2013 Wild Coho Forecasts for Puget Sound, Washington Coast, and Lower Columbia

Washington Department of Fish & Wildlife

Science Division, Fish Program

by

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Introduction

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

Wild coho run sizes (adult ocean recruits) have been predicted using various approaches across Washington's coho producing systems. Methods that rely on the relationship between adult escapement and resulting run sizes are problematic due to inaccurate escapement estimates and difficulty allocating catch in mixed stock fisheries. In addition, escapement-based coho forecasts often have no predictive value because watersheds become fully seeded at low spawner abundances (Bradford et al. 2000). Furthermore, different variables in the freshwater (Sharma and Hilborn 2001; Lawson et al. 2004) and marine environments (Nickelson 1986; Ryding and Skalski 1999; Logerwell et al. 2003) influence coho survival and recruitment to the next life stage. Therefore, the accuracy of coho run size forecasts 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 production 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 in monitoring 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 production 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. Marine survival rates for wild coho stocks have been measured at four stations in Puget Sound and at one station in the Grays Harbor system. 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 for the last eighteen years. Beginning in 1996, 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 wild coho was added in 2000 (Seiler 2000) and 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 evolve, most notable in recent years are modifications to the marine survival predictions.

Table 1 summarizes the 2013 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 based on expected natural mortality in the final months of ocean residency in order to provide appropriate inputs for coho management models (expansion = 1.23 × ocean age-3 abundance). 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. 2013 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	1,237,000	9.0%	111,330	137,124
Stillaguamish River	477,000	9.0%	42,930	52,877
Snohomish River	820,000	9.0%	73,800	90,899
Hood Canal	323,000	7.0%	22,610	27,849
Straits of Juan de Fuca	**see note below**			
Secondary Units				
Nooksack River	135,000	9.0%	12,150	14,965
Strait of Georgia	16,000	9.0%	1,440	1,774
Samish River	33,000	9.0%	2,970	3,658
Lake Washington	57,000	6.0%	3,420	4,212
Green River	123,000	6.0%	7,380	9,090
Puyallup River	188,000	5.2%	9,776	12,041
Nisqually River	102,000	5.2%	5,304	6,533
Deschutes River	3,000	5.2%	156	192
South Sound	149,000	5.2%	7,748	9,543
East Kitsap	69,000	6.0%	4,140	5,099
Puget Sound Total	3,732,000		305,154	375,856
Coast				
Queets River	326,400	7.0%	22,848	28,142
Quillayute River	434,000	7.0%	30,380	37,419
Hoh River	217,000	7.0%	15,190	18,709
Quinault River	260,000	7.0%	18,200	22,417
Independent Tributaries	254,000	7.0%	17,780	21,899
Grays Harbor				
Chehalis River and Tribs	2,626,600	7.0%	183,862	226,461
Humptulips River	285,500	7.0%	19,985	24,615
Willapa Bay	680,000	7.0%	47,600	58,629
Coastal Systems Total	5,083,500		355,845	438,291
Lower Columbia Total	456,000	7.0%	31,920	39,316
GRAND TOTAL	9,271,500		692,919	853,463

Note: Tribal biologists measured smolt production in a number of Straits tributaries. Forecasts for the Straits will be based on this work.

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).

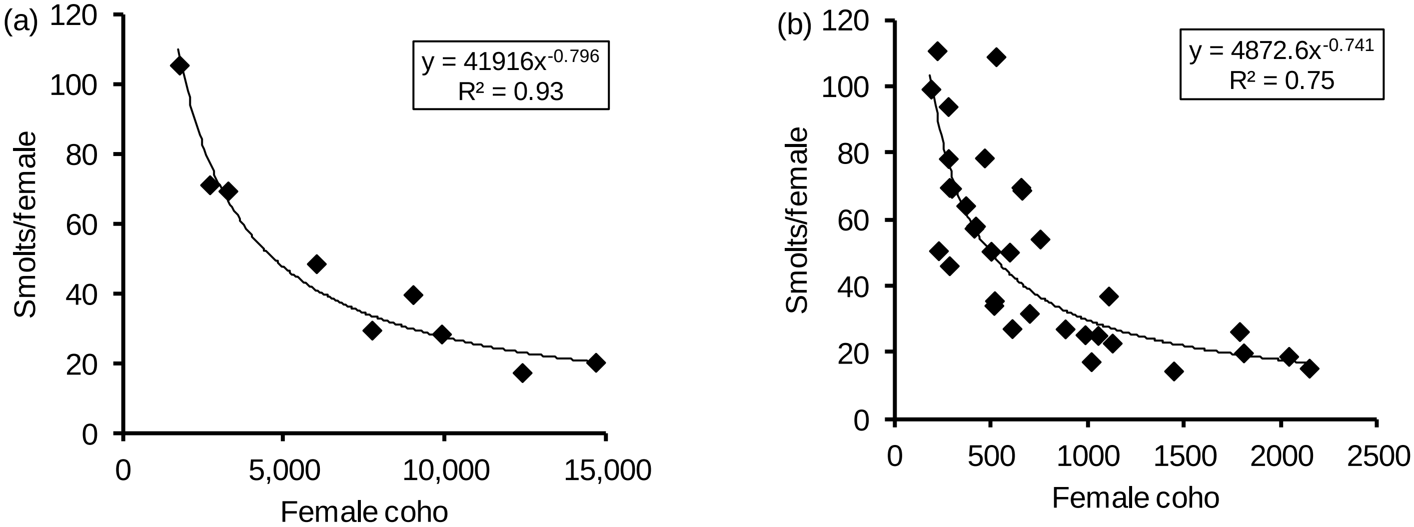

Figure 1. Freshwater productivity (juveniles/female) as a decreasing function of female coho escapement in the South Fork Skykomish (*a*, Sunset Falls, brood year 1976-1984) and Big Beef Creek (*b*, brood year 1978-2009) watersheds.

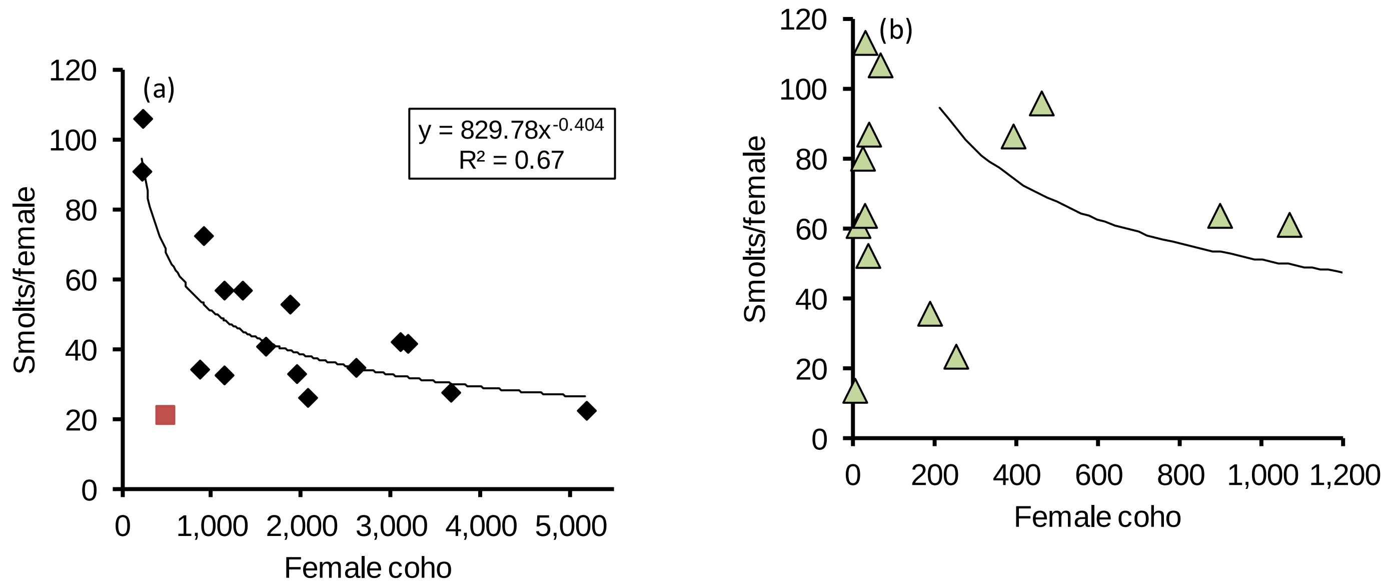

Figure 2. Freshwater productivity (juveniles/female) as a function of female coho escapement in the Deschutes River. For brood year 1978-1994 (*a*), coho productivity was a decreasing function of escapement (black square) with the exception of brood year 1989 (red square). The 1989 brood year corresponded 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 2012, WDFW measured coho smolt production 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 (Puyallup, East Kitsap, and South Sound) were available due to juvenile monitoring studies conducted by the Puyallup, Suquamish, and Squaxin Tribes. For watersheds where trapping data were not available in 2012, coho smolt production was estimated using several approaches.

One approach was based on the potential production 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 potential smolt production 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) enables 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, Appendix A). This index was used to estimate production in watershed where smolt production was historically measured in that watershed but was not available for a given year. 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 production from one year can be predicted by applying the ratio of summer low flows to smolt production from another year. 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. (Figure 3).

A third consideration when estimating coho production 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 was evident in the Skagit River but not the Green, Puyallup, or Nisqually rivers.

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	35	27,627	11,510	57,271	71.6%	29.8%	148.5%
Little Anderson	19	569	45	1,969	11.2%	0.9%	38.6%
Seabeck	19	1,369	496	2,725	13.0%	4.7%	26.0%
Stavis	19	5,413	1,549	9,667	107.7%	30.8%	192.3%
Skagit River	23	1,051,886	426,963	1,884,668	76.7%	31.1%	137.5%
SF Skykomish River	9*	249,331	212,039	353,981	82.0%	69.7%	116.4%
Stillaguamish River	3	284,142	211,671	383,756	42.9%	31.9%	57.9%
Green River	8	65,446	22,671	194,393	29.0%	10.1%	86.2%
Lake Washington							
Cedar River**	14	53,796	13,322	83,060	44.5%	11.0%	68.7%
Bear Creek	13	30,347	12,208	62,970	60.6%	24.4%	125.7%
Nisqually	4	155,048	80,048	228,054	134.2%	69.3%	197.4%
Deschutes***	34	46,701	1,187	133,198	21.3%	0.5%	60.7%

* Data does 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. Both age classes are known to contribute to adult returns.

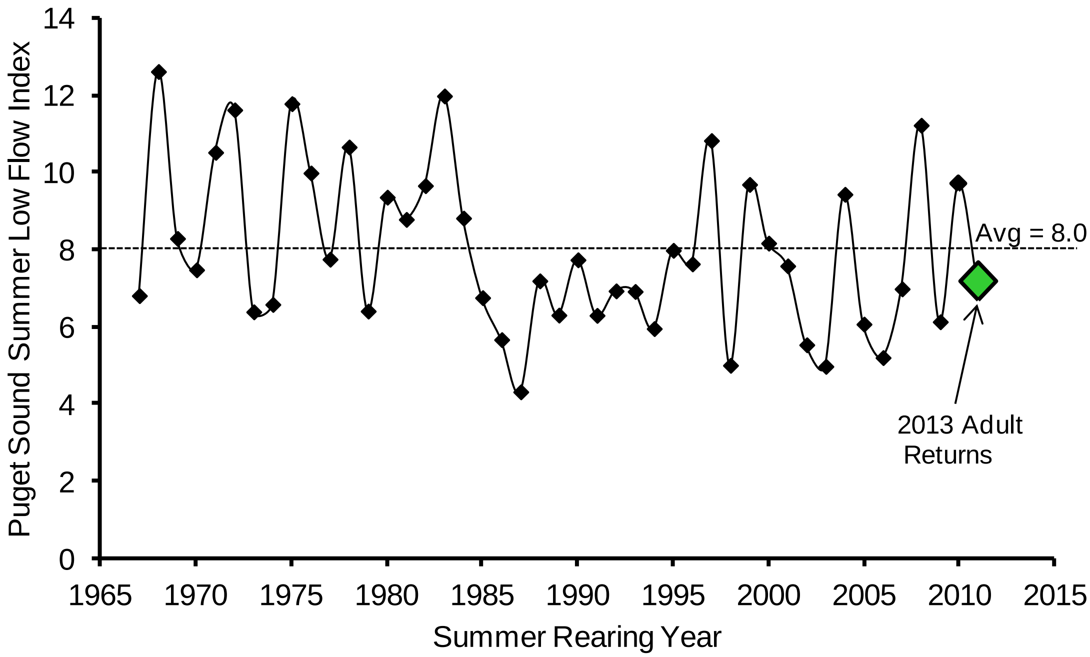

Figure 3. Puget Sound Summer Low Flow Index (PSSLFI) by summer rearing year (return year – 2). PSSLFI is based on 60-day minimum flow averages at eight stream gages in Puget Sound (see Appendix A). The minimum 60-day average flow at each gage is compared to its long-term average (1967 to present) and then summed across all eight gages. Flow index corresponding to the 2013 wild coho return is highlighted in green.

Puget Sound Primary Units

Skagit River

A total of 1,237,000 (±160,000, 95% C.I.) wild coho smolts are estimated to have emigrated from the Skagit River in 2012 (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 2012 smolt production was slightly higher than the long-term average of 1,052,000 smolts (Table 2).

Historically, coho smolt production in the Skagit River has been used to indirectly estimate production in the neighboring Stillaguamish and Snohomish rivers because no smolt data was available from these watersheds. In recent years, smolt trap operations on the Stillaguamish River (Stillaguamish Tribe) and the Skykomish and Snoqualmie rivers (Tulalip Tribe) have provided a comparison to this indirect method. Ideally, trap based estimates are a more direct measure of annual production. However, because the trap methods used to estimate smolt production are still being refined, the indirect application of Skagit River data is still useful for forecasting purposes. Therefore, further exploration of variables contributing to Skagit coho production is warranted.

Coho smolt production from the Skagit River in 2012 was 118% of its long-term average production of 1,051,886 (1990-2011). Two likely variables that influence coho smolt production from the Skagit River are summer rearing habitat and pink salmon escapement. A habitat assessment of coho summer and winter rearing habitat in the Skagit River identified that the capacity of summer rearing habitat is lower than that of winter rearing habitat (Beechie et al. 1994). Summer flows corresponding to the 2012 smolt production were more favorable in the Skagit River than other watersheds in Puget Sound. Although the PSSLFI associated with the 2012 smolt production was lower than average (Figure 3), the individual index in the Skagit River (Newhalem Creek) was 110% of its long-term average. In addition, in years when overwintering of coho parr corresponds with pink salmon egg deposition (odd year only), the resulting smolt production is positively correlated with abundance of pink salmon (Figure 4).

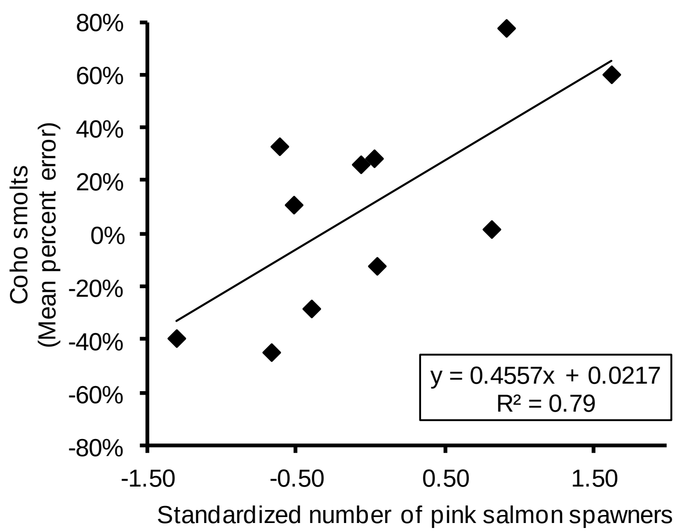

Figure 4. Coho smolt production as a function of pink spawner abundance in the Skagit River. Data are coho brood year 1988-2010 for broods when overwinter rearing overlaps with odd-year pink spawning. Smolts are the mean percent error [(Actual-Pred)/Predicted] of production predicted from female spawners alone. Pink spawner numbers were standardized to compare with other systems [(A-Avg(A)/SD(A)]. One outlier (BY 1996) was excluded from this analysis

Stillaguamish River

A total of 477,000 coho smolts are estimated to have emigrated from the Stillaguamish River in 2012 (Table 1). This estimate is based on historical data and the assumption that coho production is impacted by similar variables in the Stillaguamish and Skagit river systems. A juvenile trap was operated on the Stillaguamish River by the Tulalip Tribe in 2012; however, analyses of these data yielded an unreasonably high estimate which was not used in this forecast (J. Griffith, Stillaguamish Natural Resources, personal communication).

Between 1979 and 1981 brood years, WDFW measured coho production in the Stillaguamish River. During these years, the watershed was considered to be adequately seeded. A juvenile trap was operated upstream of river mile (R.M.) 16 between 1981 and 1983. Basin-wide production was the sum of estimated production above the trap and expanded production below the trap. The average production estimate above the trap was 284,000 smolts (Seiler 1984; Seiler et al. 1984), 42.9% of the predicted production potential for this portion of the watershed (Zillges 1977). Expanded production below the trap (86,000 smolts) was calculated by applying the ratio of measured to potential production above the trap (42.9%) to the potential production below the trap (201,520 smolts). Using this approach, average Stillaguamish coho production was estimated to be 370,000 smolts for the 1979 to 1981 brood years.

The 2012 Stillaguamish coho production was estimated to be 477,000 smolts, 129% of that measured in 1981-1983. This estimate assumed that escapement was adequate to fully seed the watershed and that coho survival was positively influenced by returns of pink salmon in 2011. Between 1985 and 2011, normalized values of pink salmon escapement were correlated between the Stillaguamish and Skagit River (Figure 5). High pink escapement resulted in a 29% increase in Skagit coho production over what would have been predicted based on escapement alone. In the Stillaguamish, assuming that a coho production of 370,000 smolts represents "average" production, this value was increased by 29% to 477,000 smolts for the 2012 smolt estimate.

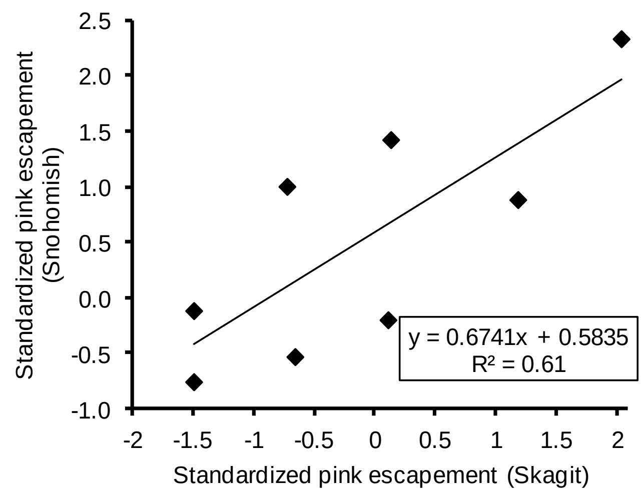

Figure 5. Correlation in pink salmon escapements between the Stillaguamish and Skagit watersheds, brood year 1985-2011. Escapement is normalized for comparison.

Snohomish River

A total of 820,000 coho smolts are estimated to have emigrated from the Snohomish River in 2012 (Table 1). The 2012 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 production 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 2012; 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. Coho production estimates were generated with a mark-recapture study design (Seber 1973). For a given brood year, the mark-recapture method applied the incidence of coded-wire tags in coho returns to the Sunset Falls adult trap to the number of tagged coho smolts released from the juvenile trap. This method accounts for South Fork Skykomish coho production above and below the trap. 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 escapement does not limited production was derived by expanding average coho production 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 production 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 2012 was estimated to be 820,000 smolts, 82% of the estimated watershed average. This estimate assumes that summer low flows limited the 2012 Snohomish coho smolt production. The adjustment was based on a comparison of the PSSLFI in 2011 to the average for 1982 to 1997 (82% = 7.15/8.78). The period between 1982 and 1997 are the summer rearing years corresponding to years when smolt production was measured. This estimate also assumes that the 2010 coho escapement to the Snohomish system was assumed to adequately seed the watershed. Returns to Sunset Falls in 2010 (8,889 adults, ~4,500 females) were at a level previously demonstrated to maximize smolt production from the South Fork Skykomish (Seiler 1996). This estimate assumes that odd-year pink salmon do not have a major influence on smolt production. Although pink salmon escapements are correlated between the Skagit and Snohomish rivers (Zimmerman 2011), the distribution of coho rearing and pink salmon spawning are less likely to overlap in the Snohomish than in the Stillaguamish and Skagit rivers. While the majority (71% estimated for 2010) of coho spawning in the Snohomish management unit occurs in the Snoqualmie River, the majority of pink salmon spawning occurs in the Skykomish and Snohomish river proper.

Hood Canal

A total of 323,000 coho smolts are estimated to have emigrated from Hood Canal tributaries in 2012 (Table 1). Production was not directly measured in all tributaries; therefore this estimate is based on an expansion of the measured production.

In 2012, wild coho production was measured in Big Beef Creek (n = 20,815), Little Anderson Creek (n = 566), Seabeck Creek (n = 1,030), and Stavis Creek (n = 2,168). 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 2012 production of coho smolts from Big Beef Creek, Seabeck, and Stavis Creeks were 75%, 40%, and 75% the long-term average production measured in these watersheds (Table 2). The 20,815 Big Beef Creek smolts were produced by 131 female spawners passed upstream of the weir in 2010 and represented a freshwater productivity of 159 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 2012 coho production from Little Anderson, which has received substantial in stream habitat restoration efforts, was 99% the long-term average production (Table 2).

Three approaches have been used to expand measured smolt production of wild coho to the entire the Hood Canal management unit. The first approach assumes that coho production 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 production from Big Beef Creek was 4.56% of Hood Canal.

The three approaches described above estimated that the 2012 wild coho production in Hood Canal ranged between 323,000 and 478,000 smolts. Using the Zillges approach, the total of 24,579 smolts from the four tributaries were expanded to an estimated 416,593 Hood Canal smolts. Using the second approach (HCJTC 1994 revision), the total of 24,579 smolts from the four tributaries were expanded to 323,400 Hood Canal smolts. The third approach expanded the 21,815 smolts from Big Beef Creek to a total of 478,399 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 135,000 coho smolts are estimated to have emigrated from the Nooksack River in 2012 (Table 1). Smolt abundance estimates from the Nooksack were not available in 2012. 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 production to be 20% and 50% of its predicted potential production 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 production in the Nooksack River (Seiler 1996). Summer low flows in 2011 were slightly below average (Figure 3) and were assumed to constrain the 2012 freshwater production of coho smolts. Based on these assumptions, the 2012 production of Nooksack wild coho was estimated to be 135,000 (30% of potential production).

Strait of Georgia

A total of 16,000 coho smolts are estimated to have emigrated from the Straits of Georgia watersheds in 2012 (Table 1). Coho smolt production has not been measured in any of the tributaries in this region. Therefore, production was estimated based on the potential predicted by Zillges (1977) and the assumption that 2011 summer low flows constrained the 2012 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 2012 coho production was estimated to be 16,000 smolts, 30% 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 2012 (Table 1). Coho smolt production has not been measured in the Samish River. Therefore smolt production 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 production from this basin would be less than the 100,000 smolts previously estimated.

The Samish River coho spawning escapement that contributed to the 2012 smolt production is estimated to be 2,005 coho, consistent with the return numbers observed over the past decade. Samish River adult coho escapement in 2010 was estimated from the number of fish enumerated and passed above the Samish Hatchery weir. Coho captured in the weir are released upstream to spawn. The Samish

Hatchery weir was operated for the collection of Chinook brood stock (late September to late October) and included the beginning but not the end of the coho run. Catch in the Samish Hatchery weir (through October 28, 2010) was expanded based on coho run timing at Sunset Falls (South Fork Skykomish River). In 2010, the 1,644 coho (754 females) released above the Samish weir were assumed to be 82% of the run, resulting in a total escapement estimate of 2,005 coho.

Assuming a marine survival rate of 6%, an average of 33,000 smolts will result in a return of 2,005 coho spawners. This estimate corresponds to 33 smolts/female (assume 1:1 male:female) and 30% of the potential production predicted by Zillges (1977), both reasonable values when compared to other watersheds. The Zillges (1977) calculated 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 57,000 coho smolts are estimated to have entered Puget Sound from the Lake Washington basin in 2012 (Table 1). This estimate is based on measured production 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 production 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 2012, coho production was estimated to be 48,168 (±9,675 95% C.I.) smolts from the Cedar River and 16,059 (±1,325 95% C.I.) smolts from Bear Creek (Kiyohara In Review). Coho production in the Cedar River and Bear Creek has been monitored from 1999 to present. Over this period of time, coho production has not been correlated between these two watersheds. 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 production 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 2012 coho production from Issaquah Creek was estimated by scaling the 2000 estimate for this creek (19,812 smolts; Seiler et al. 2002a) by the 2012 to 2000 production ratios in Bear Creek. Both watersheds should be influenced by returns of natural and hatchery coho and summer low flows. In 2012, coho smolt production in Bear Creek was 57% of that measured in 2000 (16,059/28,142 = 57%). Therefore, 2012 coho production from Issaquah Creek was estimated to be 11,293 smolts (19,812 * 0.57).

The total coho production of 57,000 smolts assumed 75% survival through Lake Washington. Coho abundance estimated to enter Lake Washington was 75,520 smolts (48,168 Cedar + 16,059 Bear +

11,293 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 low (Kiyohara and Zimmerman 2012).

Green River

A total of 123,000 natural-origin coho smolts are estimated to have emigrated from the Green River in 2012 (Table 1). This estimate is the sum of 48,148 smolts upstream of the juvenile trap (river mile 34), 27,759 smolts below the juvenile trap, and 47,471 smolts from Big Soos Creek.

In 2012, coho production above river mile 34 was 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 48,148 (±23,498 95% C.I.) smolts (Topping In Review). This represents 22% of the 223,106 production 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 27,759 smolts based 22% 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. Production of coho smolts from Big Soos Creek was not measured in 2012. A juvenile trap was operated in Big Soos Creek in 2000, and natural-origin coho production was 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, 2012 production from this creek was based on the ratio of PSSLFI values between the 2012 and 2000 outmigration years (see Appendix A for explanation of PSSLFI). This ratio (7.2/9.7 = 74.2%) converts to an estimated 47,741 smolts (0.742*64,341).

Puyallup River

A total of 188,000 coho smolts are estimated to have emigrated from the Puyallup River in 2012 (Table 1). This estimate is based on measured production in the Puyallup River above the juvenile trap (58,000), an estimated production from the White River (124,000), and an estimate from the Puyallup River below the Puyallup-White confluence (7,000).

In 2012, the Puyallup Tribe operated a juvenile fish trap on the Puyallup River just upstream of the confluence with the White River. A total of 57,704 coho smolts were estimated to have migrated past the juvenile trap (A. Berger, Puyallup Tribe, personal communication). These coho smolts represent 20.9% of the production potential for the watershed from the Puyallup-White confluence to Electron dam (Zillges 1977). However, the actual rate is lower than this percentage as the 2012 smolts had access to spawning and rearing habitat 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. Coho production below the Puyallup and White confluence was estimated to be 6,694 smolts based on a rate of 10% of potential production applied to the 66,943 potential production of the lower Puyallup (Zillges 1977).

Coho production from the White River was estimated to be 124,000 smolts. Coho production from the Puyallup White confluence to Buckley Dam was estimated to be 10,000, 10% of the potential production for this portion of the watershed (Zillges 1977). Coho production from above Buckley dam was estimated to be 114,000 smolts based on the number of females passed above Buckley Dam in 2010

(4,555/2 = 2,278) multiplied by 50 smolts per female. Fifty smolts per female is a survival that might be expected in system where moderately low escapement did not fully seed the watershed (Figure 1).

Nisqually River

A total of 102,000 coho smolts are estimated to have emigrated from the Nisqually River in 2012 (Table 1). Production was estimated based on measured production above a main-stem trap (river mile 12) and expanded production 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 production above the trap (river mile 12) was estimated to be 80,048 (±16,631 95% C.I.) smolts, 69% of the 115,554 smolt potential predicted by Zillges (1977). Production below the trap was estimated to be 21,920, which is 69% of the potential production predicted for this portion of the watershed (Zillges 1977). Total watershed production was the sum of these two estimates (80,048 + 21,920 = 101,968).

Deschutes River

A total of 3,000 coho smolts are estimated to have emigrated from the Deschutes River in 2012 (Table 1), representing 1.4% (3,000/219,574) of the production 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 804 smolts was expanded by a trap efficiency of 24.7%.

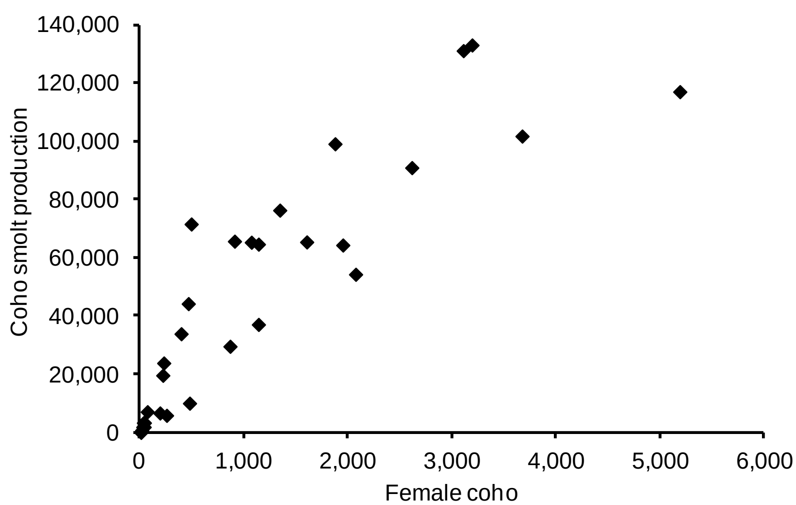

Figure 6. Coho smolt production as a function of female spawners in the Deschutes River, Washington, brood year 1978-2010.

Production of coho smolts in the Deschutes River is primarily limited by escapement (Figure 4), 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 2010 brood, one of the week brood years, just 19 females returned to spawn (Figure 6). A history of chronic and low marine survival was likely a major factor driving the current low abundance of this stock, although habitat degradation in the upper watershed and high incubation flows may also have contributed.

South Sound

A total of 149,000 coho smolts are estimated to have emigrated from South Sound tributaries in 2012 (Table 1). This estimate was based on results of juvenile monitoring studies in Cranberry and Goldsborough creeks conducted by the Squaxin Island Tribe. Wild coho smolt production in Cranberry Creek was 379 smolts and in Goldsborough Creek was 30,082 smolts (Joseph Peters, Natural Resources

Department, Squaxin Island Tribe, personal communication). This production represented 1.8% of the production potential for Cranberry Creek and 42% of the production potential for Goldsborough Creek (Zillges 1977). Low production rate of South Sound coho is likely to be driven by low escapement of South Sound coho (as observed in the Deschutes River) in addition to the general geomorphology and land development associated with watersheds in this region. Coho production for the entire South Sound management unit was estimated to be 126,000 smolts based on 21.9% of the 573,770 smolt potential for all watersheds in this management unit (including production above Minter hatchery rack) predicted by Zillges (1977).

East Kitsap

A total of 69,000 coho smolts are estimated to have emigrated from East Kitsap tributaries in 2012 (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 production 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).

In 2011, the Suquamish Tribe began a smolt monitoring study on Lost and Wildcat creeks which continued in 2012 (J. Oleyar, Suquamish Tribe, personal communication). Based on Zillges (1977) projections, the production potential above the trap locations is 2,513 smolts on Lost Creek and 6,875 smolts on Wildcat Creek. The measured 2012 coho production of 4,254 smolts from Lost (n = 1,102) and Wildcat (n = 3,152) creeks was 45.3% of the production potential calculated by Zillges. Coho production for the East Kitsap management unit was estimated to be 70,000 smolts based on 45.3% of the 154,973 smolt potential for all watersheds in this management unit predicted by Zillges (1977).

Alternately, the measured coho production represents 0.184 and 0.193 smolts/yd^2 respectively according to Zillges (1977) calculations of rearing habitat (J. Oleyar, Suquamish Tribe). If this annual productivity value (average = 0.188 smolts/yd^2) is applied to the 368,984 yd^2 of rearing habitat in the entire management unit, a total of 69,000 smolts are estimated in 2012. The forecast is based on the lower, slightly more conservative estimate.

Coastal Systems Smolt Production

Approach

The major coho producing watersheds of Coastal Washington include the Queets, Quillayute, Hoh, and Quinault rivers, Grays Harbor, and Willapa Bay as well as fourteen small tributaries (Appendix B). These watersheds range from the high-gradient northern rivers draining from the western Olympic Mountains to the low-gradient, rain-fed southern watersheds of Grays Harbor and Willapa Bay. Where juvenile trapping studies have been conducted on these watersheds, smolt production has averaged from 400 to 900 smolts per unit (mi^2) of drainage area (Table 3). Low-gradient watersheds, such as the Chehalis (Grays Harbor) or Dickey (tributary to the Quillayute) rivers, have consistently had a higher production rate than high-gradient watersheds, such as the Clearwater (Queets tributary) or Bogachiel (Quillayute tributary) rivers.

In 2012, WDFW measured wild coho production in the Chehalis River watershed. Smolt production from the Queets management unit was available due to juvenile monitoring conducted by the Quinault Tribe. Historical smolt production data is also available from the Dickey and Bogachiel rivers in the Quillayute watershed. In coastal watersheds where production was not estimated in 2012, wild coho production was estimated by applying a production rate (smolts/mi^2) to the entire drainage area of the watershed (drainage areas in Appendix B). Among the factors considered when applying a production rate to each watershed were baseline data (historical production 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	818.3	709.4	891.4
Bogachiel (Quillayute)	3	53,751	48,962	61,580	416.7	379.6	477.4
Clearwater (Queets)	31	69,505	27,314	134,052	496.5	195.1	957.5
Queets (no Clearwater)	29	199,321	53,473	352,693.5	643.0	172.5	1,137.7
Chehalis (Grays Harbor)	29	2,018,476	502,918	3,769,789	954.8	237.9	1,783.2

Queets River

A total of 326,403 wild coho smolts are estimated to have emigrated from the entire Queets watershed in 2012 (Table 1). This estimate was based on coho production measured in the Queets River by the Quinault Tribe (Tyler Jurasin, Quinault Tribe, personal communication) and includes production from the Clearwater River. Smolt production from the Clearwater River alone was not estimated in 2012. The production rate for the Queets River (including the Clearwater) was 725 smolts/mi^2.

Quillayute River

A total of 434,000 coho smolts are estimated to have emigrated from the Quillayute River system in 2012 (Table 1). This estimate is based on historical measures of smolt production in two sub-basins of the Quillayute River and a comparison of production rates in these sub-basins and the Queets River, where smolt production was measured in 2012. In past years, this adjustment was made using historical smolt production from the Clearwater (a tributary to the Queets); however, no results were available for the Clearwater in 2012.

In the Quillayute watershed, smolt production has been measured historically in the Bogachiel and Dickey rivers. Coho production above the Dickey River trap averaged 71,189 coho (818 smolts/mi^2) between 1992 and 1994. Coho production in the Bogachiel River averaged 53,751 smolts (417 smolts/mi^2) over three years (1987, 1988, and 1990). The different in production rates between watersheds was hypothesized to result from the lower gradient of the Dickey than the Bogachiel (Seiler 1996). This was further supported by the relatively high number of smolts per unit drainage area observed in the low-gradient Chehalis River (Table 3). Lower gradient topography may increase access and availability to summer and winter rearing habitats (Sharma and Hilborn 2001).

During the period of historical monitoring in the Dickey and Bogachiel rivers, average wild coho production was estimated to be 306,000 coho 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 production the remainder of the basin. Average production for the entire Dickey River sub-basin was estimated by applying the production rate above the trap (818 smolts/mi^2) to the total drainage area (108 mi^2), resulting in 88,344 smolts. Average production for the Quillayute system outside the Dickey River was estimated by applying the production rate 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 2012 Quillayute coho production was based on previously measured production of this system adjusted by the ratio of current to previous measured production from the Queets River. Because of the differences in production per unit area in the Dickey and Bogachiel rivers, the two regions of the watershed were estimated separately. The 2012 coho production in the Dickey River was estimated to be 134,283 smolts (1.52*88,344 smolts). The 1.52 expansion factor was the ratio of Queets River production in 2012 (326,403 smolts) to average Queets River production in 1992-1994 (326,403/214,114 = 1.52). The 2012 coho production in the Quillayute (excluding the Dickey) was estimated to be 299,815 smolts (1.38*217,257 smolts). The 1.38 expansion factor was the ratio of Queets River coho smolt production in 2012 to average Queets River smolt production in 1987, 1988, and 1990 (326,403/236,099 = 1.38). The total 2012 coho production of 434,000 smolts was the sum of these estimates (134,283 + 299,815).

Hoh River

A total of 217,000 wild coho smolts are estimated to have emigrated from the Hoh River in 2012 (Table 1). Smolt production was not directly measured in this watershed; therefore the estimate was based on production rate in the Queets River. The Hoh and Queets rivers have similar watershed characteristics as well as regional proximity. The production rate of 725 smolts/mi^2 from the Clearwater was applied to the 299-mi^2 of the Hoh watershed and resulted in an estimated 217,000 smolts from the Hoh River system.

Quinault River

A total of 260,000 wild coho smolts are estimated to have emigrated from the Quinault River in 2012 (Table 1). Smolt production was not directly measured in this watershed; therefore, the estimate was based on production rate of 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 2012, a production rate of 600 smolts/mi^2 was applied to the 434-mi^2 Quinault River system, resulting in an estimated 260,000 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 2012, 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 2,912,000 coho smolts are predicted to have emigrated from the Grays Harbor system in 2011 (Table 1). This estimate was derived in three steps. First, we estimated the coho smolt production for the Chehalis River (including the Wishkah). Second, this estimate was expanded to Grays Harbor tributaries excluding the Humptulips. And third, we estimated smolt production from the Humptulips River.

Coho smolt production 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 production 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). Therefore, smolt estimation is delayed one year from the actual trap operation (i.e., production is estimated after adults have passed through the fishery). The Wishkah River is included in this mark-recapture estimate because untagged fish from this tributary are assumed to be intercepted in the terminal net fishery. Production from other tributaries to Grays Harbor (Hoquaim, Elk, and Johns) as well as the Humptulips are estimated by extrapolating smolts/mi^2 from the Chehalis to these watersheds.

Due to the one-year lag in the final smolt estimate, a preliminary estimate is used for the run size forecasts. In order to derive a preliminary estimate of the 2012 smolt production, four variables were examined for their predictive value. Variables were maximum and minimum spawning flows (November 1 to December 15), maximum incubation flow (December 15 to March 1), and minimum summer rearing flows (minimum of 60-day average, March 1 to November 1). The analysis was limited to an 12 year data set (smolt year 2000 to 2011) 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). The 2012 coho smolt production was associated with moderate incubation (20,500 cfs maximum) and moderate rearing (280 cfs 60-day average) flows. The 2012 smolt production was predicted to be 2,414,885 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 1,987,181 and 2,842,588 smolts.

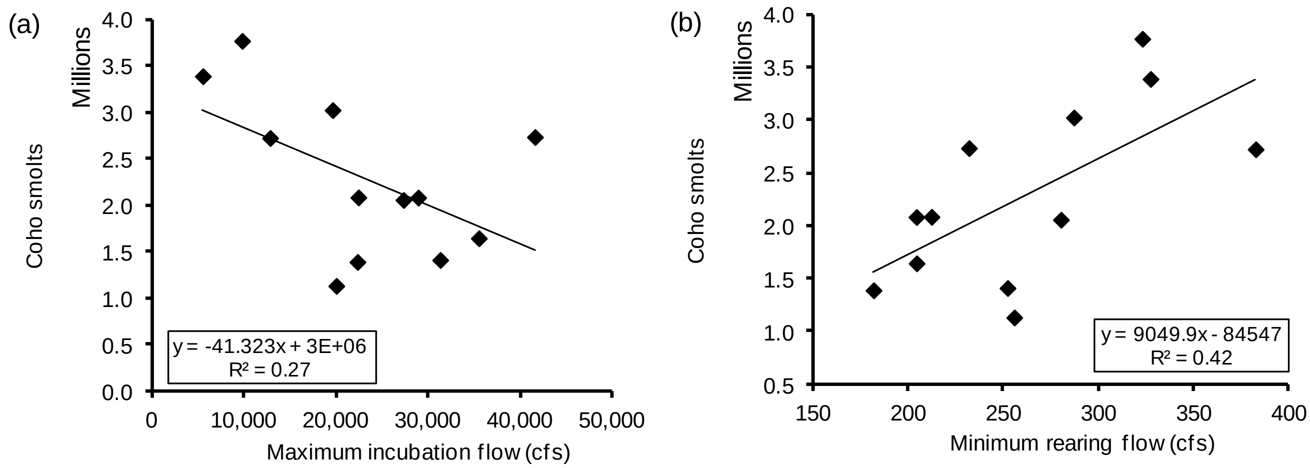

Figure 7. Chehalis River wild coho smolt production as a function of incubation flows (a) and summer rearing flows (b), brood year 1998-2009. Incubation flows are the maximum daily mean flow between December 15 and March 1. Summer rearing flows are the minimum of the 60-day average flow between March 1 and Nov 1 (USGS gage ##12027500, Grand Mound).

Coho production for other portions of the Grays Harbor management unit was estimated from the production per unit area for the Chehalis River basin. Production per unit area for the Chehalis basin including the Wishkah River was 1,142 smolts/mi^2 (2,414,885 smolts per 2,114 mi^2). A total of 2,626,600 coho smolts are estimated for the entire Chehalis Basin (2,300-mi^2, including the Hoquiam, Johns, and Elk Rivers and other tributaries below the terminal fishery). Coho production from the Humptulips River was estimated to be 285,500 smolts (1,142 smolts/mi^2*250 mi^2). After summing production estimated for all watersheds in the Grays Harbor management unit, total wild coho production was estimated to be 2,912,000 smolts (2,626,600 + 285,500).

Willapa Bay

A total of 680,000 coho smolts are estimated to have emigrated from the Willapa Bay basin in 2012 (Table 1). As production was not directly measured, this estimate is based on production per unit area of 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 production per unit area is likely to be somewhat lower than observed in the Chehalis Basin. Wild coho production in 2012 (680,000 smolts) was calculated by applying 800 smolts/mi^2 production rate to the total basin area (850 mi^2).

Lower Columbia Smolt Production

Approach

Coho smolt production is monitored in a subset of Lower Columbia watersheds. To estimate total smolt production for this management unit, densities in monitored watersheds (smolts per watershed area) were used to derive production values for non-monitored systems. The associated between coho salmon smolt production 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.

In 2012, coho smolt production was directly monitored in eight watersheds using partial-capture juvenile traps and a mark-recapture study design. Coho salmon smolt production estimates were calculated using a mark-recapture study design appropriate for single trap designs (Carlson et al. 1998; Volkhardt et al. 2007). 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 designs, where care was taken to meet the assumptions required for unbiased population estimates. 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. Therefore, actual number of emigrating smolts were fewer than the number of smolts used to estimate production densities above the trap.

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 few and high percentages of hatchery spawners as well as streams of varying size and habitat condition. Stream size ranges 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. Habitat in the Toutle and NF Toutle Rivers included only drainage areas from tributaries. Habitat in the Toutle main stems, which is still recovering from the eruption of Mt. St. Helens, was excluded because it is believed natural production is very limited in this area.

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 2012, 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 2010; Zimmerman 2011).

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. In these watersheds, smolt production was estimated by applying the mean density of smolts in “hatchery monitored” watersheds to the summed area of non-monitored watersheds. Mean coho smolt densities in “wild monitored” watersheds were applied to the summed area of non-monitored watersheds without hatchery releases.

Grays River

The Grays River juvenile trap is located at river mile 6. Based on a watershed area of 23 mi^2, the 2012 coho smolt production density was estimated to be 193 smolts/mi^2 (Table 4). A total of 5,014 natural-origin coho smolts are estimated to have emigrated from the Grays River in 2012 (Table 5).

Mill, Abernathy, and Germany Creeks

Juvenile traps on Mill, Abernathy, and Germany creeks are located near the mouth of each creek. The 2012 coho smolt production density of these watersheds ranged between 233 and 308 smolts/mi^2 (Table 4). A total of 22,374 natural- origin coho smolts were estimated to have emigrated from all three watersheds in 2012 (Table 5). This included 8,918 smolts from Mill Creek, 8,106 smolts from Abernathy Creek, and 5,350 smolts from Germany Creek.

Tilton River

The Tilton River juvenile trap is located at Mayfield Dam in the Cowlitz watershed. Collection efficiency for this site was estimated to be 66.4% for coho salmon smolts based on the only trap efficiency data known to be available (Paulik and Thompson 1967). When estimating the 2012 smolt production, a release of 1,000 smolts and a recapture of 664 were assumed in order to expand the Mayfield Dam catch to a total production estimate for the Tilton River.

Based on a watershed area of 159 mi^2, the 2012 coho smolt production density of the Tilton River was estimated to be 286 smolts/mi^2 (Table 4). The total number of coho emigrating from the Tilton was 43,159 (Table 5) smolts, this included the 30,185 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 163 smolts/mi^2 in 2012 (Table 4). The total number of coho emigrating from the Upper Cowlitz was the 9,757 smolts captured at Cowlitz Falls Dam and trucked to the Lower Cowlitz River (Table 5).

Coweeman River

Coho smolt production 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 production density from the Coweeman River was estimated to be 118 smolts/mi^2 in 2012 (Table 4).The total number of coho emigrating from the Coweeman River in 2012 was estimated to be 14,014 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 2012 coho smolt emigration from the Cedar River was estimated to be 38,263 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 production density of Cedar Creek was estimated to be 831 smolts/mi^2 (Table 4). This estimate was based on the natural-origin production above the smolt trap. Natural production was a portion of the total production. All RSI embryos are thermally marked and otoliths are collected from a subsample of smolts in the juvenile trap. Natural-origin smolt abundance was estimated by multiply the natural origin proportion by the annual smolt estimate. The proportion of natural origin coho smolts was determined from otolith decoding of the subsampled smolts. However, since otoliths have not been decoded since 2007, the mean natural origin proportion from 2004 to 2006 (0.87) was applied to the 2012 outmigration estimate.

Historically, Cedar Creek density estimates 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 used when extrapolating smolt densities to 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 141,205 (104,942 – 177,468 95% C.I.) smolts (Table 5). This estimate was derived from an average smolt production density of 175 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 151,683 (119,530 – 183,836 95% C.I.) smolts (Table 5). This estimate was derived from an average smolt production density of 244 smolts/mi^2 in "wild monitored" watersheds and an estimated 620 mi^2 of non-monitored drainage area.

Total Lower Columbia Smolt Production

The density of smolts emigrating from each Washington Lower Columbia watershed in 2012 was near or slightly higher than the 5-year (Figure 8). In total, 456,000 natural-origin coho smolts are estimated to have emigrated from the Washington Lower Columbia region in 2012 (Table 1). The 95% confidence intervals for this estimate range between 299,384 and 507,434 smolts. This production 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.

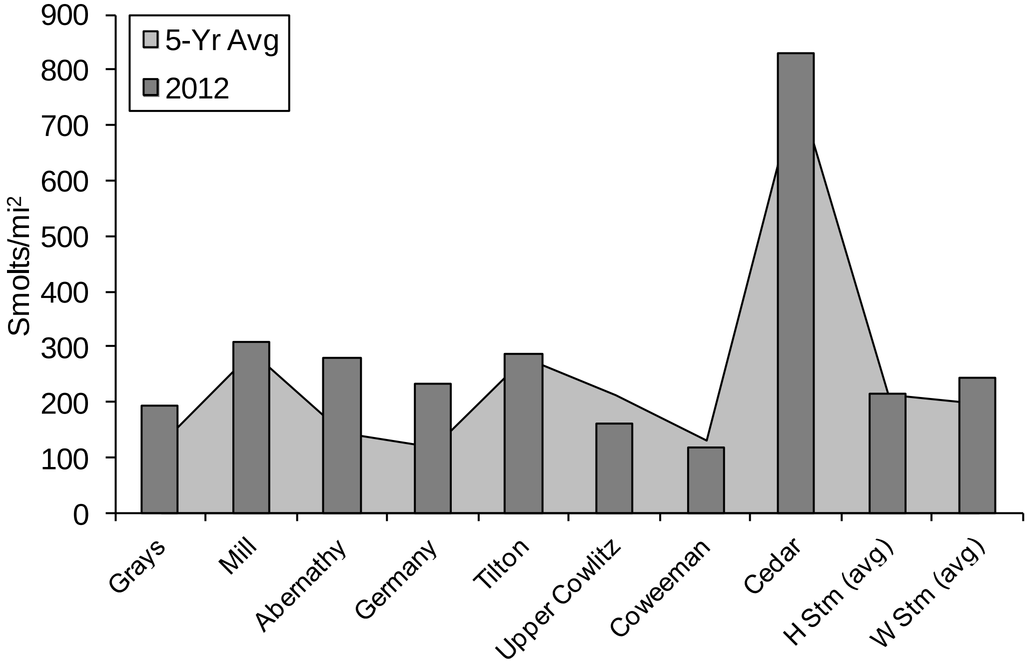

Figure 8. Coho smolt densities (smolts per mile-squared of watershed area) in eight Lower Columbia tributaries in Washington State. Graphs shows the 2012 production (bars) relative to the 5-year average production from these watersheds.

Table 4. Estimated smolt production densities above juvenile traps in from monitored coho salmon streams in the Lower Columbia River ESU during 2011. Estimates are preliminary and subject to revision.

	Density		
Watersheds	N/mi^2	95% Low	95% High
Grays	192.8	76.9	308.8
Mill	307.5	246.0	369.0
Abernathy	279.6	223.2	335.9
Germany	232.6	135.7	329.4
Tilton	285.8	---	---
Upper Cowlitz	162.6	81.7	243.4
Coweeman	117.8	85.9	149.7
Cedar	831.0	761.7	900.3
Average Hatchery Streams	213.7	143.9	283.6
Average Wild Streams	244.7	192.8	296.5

Table 5. Estimated number of coho smolt emigrants 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	5,014	1,998	8,030
Mill	8,918	7,135	10,701
Abernathy	8,106	6,471	9,741
Germany	5,350	3,122	7,578
Tilton	43,159	---	---
Upper Cowlitz	9,757	---	---
Coweeman	14,014	10,224	17,804
Cedar	38,263	35,073	41,454
Non-monitored Hatchery Streams	172,061	115,831	228,290
Non-monitored Wild Streams	151,683	119,530	183,836
Total Smolt Emigration	456,315	299,384	507,434

Marine Survival

Approach

The early marine environment is believed to be a major bottleneck to coho marine survival (Beamish and Mahnken 2001; Beamish et al. 2004). If survival of coho salmon in the first few months of marine rearing sets the survival trajectory for the 18-month ocean period, 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. Sibling regressions are a common forecasting tool and have been used to predict marine survival in wild coho forecasts produced by WDFW Fish Science since 1996 (Seiler 1996; Zimmerman 2011). 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. Furthermore, a defensible framework for extrapolating marine survival predictions to all management units was needed. 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 (NWFSC, Bill Peterson and colleagues) and through the Salish Sea Marine Survival project facilitated by Long Live the Kings.

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 wild coho marine survival for Washington 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 ocean shelf. 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

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 [Lewis]) was 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 populations included in the long-term 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 output and terminal run reconstruction as compiled by state and tribal co-managers in the basin. This estimate assumes a smolt survival rate of 75% from tributary traps through Lake Washington and does not include harvest in mixed stock ocean fisheries.

The marine survival estimate used for the Snohomish MU was directly measured 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) has not been directly calculated. Based on recent improvements in coho escapement methods, a smolt-to-adult return (SAR) estimate was derived for the 2010 and 2011 return years in five watersheds where smolt production was 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. SAR was combined for the Cowlitz and Tilton rivers because not all unmarked coho returning to the Mayfield Dam trap could be differentially assigned to these watersheds (Tilton coho were partially tagged through the 2011 return year). In the case of Cedar Creek, smolt production and adult returns included the entirety of unmarked fish, including fish added via remote site incubators in this basin (RSI plants are not externally marked)

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 indicators previously selected for the Oregon Coast and Columbia River to the Washington Coast and Lower Columbia and have derived comparable indicators from the Race Rocks lighthouse data set and applied these to 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), upwelling index at 48N, and Skagit River flows. 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 year 1998 - 2011 based on the limitations of some of the indicator data sets. Predicted values for the 2012 outmigrants were calculated for all statistically significant regressions ($\alpha = 0.10$). The 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 in the Skagit River watershed 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 Local scales but not with any of the Region scale indicators (Table 6). Marine survival was higher when the PDO and ONI indices were lower (cooler) during the period of marine entry. Marine survival was also higher when the local surface temperautre was cooler and local chlorophyll densities were higher during the period of marine entry.

These indicators predicted marine survival to be between 6.9% and 9.1%. Model averaging resulted in a predicted marine survival rate of 9% (±2%, 95% C.I.). A 9% 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.

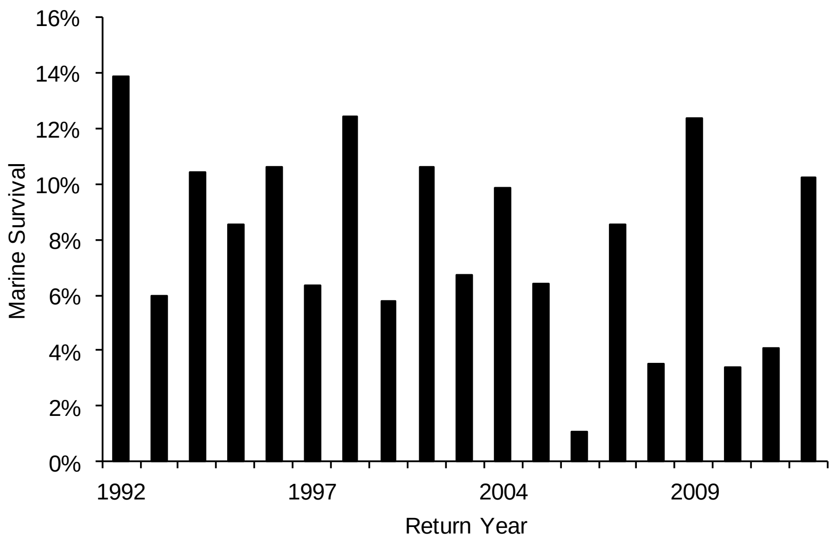

Figure 9. Marine survival of wild coho salmon form the Baker River (Skagit), return years 1992 to 2012.

Snohomish River

Marine survival of wild coho in the Snohomish River has ranged from 3.5% to 28.6% between return year 1979 and 2012 with no apparent trend over this time period (Figure 10). Marine survival of Snohomish River wild coho was weakly correlated with three indicators – one at the Region scale and two at the Local scale. Marine survival was higher when sea surface salinity was higher at Race Rocks lighthouse (April – June) and higher in the upper 20 m of the local WA Ecology buoy (May). Marine survival was also higher when May chlorophyll densities were higher in the upper 20 m. All three indicators predicted a marine survival ranging between 8.6% and 9.6%. Based on the weak correlations, however, the confidence intervals in these predictions were wide. Model averaging predicted a marine survival of 9% (± 4%, 95% C.I.), which was the marine survival applied to the Snohomish and Stillaguamish management units.

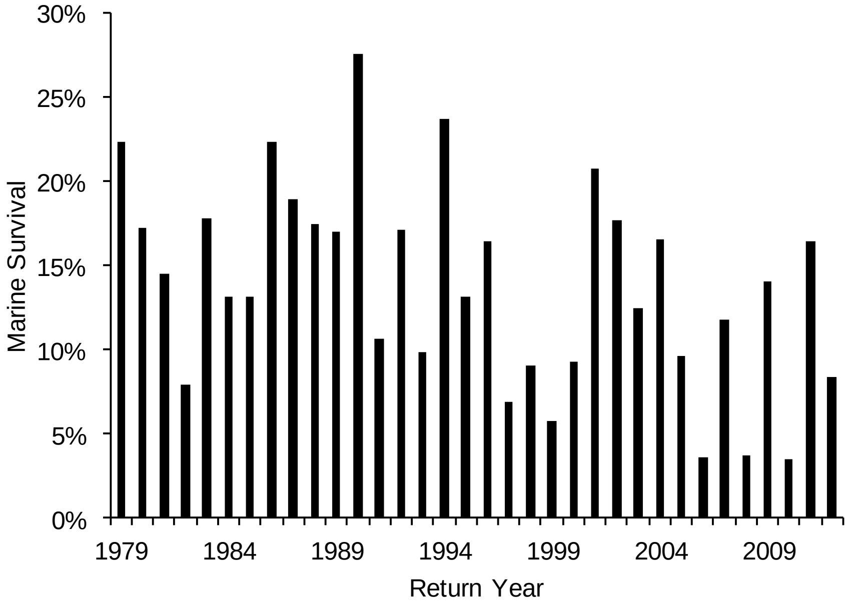

Figure 10. Marine survival of wild coho salmon in the SF Skykomish River, return years 1979 to 2012.

Lake Washington

Marine survival for natural coho in Lake Washington has ranged between 0.5% and 14.4% between the 2003 and 2012 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, marine survival for the 2013 returns is predicted to be 7% for the Lake Washington MU. However the confidence intervals on this prediction range between 3% and 11% reflecting a high uncertainty in the selected value. Based on this uncertainty, the marine survival rate applied to the Lake Washington MU was decreased to 6%. This rate 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.

None of the indicators provided good predictions of marine survival for Deschutes River natural coho salmon. As a result, a marine survival of 5.2% was applied to this management unit. This rate is the average marine survival observed between 1995 and 2012. This time period was selected because it represents a period of consistently low marine survival in South Sound following the dramatic decline in survival in the early to mid 1990s. A 5.2% 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).

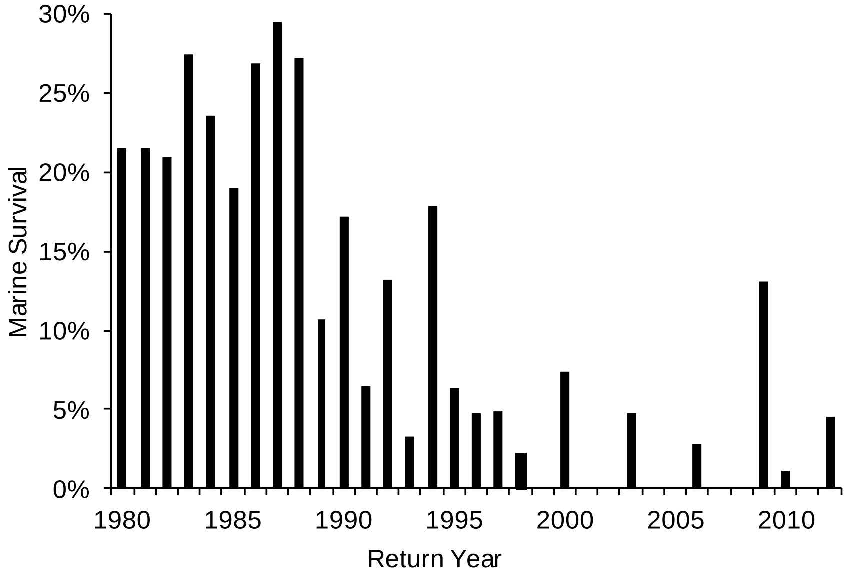

Figure 11. Marine survival of Deschutes River natural coho salmon, return years 1980 to 2012.

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 into the eastern side of Hood Canal. Marine survival of Big Beef Creek wild coho has ranged from 2% to 32% between return year 1978 and 2012 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).

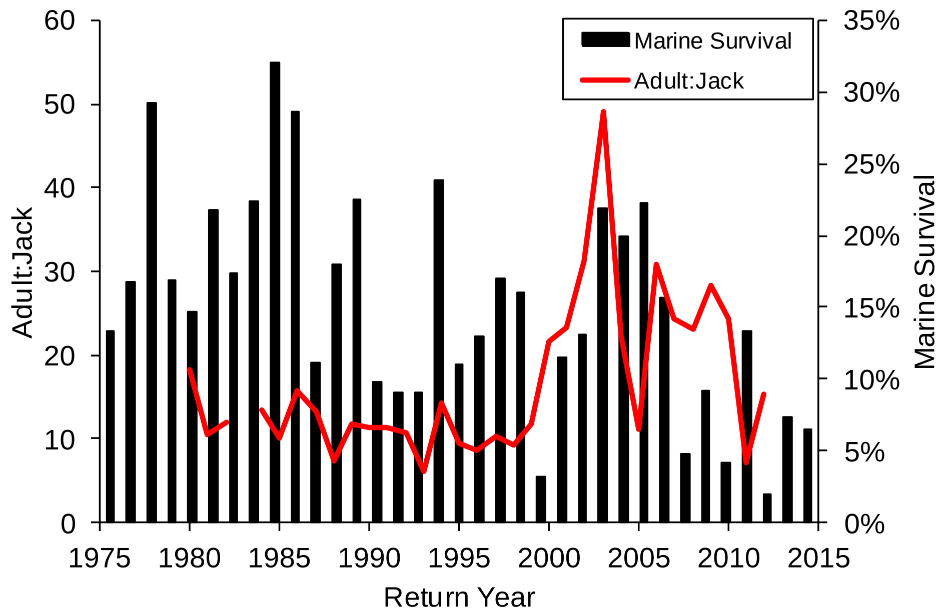

Figure 12. Marine survival and adult (age-3) per jack (age-2) ratio for Big Beef Creek wild coho, return year 1978 to 2012.

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 9). Marine survival was higher under higher salinities at Race

Rocks light house and high jack returns to Big Beef Creek. Marine survival was also higher when light transmission was lower (water more opaque). However, the correlation with light transmission predicted a marine survival rate more than double that of the other two regressions and the relationships itself appears to be potentially non-linear or “step-like”. Although the light transmission variable will continue to be monitored as a potential predictor, this indicator was not used for the purpose of this year’s forecast.

Marine survival for the 2013 return was predicted to be between 7.5% and 9.8% based on the Race Rocks salinity and Big Beef jack return respectively (Table 10). Model averaging of these regressions predicted a 7% marine survival; however, the 95% confidence interval of this prediction was ± 4%. A marine survival of 7.0% was applied to the Hood Canal management unit (Table 1).

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 2012 with no apparent trend over this time period (Figure 13). The adult-to-jack survival ratio has varied widely over this time period (range 8 to 153 adults per jack coho).

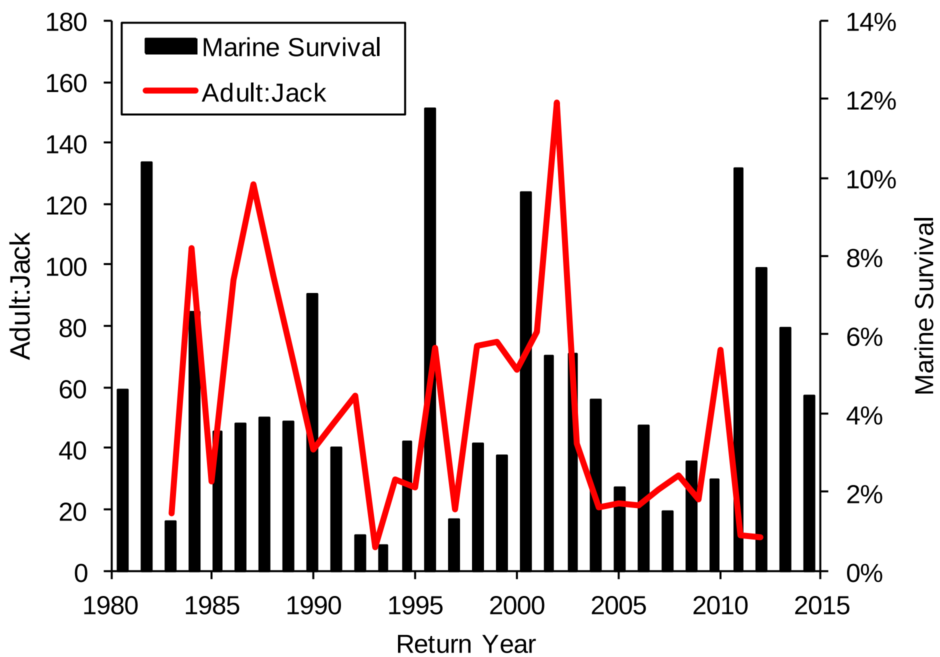

Figure 13. Marine survival and adult (age-3) per jack (age-2) return ratio of wild coho to Bingham Creek, Washington, return year 1983 to 2012.

Marine survival of Bingham Creek wild coho was correlated with nine of the selected indicators at both the “Ocean” and “Region” scales (Table 10). 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 jack returns or with physical indicators at the regional scale.

Individual regression equations predict that marine survival for the 2013 return will be between 5.0 and 8.6% (Table 10). Model averaging of these regressions predicted a 7% (±2%, 95% C.I.) marine survival. Therefore, a marine survival of 7.0% 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 2013 coho returns were based on statistically significant correlations.

Indicator	Regression	adjR^2	P Value	2013 Predict
Ocean Scale				
PDO Dec-Mar	---	-0.08	0.71	
PDO May-Sept	MS = 0.0629 - 0.0052x	0.25	0.05	8.93%
ONI Jan-Jun	MS = 0.0707 - 0.0318x	0.34	0.03	8.40%
Region Scale (Physical)				
Skagit River Flow Apr-Jun	---	0.04	0.26	
Race Rocks SST Apr-Jun	---	0.11	0.16	
Race Rocks SSS Apr-Jun	---	-0.1	0.87	
Upwelling 48° N Apr-Jun	---	-0.005	0.35	
Local Scale (Physical)				
Temp 20 m Apr-Jun	MS = 0.5405 - 0.0473x	0.33	0.03	9.07%
Salinity 20 m Apr-Jun	---	0.03	0.27	
Local Scale (Biological)				
Chlorophyll 20 m May	MS = 0.0354 + 0.0047x	0.29	0.08	6.94%
Light transmission May	---	-0.09	0.86	

Table 7. Marine indicators of wild coho marine survival from SF Skykomish River, Washington, return year 1999 to 2012. Marine survival predictions for the 2013 coho returns were based on statistically significant correlations.

Indicator	Regression	adjR^2	P-value	2013 Predict
Ocean Scale				
PDO Dec-Mar	---	-0.07	0.79	
PDO May-Sept	---	0.03	0.25	
ONI Jan-Jun	---	-0.01	0.37	
Region Scale (Physical)				
Skagit River Flow Apr-Jun	---	-0.08	0.90	
Race Rocks SST Apr-Jun	---	-0.06	0.63	
Race Rocks SSS Apr-Jun	MS = -2.8351 + 0.0948x	0.22	0.05	8.60%
Upwelling 48° N Apr-Jun	---	-0.08	0.82	
Local Scale (Physical)				
Temp 20 m Apr-Jun	---	-0.08	0.93	
Salinity 20 m Apr-Jun	MS = -.8356 + 0.0347x	0.14	0.10	9.60%
Local Scale (Biological)				
Chlorophyll 20 m May	MS = 0.0643 + 0.0052x	0.23	0.10	9.42%
Light transmission May	---	-0.01	0.37	

Table 8. Marine indicators of wild coho marine survival from the Lake Washington basin, return year 2003 to 2012. Marine survival does not include pre-terminal exploitaiton rates. Marine survival predictions for the 2013 coho returns were based on statistically significant correlations.

Indicator	Regression	AICc	adjR^2	P Value	2013 Predict
Ocean Scale					
PDO Dec-Mar	---	-22.08	-0.07	0.53	
PDO May-Sept	---	-24.31	0.16	0.16	
ONI Jan-Jun	SAR = 0.0489 - 0.0509x	-26.29	0.33	0.06	7.02%
Region Scale (Physical)					
Skagit River Flow Apr-Jun	---	-22.19	-0.06	0.49	
Race Rocks SST Apr-Jun	---	-23.03	0.03	0.30	
Race Rocks SSS Apr-Jun	---	-23.53	0.08	0.23	
Upwelling 48° N Apr-Jun	---	-22.05	-0.07	0.54	
Local Scale (Physical)					
Duwamish Flow Apr-Jun	---	-22.54	-0.02	0.39	
Temp 20 m Apr-Jun	---	-21.98	-0.08	0.57	
Salinity 20 m Apr-Jun	---	-21.54	-0.14	0.98	
Local Scale (Biological)					
Chlorophyll 20 m May	---	-17.2	0.01	0.34	
Light transmission May	---	-22.52	-0.02	0.40	

Table 9. Marine indicators of wild coho marine survival from Big Beef Creek, return year 1999 to 2012. Marine survival predictions for the 2013 coho returns were based on statistically significant correlations.

Indicator	Regression	AICc	$adjR^2$	P-value	2013 Predict
Ocean Scale					
PDO Dec-Mar	---	-28.50	-0.02	0.41	
PDO May-Sept	---	-27.67	-0.08	0.96	
ONI Jan-Jun	---	-28.00	-0.06	0.60	
Region Scale (Physical)					
Skagit River Flow Apr-Jun	---	-27.82	-0.07	0.73	
Race Rocks SST Apr-Jun	---	-27.74	-0.08	0.81	
Race Rocks SSS Apr-Jun	MS = -4.3589 + 0.1439x	-35.63	0.39	0.01	7.48%
Upwelling 48° N Apr-Jun	---	-27.98	-0.05	0.61	
Local Scale (Physical)					
Skokomish River Flow Apr-Jun	---	-28.75	0.00	0.34	
Temp 20 m Apr-Jun	---	-16.55	-0.08	0.61	
Salinity 20 m Apr-Jun	---	-17.61	0.02	0.30	
Local Scale (Biological)					
Chlorophyll 20 m May		-4.02	-0.12	0.58	
Light transmission May	MS = 0.7896 - 0.0085x	-24.88	0.53	0.01	17.95%
Percent Jack Return	MS = 0.053+10.6138x	-33.47	0.28	0.03	9.77%

Table 10. Marine indicators of wild coho marine survival from Bingham Creek, Washington, return year 1999 to 2012. Marine survival predictions for the 2013 coho returns were based on statistically significant correlations.

Indicator	Regression	AICc	adjR^2	P-Value	2013 Predict
Ocean Scale					
PDO Dec-Mar	MS = 0.0501 - 0.0045x	-60.24	0.32	0.02	7.3%
PDO May-Sept	MS = 0.0403 - 0.0059x	-66.77	0.56	0.0009	8.6%
ONI Jan-Jun	MS = 0.0482 - 0.0240x	-60.32	0.33	0.02	5.8%
Region Scale (Physical)					
Sea Surface Temp 46N	---	-56.77	0.13	0.10	
NH05.Upper.20mT.NovMar	---	-57.09	0.15	0.09	
NH05.Upper.20mT.MaySept	---	-55.09	0.02	0.27	
NH05.DeepT.MaySept	---	-57.17	0.16	0.08	
NH05DeepS.MaySept	---	-55.25	0.03	0.25	
Phys. Spring Transition Date	---	-55.11	0.02	0.27	
Upwelling Apr-May	---	-58.09	0.21	0.06	
Length Upwelling	---	-54.55	-0.02	0.39	
SST NH05 Summer	---	-55.32	0.03	0.24	
Region Scale (Biological)					
Copepod Richness May Sept	MS = 0.4980 - 0.0056x	-58.58	0.24	0.04	5.9%
N Copepod Biomass May Sept	---	-57.85	0.19	0.06	
S Copepod Biomass May Sept	MS = 0.0489 - 0.0530x	-60.34	0.33	0.02	6.1%
Biological Transition	MS = 0.0885 - 0.0003x	-58.75	0.24	0.04	5.0%
Winter Ichthyoplankton	MS = 0.0185 + 0.03240x	-60.26	0.32	0.02	5.1%
June Chinook	MS = 0.0195 + 0.0362x	-67.05	0.58	0.0009	6.7%
September Coho	---	-55.31	0.04	0.24	
Copepod Community Structure	MS = 0.0367 - 0.0305x	-60.67	0.35	0.02	6.1%
Percent Jack Return	---	-56.82	0.13	0.11	

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 14). The average SAR for these two years was 6.8% which is equivalent to an 8.5% marine survival (assuming 20% exploitation rate). This suggests that marine survival rates of Lower Columbia natural coho may be comparable to wild coho survival observed in the coastal indicator stock (Bingham Creek averaged 7.3% marine survival for the 2010 and 2011 return years). This result 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.

For the 2013 return year, marine survival of naturally produced coho in the Lower Columbia River Evolutionary Significant Unit was assumed to be comparable to coastal Washington stocks and a 7.0% marine survival rate was also applied to this ESU (Table 1).

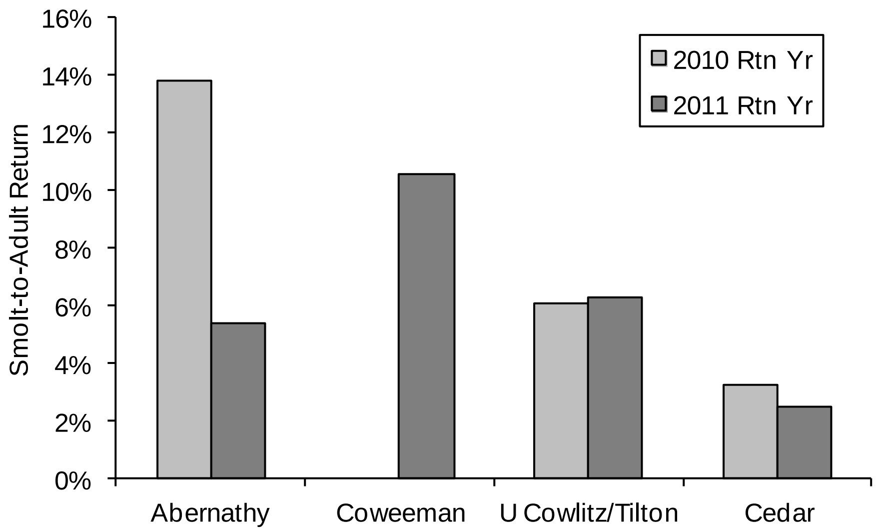

Figure 14. Smolt-to-adult return rates for natural coho salmon in five Lower Columbia watersheds.

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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