0.739 - 0.0078x	-25.12	0.49	0.01.	3.39%
Chlorophyll 20 m May	---	-4.32	---	*n.s.*	---

Table 11. Marine indicators of wild coho marine survival from Bingham Creek, Washington, return year 1999 to 2012. Marine survival predictions for the 2014 coho returns were based on statistically significant correlations ($\alpha = 0.10$).

Indicator	Regression	AICc	Adj R^2	p-value	2014 Predict
Ocean Scale					
PDO.Dec.March	MS = 0.0516 + -0.0044x	-58.9	0.29	0.03	5.9%
PDO.May.September	MS = 0.0416 + -0.006x	-66.32	0.58	< 0.001	6.2%
ONI.Jan.June	MS = 0.0471 + -0.0231x	-58.78	0.27	0.03	5.6%
Regional Scale (Physical)					
SST.46050.May.Sept	---	-55.74	---	*n.s.*	---
NH.05.20.T.Nov.Mar	---	-55.83	---	*n.s.*	---
NH.05.20.May.Sept	---	-54.05	---	*n.s.*	---
NH05.Deep.Temp	---	-55.41	---	*n.s.*	---
NH05.DeepSal	---	-53.83	---	*n.s.*	---
Phys.Spr.Trans	---	-53.83	---	*n.s.*	---
Upwell.April.May	MS = 0.0616 + 0.0006x	-56.83	0.17	0.08	4.9%
Length.Upwell	---	-53.83	---	*n.s.*	---
NH05.SST.May.Sept	---	-53.83	---	*n.s.*	---
Regional Scale (Biological)					
Copepod.Rich.May.Sept	MS = 0.0517 - 0.0053x	-57	0.18	0.07	6.8%
N.Cop.May.Sept	MS = 0.0487 + 0.0396x	-56.7	0.19	0.08	6.3%
S.Cop.May.Sept	MS = 0.0503 - 0.0489x	-58.44	0.24	0.06	6.3%
Bio.Trans	MS = 0.0784 - 0.0002x	-56.73	0.16	0.08	6.0%
Winter.Ichth	MS = 0.0208 + 0.0316x	-59.1	0.29	0.03	5.7%
Chk.Juv.June	MS = 0.0231 + 0.0336x	-63.28	0.47	< 0.001	6.9%
Coho.Juv.Sept	---	-53.83	---	*n.s.*	---
Cop.Comm.Structure	MS = 0.0393 - 0.0305x	-58.49	0.26	0.03	6.3%

Lower Columbia

Smolt-to-adult return (SAR) estimates for the 2010 and 2011 return years ranged between 2.5% and 13.8% and varied among watersheds within years (Figure 15). At the time of this forecast SAR data are not available for the 2012 return year. The average SAR for the 2010 and 2011 return years was 6.8% which is equivalent to an 8.0% marine survival (assuming 15% exploitation rate). This suggests that marine survival rates of natural coho in the Lower Columbia may be comparable to wild coho survival on the Washington coast (Bingham Creek averaged 7.3% marine survival for the 2010 and 2011 return years). The differences among populations also suggests that marine survival of Lower Columbia populations vary across the region, warranting further investigation on spatially explicit indicators within the region as additional years of SAR values become available.

The longest data set of natural-origin coho SAR in the Lower Columbia is in the Cowlitz River where juvenile coho smolts were tagged (blank or coded-wire) at Mayfield Dam between 2001 and 2010. Over this time period, SAR ranged between 0.7% and 6.9%. The SAR of natural-origin Cowlitz River coho was correlated with just two ecosystem indicators at the "Region" scale (Table 12). Marine survival was higher in years with earlier dates for the physical spring transition and longer periods of upwelling. Individual regressions predicted that marine survival for the 2014 return will be between 2.0% and 4.1%. Model averaging predicted a 3.0% (±2%, 95% C.I.) marine survival which was applied to the Lower Columbia region (Table 1).

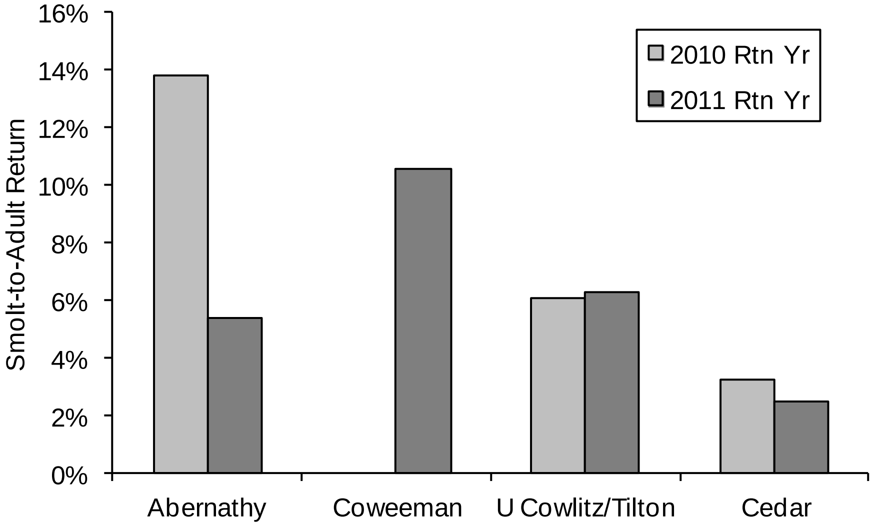

Figure 15. Smolt-to-adult return rates for natural coho salmon in five Lower Columbia watersheds.

Table 12. Marine indicators of wild coho marine survival from Cowlitz River, Washington, return year 2002 to 2011. Marine survival predictions for the 2014 coho returns were based on statistically significant correlations ($\alpha = 0.10$).

Indicator	Regression	AICc	Adj R^2	p-value	2014 Predict
Ocean Scale					
PDO.Dec.March	---	-45.76	---	*n.s.*	---
PDO.May.September	---	-43.05	---	*n.s.*	---
ONI.Jan.June	---	-43.00	---	*n.s.*	---
Regional Scale (Physical)					
SST.46050.May.Sept	---	-43.34	---	*n.s.*	---
NH.05.20.T.Nov.Mar	---	-44.31	---	*n.s.*	---
NH.05.20.May.Sept	---	-45.88	---	*n.s.*	---
NH05.Deep.Temp	---	-45.26	---	*n.s.*	---
NH05.DeepSal	---	-43.97	---	*n.s.*	---
Phys.Spr.Trans	MS = 0.0989 + -0.0006x	-51.23	0.51	0.01	4.07%
Upwell.April.May	---	-44.26	---	*n.s.*	---
Length.Upwell	MS = -0.0626 + 0.0005x	-51.63	0.53	0.01	1.94%
NH05.SST.May.Sept	---	-43.94	---	*n.s.*	---
Regional Scale (Biological)					
Copepod.Rich.May.Sept	---	-44.59	---	*n.s.*	---
N.Cop.May.Sept	---	-44.33	---	*n.s.*	---
S.Cop.May.Sept	---	-44.59	---	*n.s.*	---
Bio.Trans	---	-43.80	---	*n.s.*	---
Winter.Ichth	---	-43.20	---	*n.s.*	---
Chk.Juv.June	---	-43.70	---	*n.s.*	---
Coho.Juv.Sept	---	-44.80	---	*n.s.*	---
Cop.Comm.Structure	---	-45.08	---	*n.s.*	---

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 (Figure A-1). 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 2011 (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 2011 (corresponding to the 2012 outmigration and 2013 returning adults) had an index value of 7.2 or 90% 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.

			Puget Sound						
Scale	Type	Indicator	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]
R	P	River Flow Apr-Jun	12200500	12200500	12200500	12200500	12200500		USGS[2]
R	P	Race Rocks SST Apr-Jun	▨	▨	▨	▨	▨		DFO[3]
R	P	Race Rocks SSS Apr-Jun	▨	▨	▨	▨	▨		DFO [3]
R	P	Upwelling 48° N Apr-Jun	▨	▨	▨	▨	▨		NOAA-PFEL[4]
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[2]
L	P	Temp 20 m Apr-Jun	SAR003	PSS109	PSB003	BUD005	HCB003		WA ECY-MWMP[5]
L	P	Salinity 20 m Apr-Jun	SAR003	PSS109	PSB003	BUD005	HCB003		WA ECY-MWMP[5]
L	B	Chlorophyl 20 m May	SAR003	PSS109	PSB003	BUD005	HCB003		WA ECY-MWMP[5]
L	B	Light transmission May	SAR003	PSS109	PSB003	BUD005	HCB003		WA ECY-MWMP[5]
L	B	Percent Jack Return					▨	▨	WDFW Fish Science

[1] Ocean indicator data were provided by 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] River flow was daily average flows measured at USGS gage stations in associated rivers. Gage station IDs are provided in basin specific cells. Skagit River flow was used as a regional indicator for all Puget Sound regions. Data are available at http://waterdata.usgs.gov/wa/nwis/current/?type=flow

[3] 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

[4] 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

[5] Average water temperature (°C), salinity (PSU), chlorophyll (ug/l), and light transmission (%) in upper 20 m at marine station near associated river mouth. Marine station IDs are provided in basin specific cells. Data are available at http://www.ecy.wa.gov/programs/eap/mar_wat/ index.html

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