2012 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 at the level of management units are needed 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 fishery catches by stock. In addition, escapement-based coho forecasts often have no predictive value because watersheds become fully seeded at low spawner abundances (Bradford et al. 2000). Furthermore, different variables in the freshwater (Lawson et al. 2004; Sharma and Hilborn 2001) and marine environments (Logerwell et al. 2003; Nickelson 1986; Ryding and Skalski 1999) 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 escapement goals and 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 correlated to extrapolate 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. For stocks where marine survival is not measured, adult ocean recruits are predicted by extrapolating information from neighboring or comparable watersheds.

The Wild Salmon Production Evaluation (WSPE) Unit within the WDFW Fish Program Science Division has developed forecasts of wild coho run size for the last seventeen 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).

Table 1 summarizes the 2012 run-size forecasts for wild coho for Puget Sound, Washington Coast, and Lower Columbia River systems. Forecasts of three-year old ocean recruits were adjusted to January age-3 recruits in order to provide appropriate inputs for coho management models (expansion factor = 1.23, expansion provides for natural mortality). December age-2 recruits, which have been included in this table in previous years, are not provided as they are no longer used by fisheries managers. The following sections describe the approach used to derive smolt production and marine survival estimates.

Table 1. 2012 wild coho run forecast summary for Puget Sound, Coastal Washington, and Lower Columbia.

	Production X	Marine Survival =	Recruits	
Production Unit	**Estimated Smolts Spring 2011**	**Predicted Marine Survival**	**Adults (Age 3)**	**Jan. (Age 3)**
Puget Sound				
Primary Units				
Skagit River	952,000	5.4%	51,400	63,300
Stillaguamish River	370,000	8.7%	32,200	39,700
Snohomish River	1,000,000	8.7%	87,000	107,200
Hood Canal	804,000	9.0%	72,400	89,100
Straits of Juan de Fuca	**see note below**			
Secondary Units				
Nooksack River	181,000	5.4%	9,800	12,000
Strait of Georgia	21,000	5.4%	1,100	1,400
Samish River	60,000	5.4%	3,200	4,000
Lake Washington	83,000	6.5%	5,400	6,600
Green River	163,000	6.5%	10,600	13,100
Puyallup River	214,000	4.0%	8,600	10,500
Nisqually River	291,000	4.0%	11,600	14,300
Deschutes River	54,000	4.0%	2,160	2,700
South Sound	149,000	4.0%	6,000	7,300
East Kitsap	82,000	6.5%	5,300	6,600
Puget Sound Total	4,424,000		306,760	377,800
Coast				
Queets River	413,000	6.5%	26,845	33,100
Quillayute River	655,000	7.5%	49,125	60,500
Hoh River	286,000	6.5%	18,590	22,900
Quinault River	304,000	6.5%	19,760	24,300
Independent Tributaries	297,000	5.3%	15,741	19,400
Grays Harbor				
Chehalis River	2,870,000	5.3%	152,110	187,400
Humptulips River	312,000	5.3%	16,536	20,400
Willapa Bay	680,000	5.3%	36,040	44,400
Coastal Systems Total	5,817,000	5.3%	334,747	412,400
Lower Columbia Total	577,000	5.3%	30,581	37,700
GRAND TOTAL	10,818,000		672,088	827,900

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 the WSPE Unit. Over the past 30 years, the WSPE unit 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 (Mathews and Olson 1980; Smoker 1955), 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).

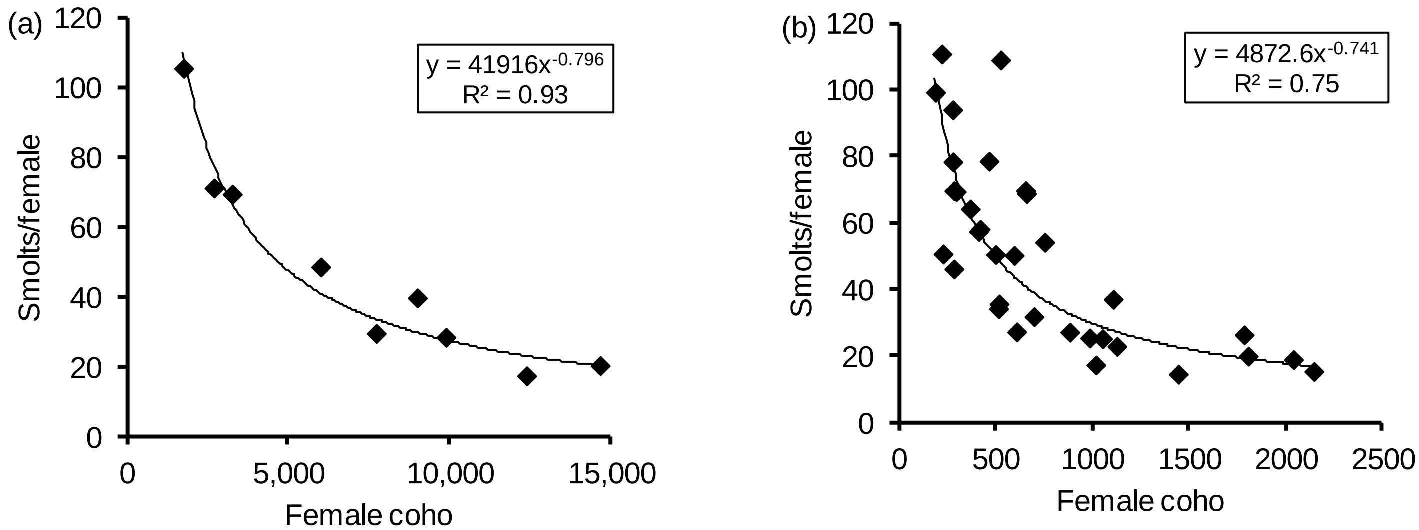


Figure 1. Freshwater productivity (juveniles/female) as a decreasing function of female coho escapement in the South Fork Skykomish (*a*, Sunset Falls, brood year 1976-1984) and Big Beef Creek (*b*, brood year 1978-2009) watersheds.

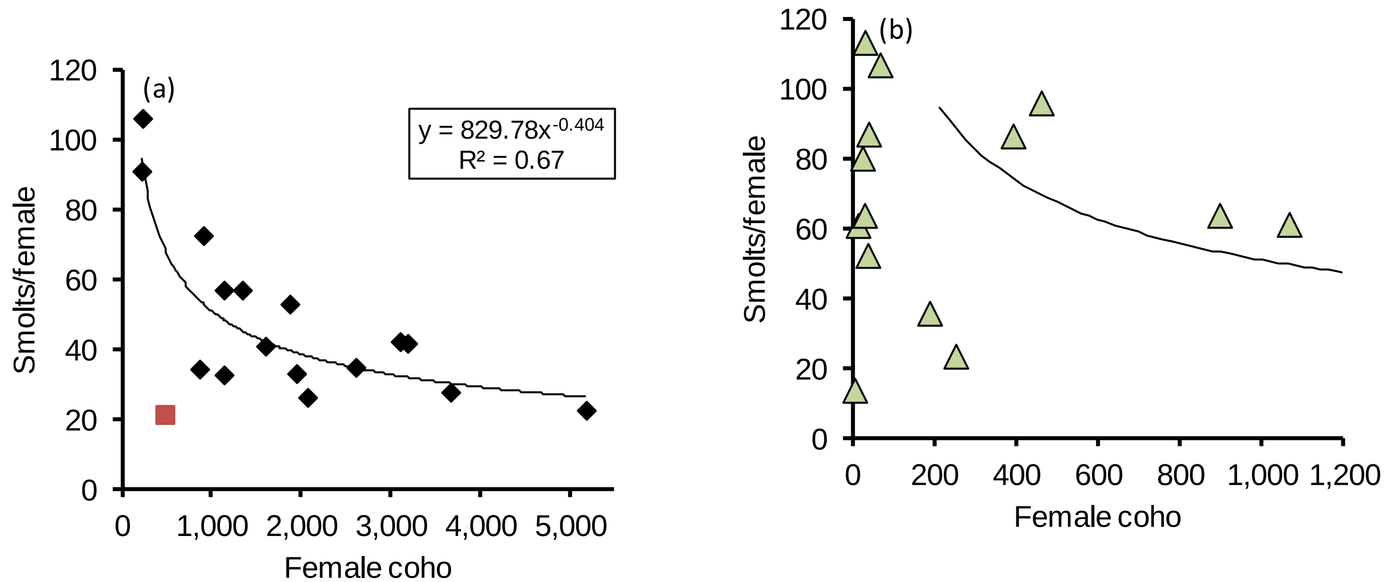


Figure 2. Freshwater productivity (juveniles/female) as a function of female coho escapement in the Deschutes River. For brood year 1978-1994 (*a*), coho productivity was a decreasing function of escapement (black square) with the exception of brood year 1989 (red square). The 1989 brood year corresponded 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 2011, the WSPE Unit measured coho smolt production in six of the Puget Sound management units (Skagit, Hood Canal, Lake Washington, Green, Nisqually, and Deschutes). Smolt production from two additional management units (Puyallup and South Sound) was available due to juvenile monitoring studies conducted by the Puyallup and Squaxin Tribes. For watersheds where trapping data were not available in 2011, 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 155% of the predicted potential production (Table 2). The common metric developed by Zillges (1977) makes his predictions useful for expanding production measured in one portion of the watershed to other areas of the watershed.

A second approach was the use of a Puget Sound Summer Low Flow Index (PSSLFI, 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 2010 (corresponding to the 2011 outmigration and 2012 returning adults) had an index value of 9.7 or 121% of the long-term average. (Figure 3).

A third approach to estimating coho production was based on marine derived nutrients provided by pink salmon. Over the past decade, odd-year pink salmon escapements in Puget Sound have increased to levels unprecedented in recent history. This approach was not applied to the 2012 forecast, as the freshwater rearing phase of this cohort (summer of 2010) did not overlap with odd-year pink salmon returns.

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	34	27,828	11,510	57,271	72.2%	29.8%	148.5%
Little Anderson	18	569	45	1,969	11.2%	0.9%	38.6%
Seabeck	18	1,387	496	2,725	13.2%	4.7%	26.0%
Stavis	18	5,594	1,549	9,667	111.3%	30.8%	192.3%
Skagit River	22	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**	13	54,229	13,322	83,060	44.9%	11.0%	68.7%
Bear Creek	13	34,593	12,208	62,970	69.1%	24.4%	125.7%
Nisqually	3	180,048	135,512	228,054	155.8%	117.3%	197.4%
Deschutes***	33	47,026	1,187	133,198	21.4%	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.

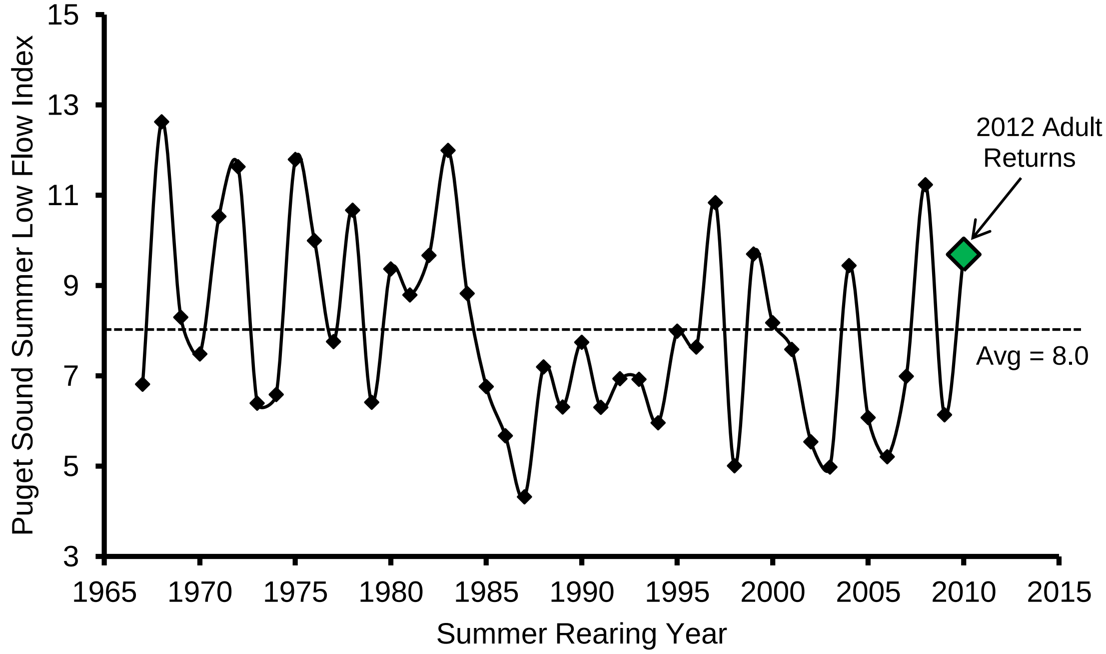


Figure 3. Puget Sound Summer Low Flow Index (PSSLFI) by summer rearing year (return year – 1). PSSLFI is based on 60-day minimum flow averages at eight stream gages in Puget Sound (see Appendix A). The minimum 60-day average flow at each gage is compared to its long-term average (1967 to present) and then summed across all eight gages. Flow index corresponding to the 2012 wild coho return is highlighted in green.

Puget Sound Primary Units

Skagit River

A total of 952,000 wild coho smolts are estimated to have emigrated from the Skagit River in 2011 (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 2011 smolt production was slightly lower than the long-term average of 1,052,000 smolts (Table 2).

Stillaguamish River

A total of 370,000 coho smolts are estimated to have emigrated from the Stillaguamish River in 2010 (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.

Between 1979 and 1981 brood years, the WSPE Unit 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.

In 2011, freshwater conditions in the neighboring Skagit River (e.g., few to no pink salmon, average summer low flows) resulted in a coho smolt production that was slightly below the long-term average. The 2011 Stillaguamish coho production was estimated to be 370,000 smolts, comparable to average smolt production between 1981 and 1983. The 2011 Stillagumish coho smolt production estimate assumed that coho escapement in the Stillaguamish was adequate to fully seed the watershed and that low summer flows were comparable for the 1981-1983 (average PSSLFI = 9.3) and 2011 (PSSLFI = 9.7) outmigrations. Unlike 2010, when high numbers of pink salmon spawners were hypothesized to positively influence coho smolt production, the freshwater rearing phase of the 2011 outmigrants did not overlap with odd-year pink salmon in the Stillaguamish River.

Snohomish River

A total of 1,000,000 coho smolts are estimated to have emigrated from the Snohomish River in 2011 (Table 1). The 2011 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 2011; however, analyses of these data will not be completed until later in the year. The approach used in this forecast will be validated with the Tulalip trap estimates once these data become available.

Between 1978 and 1986, the WSPE unit operated a juvenile trap below Sunset Falls on the South Fork Skykomish River. Coho production estimates were generated with a mark-recapture study design and a Peterson-Chapman estimator (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 2011 was estimated to be 1,000,000 smolts, comparable to the average smolt production between 1978 and 1983. Similar to the Skagit and Stillaguamish systems, this estimate assumed that freshwater conditions, such as summer low flows and marine derived nutrients (i.e., pink salmon), did not have large effects (positive or negative) on the 2011 outmigration. Furthermore, the 2009 coho escapement to the Snohomish system was assumed to adequately seed the watershed. Returns to Sunset Falls in 2009 (25,038 adults, ~12,500 females) were at a level previously demonstrated to maximize smolt production from the South Fork Skykomish (Seiler 1996).

Hood Canal

A total of 804,000 coho smolts are estimated to have emigrated from Hood Canal tributaries in 2011 (Table 1). Production was not directly measured in all tributaries; therefore this estimate is based on an expansion of the measured production.

In 2011, wild coho production was measured in Big Beef Creek (n = 57,271), Little Anderson Creek (n = 917), Seabeck Creek (n = 1,153), and Stavis Creek (n = 1,549). Coho smolts in these watersheds were captured in fan traps (BBC) and fence weirs. Catch was extrapolated for early and late migrants using historical migration timing data. The extrapolation was less than 5% of each estimate.

The 2011 production of coho smolts from Big Beef Creek was the highest observed since trapping began in 1976 and two times the long-term average production (Table 2). The 57,271 smolts were produced by 525 female spawners released upstream of the weir in 2009 and represented a freshwater productivity of 109.1 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). Neighboring creeks had variable production with respect to their long-term averages. Coho production from Little Anderson Creek, which has been monitored since 1992, was 1.6 times its long-term average (Table 2). Coho production from Seabeck and Stavis creeks, both monitored since 1993, were just 83% and 27% of their long-term averages, respectively. These variable results suggest that localized factors may have played an important role in determining freshwater production in 2011 and that expansions of the measured production to the entire management unit should be done cautiously.

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 2011 wild coho production in Hood Canal ranged between 804,000 and 1,256,000 smolts. Using the Zillges approach, the total of 60,890 smolts from the four tributaries were expanded to an estimated 1,035,452 Hood Canal smolts. Using the second approach (HCJTC 1994 revision), the total of 60,890 smolts from the four tributaries were expanded to 803,971 Hood Canal smolts. The third approach expanded the 57,271 smolts from Big Beef Creek to a total of 1,255,943 Hood Canal smolts. Based on the uncertainties described above, this forecast is based on the most conservative result, provided by the second approach.

Puget Sound Secondary Units

Nooksack River

A total of 181,000 coho smolts are estimated to have emigrated from the Nooksack River in 2011 (Table 1). Smolt abundance estimates from the Nooksack were not available in 2011. 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 2010 were slightly above average (Figure 3, Appendix A) and were assumed to neither constrain nor benefit the 2011 freshwater production of coho smolts. Based on the assumption that escapement and habitat degradation continue to limit production but that summer low flows were neither a constraint nor benefit, the 2011 production of Nooksack wild coho was estimated to be 181,000 (40% of potential production).

Strait of Georgia

A total of 21,000 coho smolts are estimated to have emigrated from the Straits of Georgia watersheds in 2011 (Table 1). Production was not directly measured in 2011, nor are historical estimates available from these watersheds. Therefore, production was estimated based on the potential predicted by Zillges (1977) and the assumption that 2010 summer low flows neither constrained or benefited the 2011 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 2011 coho production was estimated to be 21,000 smolts, 40% of the total production potential for these watersheds (51,821 smolts per Zillges 1977).

Samish River

A total of 60,000 coho smolts are estimated to have emigrated from the Samish River in 2011 (Table 1). Production was not directly measured in 2011; therefore this estimate is based on adult escapement and an assumed number of smolts per spawner. 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). In recent years, however, spawner abundances have not exceeded 2,000 adults. For the purpose of this forecast, smolt production has been estimated from spawner escapement and an assumed freshwater productivity (smolts/female). Freshwater productivity is assumed to be a density-dependent function of spawner abundance (per Figure 1).

Samish River adult coho escapement in 2009 was estimated from the number of fish enumerated and passed above the Samish Hatchery weir. The weir was operated for the collection of Chinook brood stock (late September to late October) and missed the latter portion of the coho run. Therefore, catch in the Samish Hatchery weir (through October 21, 2009) was expanded based on coho run timing at Sunset Falls (South Fork Skykomish River). In 2009, the 965 coho handled at the Samish weir were assumed to be 48% of the run, resulting in a total escapement estimate of 2,010 coho. Assuming a 1:1 sex ratio and a high production rate of 60 smolts/female spawner (Figure 1), a total of 60,000 smolts were estimated to have emigrated from the Samish River in 2011.

Lake Washington

A total of 83,000 coho smolts are estimated to have entered Puget Sound from the Lake Washington basin in 2011 (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. Wild coho production was estimated with a Bailey modification of the Petersen estimator (Carlson et al. 1998; Volkhardt et al. 2007).

The potential coho production for the Lake Washington basin (768,740 smolts) predicted by Zillges (1977) is unrealistically high for 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 2011, coho production was estimated to be 52,458 smolts from the Cedar River and 34,513 smolts from Bear Creek (Kiyohara and Zimmerman 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 2011 coho production from Issaquah Creek was estimated by scaling the 2000 estimate for this creek (19,812 smolts; Seiler et al. 2002a) by the 2011 to 2000 production ratios in Bear Creek. Both watersheds should be influenced by returns of natural and hatchery coho and summer low flows. In 2011, coho smolt production in Bear Creek was 123% of that measured in 2000 (34,513/28,142 = 50.1%). Therefore, 2011 coho production from Issaquah Creek was estimated to be 24,369 smolts (19,812 * 1.23).

The total coho production of 83,000 smolts assumed 75% survival through Lake Washington. Coho abundance entering Lake Washington was rounded to 111,000 smolts (52,458 Cedar + 34,513 Bear + 24,369 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).

Green River

A total of 163,000 natural-origin coho smolts are estimated to have emigrated from the Green River in 2011 (Table 1). This estimate is based on an estimated production of 62,280 smolts upstream of the juvenile trap (river mile 34), 35,907 smolts below the juvenile trap, and 64,341 smolts from Big Soos Creek.

In 2011, 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 62,280 smolts using a Bailey modification of the Petersen estimator (Topping and Zimmerman In prep). This represents 27.9% 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 35,907 smolts based 27.9% 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 2011. 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, 2011 production from this creek was based on the ratio of PSSLFI values between the 2011 and 2000 outmigration years (see Appendix A for explanation of PSSLFI). This ratio (9.69/9.70 = 99.9%) was nearly 1 to 1 and the 2000 production estimate (64,341 smolts) was used as the 2011 estimate.

Puyallup River

A total of 214,000 coho smolts are estimated to have emigrated from the Puyallup River in 2011 (Table 1). This estimate is based on measured production in the Puyallup River above the juvenile trap (91,000), an estimated production from the White River (113,000), and an estimate from the Puyallup River below the Puyallup-White confluence (10,000).

In 2011, the Puyallup Tribe operated a juvenile fish trap on the Puyallup River just upstream of the confluence with the White River. A total of 91,196 coho smolts were estimated to have migrated past the juvenile trap (A. Berger, Puyallup Tribe, personal communication). These coho smolts represent 33.1% of the production potential for the watershed from the Puyallup-White confluence to Electron dam (Zillges 1977). However, the actual rate should be lower than this percentage as a portion of the smolts in 2011 reared in 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 10,000 smolts based on a rate of 15% 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 113,000 smolts. Coho production from the Puyallup White confluence to Buckley Dam was estimated to be 15,000, 15% of the potential production for this portion of the watershed (Zillges 1977). Coho production from above Buckley dam was estimated to be 98,000 smolts based on the number of females passed above Buckley Dam in 2009 (9,801/2 = 4,901) multiplied by 20 smolts per female. Twenty smolts per female is a moderate survival that might be expected in system where escapement is adequate to fully seed the watershed (Figure 1).

Nisqually River

A total of 291,000 coho smolts are estimated to have emigrated from the Nisqually River in 2011 (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. Production was calculated with a Bailey modification of the Petersen estimator (Carlson et al. 1998; Volkhardt et al. 2007).

Wild coho production above the trap (river mile 12) was estimated to be 228,054 smolts, 197% of the 115,554 smolt potential predicted by Zillges (1977). Production below the trap was estimated to be 62,450, which is 197% of the potential production predicted for this portion of the watershed (Zillges 1977). Total watershed production was the sum of these two estimates (228,054 + 62,450 = 290,504). Of note, the 2009-2011 production level have been substantially higher than the production estimated in previous forecasts when no trap was operated (range 10,000 to 60,000) and consistently higher than the potential production predicted by Zillges (1977).

Deschutes River

A total of 54,000 coho smolts are estimated to have emigrated from the Deschutes River in 2011 (Table 1), representing 25% 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 13,372 smolts was expanded by a trap efficiency of 24.7%.

At present, 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. The 2009 brood is the strong brood line but freshwater production is still well below capacity (Figure 4) and the predicted potential for this watershed (Zillges 1977). A combination of variables may have contributed to this trend - habitat degradation in the upper watershed, high incubation flows, and low escapement. A history of chronic and low marine survival was likely a major factor driving the current status of this stock. While adult coho returning between 1980 and 1990 experienced an average marine survival of 22.3%, adult coho returning between 1991 and 2010 experienced an average marine survival (prior to harvest) of just 7.2%.

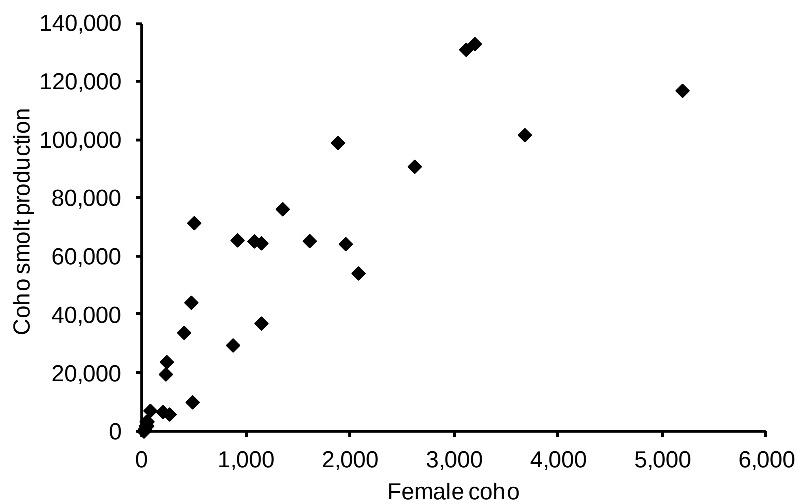


Figure 4. Coho smolt production as a function of female spawners in the Deschutes River, Washington, brood year 1978-2009.

South Sound

A total of 149,000 coho smolts are estimated to have emigrated from South Sound tributaries in 2011 (Table 1). This estimate was based on results of juvenile monitoring studies in representative creeks in the southern extent of this management unit (Cranberry, Mill, Skookum and Goldsborough creeks). In 2011, the Squaxin Island Tribe conducted juvenile trapping studies in Cranberry Creek (*n* =

643), Mill Creek (*n* = 421), Skookum Creek (*n* = 1,084), and Goldsborough Creek (*n* = 46,889, Joseph Peters, Natural Resources Department, Squaxin Island Tribe, personal communication). This production represented 25.9% of the 177,334 smolt potential that Zillges (1977) predicted for these watersheds. Coho production for the entire South Sound management unit was estimated to be 149,000 smolts based on 25.9% 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 82,000 coho smolts are estimated to have emigrated from East Kitsap tributaries in 2011 (Table 1). In previous years, this estimate has been based on an expansion of measured production in Steele Creek, an East Kitsap tributary (Steele Creek Organization for Resource Enhancement; www.bougan.com/SCORE). Between 2001 and 2010, 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). Freshwater productivity curves showed evidence of density-dependent survival similar to that observed in other watersheds and no evidence that spawning escapement was limiting freshwater production. Smolt production was not a function of summer low flows (as measured by the PSSLFI) and did not show a trend over time.

Monitoring of Steele Creek was discontinued in 2011. In the absence of a direct measure within the management unit, the average production from Steele Creek (2,184 smolts or 52.8% of the Zillges potential) was applied to the 154,973 smolt potential predicted for the entire East Kitsap management unit (Zillges 1977). Total coho production for all East Kitsap tributaries was estimated to be 82,000 smolts in 2011.

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 (Appendix B). In addition to these larger watersheds, coho are produced in fourteen smaller tributaries. These watersheds range from the high-gradient rivers draining from the western Olympic Mountains to the low-gradient, rain-fed 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 2011, the WSPE unit 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 abundance data was also available from the Dickey and Bogachiel rivers in the Quillayute watershed. In coastal watersheds where production was not estimated in 2011, 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/mi^2		
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	442.9	118.8	783.8
Chehalis (Grays Harbor)	28	1,956,137	502,918	3,592,275	911.6	237.9	1,699.3

Queets River

A total of 413,000 wild coho smolts are estimated to have emigrated from the entire Queets watershed in 2011 (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. The 2011 coho production from the Clearwater River, a sub basin of the Queets system, was 134,052 smolts or 958 smolts/mi^2 (Tyler Jurasin, Quinault Tribe, personal communication). The production rate for the Queets River (excluding the Clearwater) was 619 smolts/mi^2. The 2011 production from the Clearwater River was the highest observed in 31 years of study (Table 3).

Quillayute River

A total of 655,000 coho smolts are estimated to have emigrated from the Quillayute River system in 2011 (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 Clearwater drainage, where smolt production was measured in 2011.

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 2011 Quillayute coho production was based on previously measured production of this system adjusted by the ratio of current to previous measured production from the Clearwater River (Queets basin). 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 2011 coho production in the Dickey River was estimated to be 194,357 smolts (2.20*88,344 smolts). The 2.20 expansion factor was the ratio of Clearwater production in 2011 (134,052 smolts) to average Clearwater production in 1992-1994 (134,052 /61,000 = 2.20). The 2011 coho production in the Quillayute (excluding the Dickey) was estimated to be 460,585 smolts (2.12*217,257 smolts). The 2.12 expansion factor was the ratio of Clearwater coho smolt production in 2011 to average Clearwater smolt production in 1987, 1988, and 1990 (134,052/63,333 = 2.12). The total 2011 coho production of 655,000 smolts was the sum of these estimates (194,357 + 460,585).

Hoh River

A total of 286,000 wild coho smolts are estimated to have emigrated from the Hoh River in 2011 (Table 1). Smolt production was not directly measured in this watershed; therefore the estimate was based on production rate of the Clearwater system. The Hoh and Clearwater watersheds have similar watershed characteristics as well as regional proximity. The production rate of 958 smolts/mi^2 from the

Clearwater was applied to the 299-mi^2 of the Hoh watershed and resulted in an estimated 286,000 smolts from the Hoh River system.

Quinault River

A total of 304,000 wild coho smolts are estimated to have emigrated from the Quinault River in 2011 (Table 1). Smolt production was not directly measured in this watershed; therefore, the estimate was based on production rate of the Clearwater system. When compared with the Clearwater, 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 2011, a production rate of 700 smolts/mi^2 was applied to the 434-mi^2 Quinault River system, resulting in an estimated 304,000 smolts.

Independent Tributaries

A total of 297,000 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 2011, an average production rate of 700 smolts/mi^2 was applied to the total watershed area (424 mi^2; Appendix B), resulting in an estimated 297,000 smolts.

Grays Harbor

A total of 3,182,000 coho smolts are predicted to have emigrated from the Grays Harbor system in 2011 (Table 1). This estimate was derived in two steps. Wild coho production was first estimated for the Chehalis River. Production per unit drainage area of the Chehalis River system was then applied to the southern (Hoquaim, Johns, and Elk rivers) and northern (Humptulips) tributaries to Grays Harbor.

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 fishery. Coded-wire tag recoveries in this fishery are processed and reported by the Quinault Tribe (Jim Jorgeson, Quinault Tribe, personal communication). Smolt production was estimated after adults have passed through the fishery and returned to the river. Between 1980 brood and present, wild coho production in the Chehalis River has ranged between 503,000 and 3.6 million smolts.

Smolt abundance estimates from the mark-recapture method are not available in the year that coho recruit into the fishery; therefore, a preliminary estimate is used for the run size forecasts. Historically, the preliminary estimate was based on a strong predictive relationship between minimum spawning flows and coho smolt production in the Chehalis watershed (Seiler 1996). However, the predictive ability of this relationship has degraded over time (Figure 5).

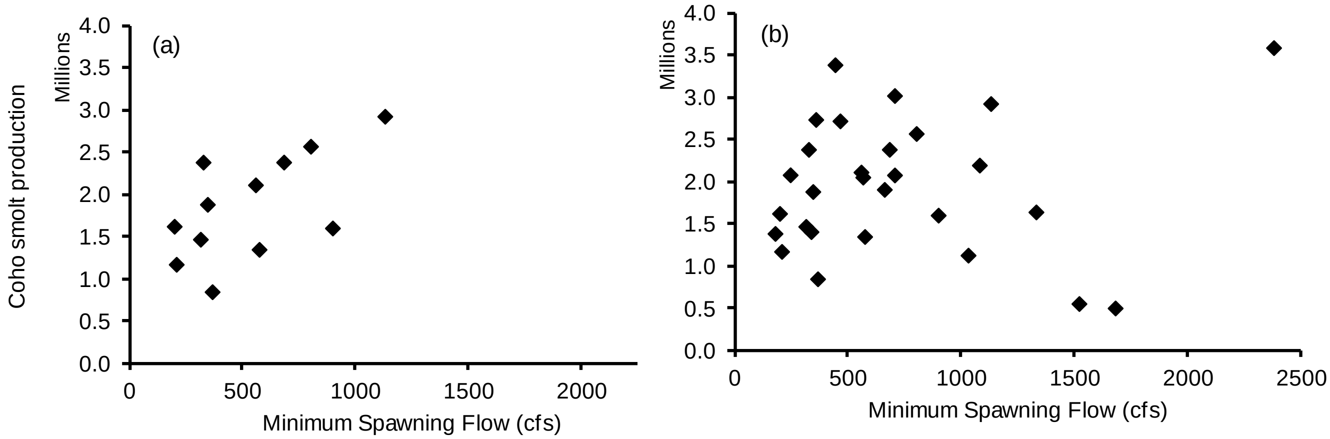


Figure 5. Predictive relationship between minimum spawning flow (Nov 1 to Dec 15) and wild coho smolt production from the Chehalis River, brood year 1980 to 1993 (*a*) and brood year 1980 to 2008 (*b*). Flow data are from USGS gage #12027500 in Grand Mound, Washington.

In order to derive a preliminary estimate of the 2011 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 11 year data set (smolt year 2000 to 2010) 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 (more water = more smolts, Figure 6). However, this relationship is weak and results in a prediction with high uncertainty. For example, the summer low flow relationship predicted a 2010 smolt production of 1,880,626 (714,522 – 3,045,141 95% C.I.). The mark-recapture estimate of 2010 smolt production was 2,637,932 (2,371,015 – 2,904,849 95% C.I.). Although the final mark-recapture estimate was within the 95% confidence interval of the preliminary flow-based estimate, the final mark-recapture estimate was 146% the preliminary abundance estimate used for forecasting purposes. Future research is needed to identify alternate metrics that improve the precision of the flow-based model used for forecasting.

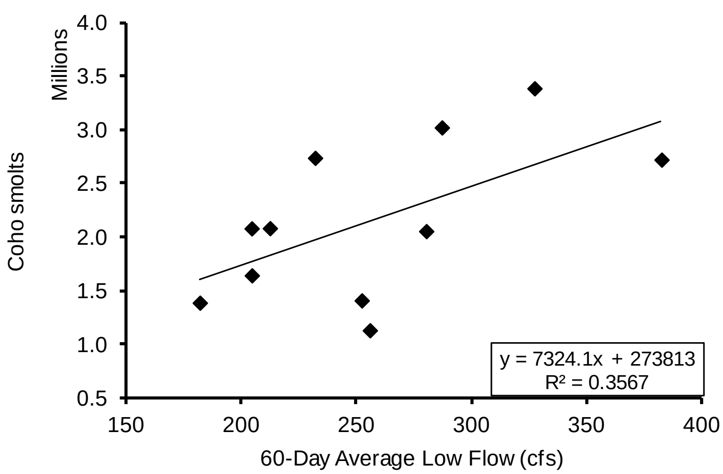


Figure 6. Chehalis River wild coho smolt production as a function of summer rearing flows, brood year 1998-2008. Summer rearing flows are the minimum of the 60-day average flow between March 1 and Nov 1 (USGS gage ##12027500, Grand Mound).

Based on the minimum 60-day average summer flow of 323 cfs in summer of 2010, coho smolt production for the Chehalis basin was predicted to be 2,639,487. Although this preliminary estimate is used for forecasting purposes, note that the 95% confidence intervals for this estimate range between 1,419,348 and 3,859,626 smolts.

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 1,248 smolts/mi^2 (2,639,487 smolts per 2,114 mi^2). A total of 2,870,000 coho smolts are estimated for the entire Chehalis Basin (2,300-mi^2, including the Hoquiam, Johns, and Elk Rivers and other south side tributaries below the terminal fishery). Coho production from the Humptulips River was estimated to be 312,000 smolts (1,248 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 3,182,000 smolts (2,870,000 + 312,000).

Willapa Bay

A total of 680,000 coho smolts are estimated to have emigrated from the Willapa Bay basin in 2011 (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 2011 (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 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. Extrapolations of smolt densities in this forecast were based on watershed area (smolts per square mile), as information on the linear miles of spawning and rearing habitat were not readily available.

In 2011, coho smolt production was directly monitored in 9 watersheds using partial-capture juvenile traps and a mark-recapture study design. Monitored watersheds include Grays River, Mill Creek, Abernathy Creek, Germany Creek, Tilton River, Upper Cowlitz, Coweeman River, Cedar Creek, and the Wind River. In the case of the Upper Cowlitz and Tilton rivers, where coho smolts are actively transported around the dam-reservoir systems, estimates of the number of emigrating smolts differed from the number of smolts used to estimate production densities above the trap. Details for these, and other systems, are provided below.

Coho smolt production densities of 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 2011, 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.

Coho salmon smolt production estimates were calculated using a mark-recapture study design and a Bailey modification of the Petersen estimator (Carlson et al. 1998; Volkhardt et al. 2007). Although final estimates are still underway, preliminary estimates for this forecast are based on pooled capture, releases, and recapture data from each juvenile trap study in 2011. The estimates used in this forecast are believed to be relatively unbiased because estimates were obtained from a census or mark-recapture programs, where care was taken to meet the assumptions required for unbiased population estimates. 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 that include a high percentage of hatchery spawners and stream with few hatchery spawners, along with streams of varying size and habitat condition. Hatchery streams, where coho production is primarily from hatchery or 1st generation hatchery fish include the Upper Cowlitz and the Tilton Rivers. Production from primarily wild adults occurs in the Coweeman River, and production from streams with a mix of wild and hatchery fish occurs in Mill, Abernathy, Germany, and Cedar Creeks. 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.

The coho smolt estimates provided should be considered a minimum number as the number of coho salmon smolts emigrating from areas below the traps is unknown. Each year, coho parr (sub yearlings) are observed emigrating past the trap sites. Some of these parr are likely to continue rearing in freshwater below the traps and in the main stem Columbia River. If they survive, these juveniles will emigrate as smolts in subsequent years.

Grays River

The Grays River juvenile trap is located at river mile 6. Based on a watershed area of 23 mi^2, the 2011 coho smolt production density was estimated to be 83.9 smolts/mi^2 (Table 4). A total of 2,182 natural-origin coho smolts are estimated to have emigrated from the Grays River in 2011 (Table 5).

Mill, Abernathy, and Germany Creeks

Juvenile traps on Mill, Abernathy, and Germany creeks are located near the mouth of each creek. The 2011 coho smolt production density of these watersheds ranged between 153.7 smolts/mi^2 and 295.2 smolts/mi^2 (Table 4). A total of 17,619 natural- origin coho smolts were estimated to have emigrated from all three watersheds in 2011 (Table 5). This included 8,563 smolts from Mill Creek, 5,520 smolts from Abernathy Creek, and 3,535 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 2011 smolt production, a release of 1,000 smolts and a recapture of 664 were assumed in order to include a measure of uncertainty in the smolt production estimates for the Tilton River.

Based on a watershed area of 159 mi^2, the 2011 coho smolt production density of the Tilton River was estimated to be 370.6 smolts/mi^2 (Table 4). The total number of coho emigrating from the Tilton was 55,950 (Table 5) smolts, this included the 39,140 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 366.6 smolts/mi^2 in 2011 (Table 4). The total number of coho emigrating from the Upper Cowlitz was the 33,739 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 near the stream gage 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 195.5 smolts/mi^2 in 2011 (Table 4).The total number of coho emigrating from the Coweeman River in 2011 was estimated to be 23,261 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 2011 coho smolt emigration from the Cedar River was estimated to be 60,778 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 996.1 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 2011 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 this reason, 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 220,325 (189,161 – 251,489 95% C.I.) smolts (Table 5). This estimate was derived from an average smolt production density of 273.7 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 163,024 (144,400 – 181,647 95% C.I.) smolts (Table 5). This estimate was derived from an average smolt production density of 262.9 smolts/mi^2 in “hatchery monitored” watersheds and an estimated 620 mi^2 of non-monitored drainage area.

Total Lower Columbia Smolt Production

A total of 576,877 (426,088-548,288 95% C.I.) natural-origin coho smolts are estimated to have emigrated from the Lower Columbia region in 2011 (Table 1).

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	83.9	66.2	101.6
Mill	295.2	272.0	318.5
Abernathy	190.4	152.2	228.6
Germany	153.7	136.4	171.0
Tilton	370.6	354.2	387.1
Upper Cowlitz	366.6	284.6	448.5
Coweeman	195.5	153.3	237.8
Cedar	996.1	936.2	1056.0
Average Hatchery Streams	273.7	235.0	312.4
Average Wild Streams	262.9	232.9	293.0

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	2,182	1,721	2,643
Mill	8,563	7,888	9,238
Abernathy	5,520	4,413	6,628
Germany	3,535	3,137	3,934
Tilton	55,950	---	---
Upper Cowlitz	33,739	---	---
Coweeman	23,261	18,237	28,285
Cedar	60,778	57,132	64,424
Non-monitored Hatchery Streams	220,325	189,161	251,489
Non-monitored Wild Streams	163,024	144,400	181,647
Total Smolt Emigration	576,877	426,088	548,288

Marine Survival

Approach

The WSPE Unit has measured marine survival of wild coho for over thirty years at five long-term monitoring stations, four in Puget Sound and one in coastal Washington. 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. These wild coho tagging programs are similar to those used to assess exploitation rates and survival of hatchery stocks with the major difference that the wild coho tag groups represent survival of coho spawned and reared naturally. 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/).

Marine survival has ranged twenty-fold among the years of study. Differences in marine survival are dramatic among adjacent brood years and among regions, a result consistent with that reported from broader examinations of coho survival in the Pacific (Coronado and Hilborn 1998). In previous years, this forecast has relied heavily on sibling regression models. Sibling regression models predict the survival of a later age class (i.e., adult age-3) based on returns of an earlier age class (i.e., jack age-2). As such, the sibling regression approach to forecasting relies on consistent adult per jack coho survival rates among years. Although adults per jack coho survival rates were consistent in early years of this forecast (Seiler 1996), variability in this ratio over time has decreased the ability to accurately forecast adult marine survival. This issue was particularly apparent with the 2011 returns (2008 brood year) where survival of Big Beef Creek coho (Hood Canal management unit) dropped from 24.3 adults per jack coho in the 2010 return (2007 brood year) to 3.9 adults per jack coho in the 2011 return (2008 brood year). This shift meant that the forecasted marine survival was nearly 5-times the observed survival (see text below). Similar variability in the adult per jack survival rates was observed for Bingham Creek coho (Grays Harbor management unit) adding uncertainty to forecasts for the coastal Washington coho stocks.

The 2012 forecast takes two approaches to improving the marine survival predictions for wild coho management units in Washington State. Both approaches rely on metrics of ocean conditions provided by the Northwest Fisheries Science Center's Ocean Ecosystem Indicators research program. Physical and biological metrics of ocean conditions related to salmon survival are described in detail by NWFSC scientists online: http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/a-ecinhome.cfm. Ocean data have been collected during the NWFSC Washington and Oregon coastal surveys and compiled from 1998 to 2011. This time period represents the ocean entry timing of the 1999 to 2012 coho return years (brood year 1996 to 2009).

Two likely explanations for the variability in adult:jack ratios are that either maturation rates (i.e., proportion maturing as age-2 fish) or ocean survival (age-2 to age-3) varies among years. If maturation rates change as a function of environmental conditions, the current year jack returns may still be useful as a forecasting tool. However, if ocean survival from age-2 to age-3 differs among years then predictive relationships between environmental metrics and age-3 marine survival will be the most useful forecasting tool.

The first approach to improving the marine survival predictions examines whether variability in adult to jack survival rates can be explained by known environmental conditions. The second approach examines whether variability in adult marine survival rates can be explained by variability in ocean conditions. This approach is also useful for populations where sibling regression models have never been useful predictors of adult marine survival. Multiple studies have demonstrated predictive correlations between ocean conditions (e.g., sea surface temperature, upwelling, spring transition timing) and coho marine survival (Logerwell et al. 2003; Nickelson 1986; Ryding and Skalski 1999) and have suggested that early ocean survival is an important determinant of overall survival in the marine life stage (Quinn et al. 2005). The NWFSC Ocean Ecosystem Indicators research program has compiled these physical metrics as well as collecting information on various biological metrics including copepod community composition, winter ichthyoplankton, and densities of juvenile coho and Chinook during June and September trawl surveys along the Washington and Oregon coast.

Rather than derive a single, multi-variable prediction of marine survival, this forecast makes use of individual marine survival predictions based on statistically significant correlations. The range of these individual predictions gives an indication of the uncertainty in the forecasted survival rate.

Puget Sound

Marine survival rates of wild coho stocks have been measured in four geographic regions of Puget Sound and has ranged between 1 and 32% and generally declined since 1975 (Figure 7, Appendix C). In Big Beef Creek (Hood Canal), marine survival of wild coho has ranged between 2 and 32% for brood years 1975 to 2008. In the Deschutes River (South Sound), marine survival of natural-origin coho has ranged between 2% and 29% for brood years 1977 to 2007. Since 1995, low returns to the Deschutes River have resulted in too few smolts for a coded-wire tag group in 2 of the 3 brood years. At Sunset Falls (South Fork Skykomish River, southern Whidbey Basin), marine survival of wild coho ranged between 8% and 22% over nine broods (1976 to 1984 brood). 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 the escapement rate of coded-wire tagged coho from each brood year. In previous forecasts, the escapement rate was based on an assumed harvest of 15% for most years (Zimmerman 2011). In this forecast, the escapement rate was updated using coded-wire tag groups from Wallace hatchery (CWT/non-mark since 1996). In the Baker River (Skagit River, northern Whidbey Basin), marine survival of coho smolts has ranged between 1% and 14% over seventeen brood years (1989-1997, 2003-2008).

Previous forecasting approaches for Puget Sound have relied on a sibling regression of adult (age-3) to jack (age-2) survival rates of Big Beef Creek wild coho. Between brood year 1975 and 1996, the adult per jack survival rates were fairly consistent and averaged 11.4 ±2.9 (±1 St. Dev) adults per jack coho (Figure 8). During these years, 78% of the variation in age-3 coho marine survival could be predicted from jack return rates. However, between brood year 1997 and 2007, the adult per jack survival rates were much more variable and averaged 26.3 ±9.3 adults per jack coho. In comparison, a survival rate of 3.2 adults per jack coho was observed for brood year 2008, corresponding to a preliminary marine survival of 4%. This rate was far below the 20.7% marine survival rate forecasted based on a jack return rate of 1.0% and the 1997-2007 adult:jack survival ratio (Zimmerman et al 2011).

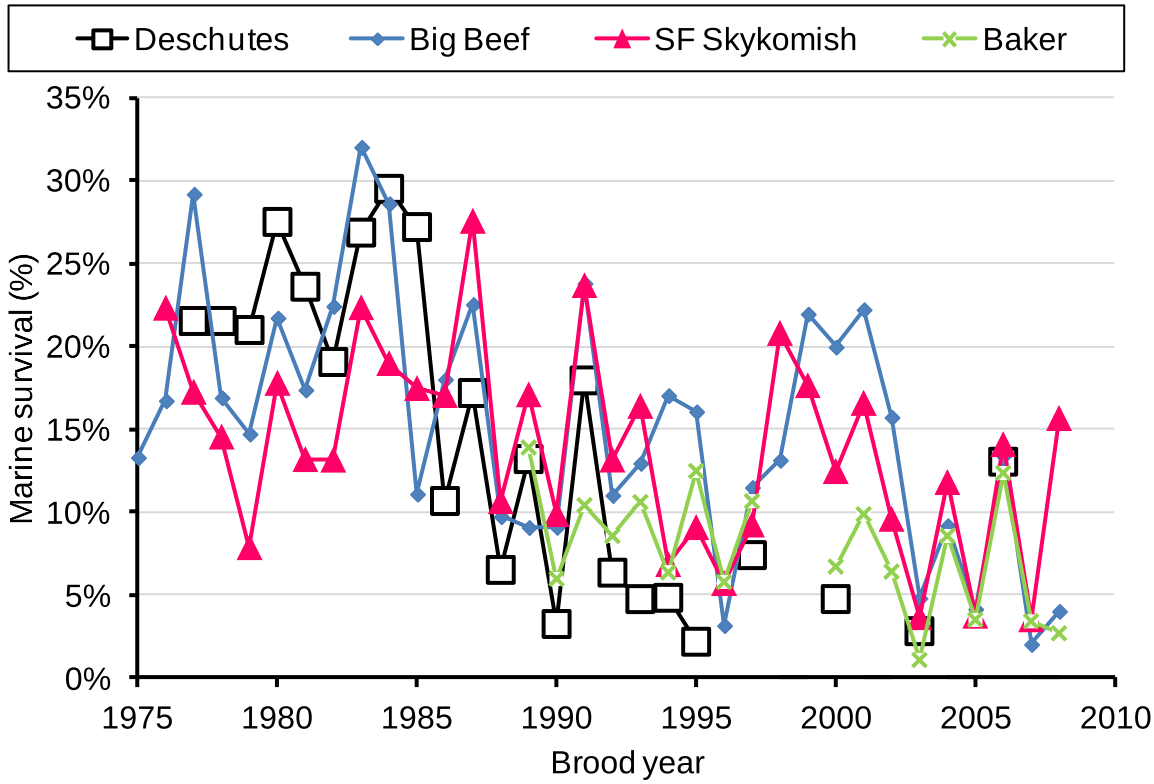


Figure 7. Marine survival (harvest + escapement) of four wild coho populations in Puget Sound, brood year 1975-2008. Marine survival estimated from coded-wire tag groups of wild smolts (except SF Skykomish 1985 to present, see text). Gaps in the plot represent years when marine survival was not measured.

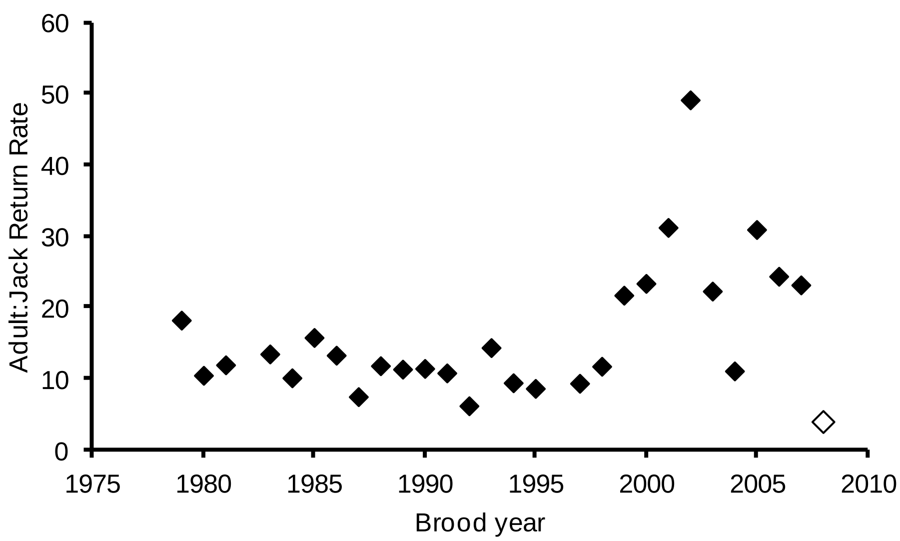


Figure 8. Adult (age-3) per Jack (age-2) survival rate of Big Beef Creek wild coho, brood year 1975-2008. Open diamond represents 2008 return, the lower adult per jack survival rate observed in this dataset.

Due to the uncertainty of the sibling regression prediction from Big Beef Creek, alternate approaches were explored for predicting marine survival of the 2012 coho return (brood year 2009). Marine survival (age-3) of wild coho from each of the long-term monitoring stations were regressed on physical and biological ocean indicators measured by the NWFSC Ocean Ecosystem Indicators research program (Bill Peterson and Laurie Weitkamp, NWFSC, personal communication). In addition, the relationship between these indicators and the adult to jack coho survival ratio from Big Beef Creek was also explored.

Marine survival of Big Beef Creek wild coho was not correlated with any of the physical ocean indicators. However, the adult-to-jack coho survival ratio at Big Beef Creek was negatively correlated with sea surface temperatures (SST) in the months of November to March preceding ocean entry (Figure 9). This relationship will continue to be examined as well as the potential mechanisms responsible. An average SST between Nov 2010 and March 2011 of 10.04ºC predicts a 27.9 adult per jack coho survival ratio. Based on the 0.4% survival of tagged jacks returning to Big Beef Creek in fall 2011, a 27.9 adult per jack coho survival ratio will result in an 11.5% marine survival for the 2009 brood year (2012 returns) This ratio was adjusted downward based on the uncertainty of this new approach and a marine survival of 9% was selected to represent the Hood Canal management unit for the 2012 forecast.

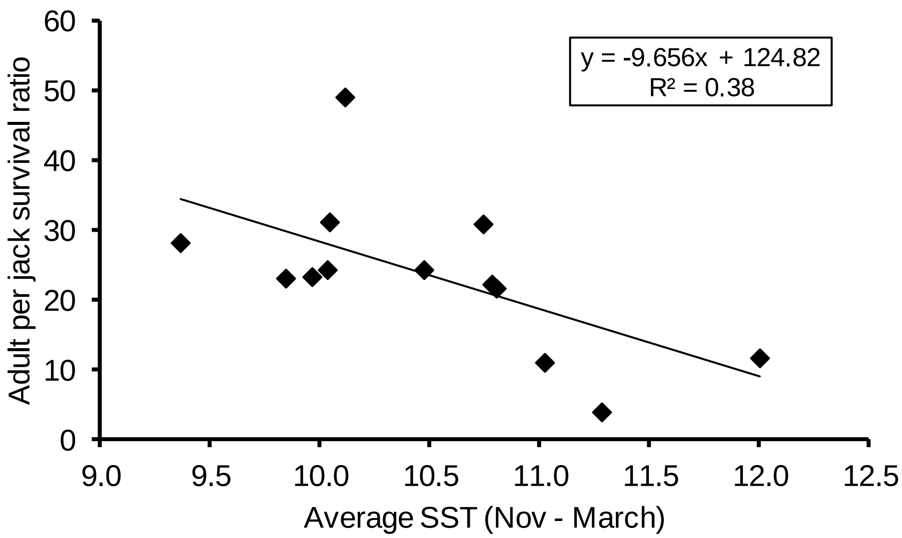


Figure 9. Adult (age-3) per jack (age-2) coho survival ratio as a function of average sea surface temperature (SST). Coho data are wild coho from Big Beef Creek, brood year 1996 to 2008. Sea surface temperature data are from NOAA Buoy 46050 near Newport, OR.

Marine survival of Baker wild coho was correlated with 3 of the 11 physical ocean indicators (May – September Pacific Decadal Oscillation Index, Oceanic Nino Index, and summer sea surface temperature) and 1 of the 7 biological ocean indicators (June Chinook catch densities, Table 6). All three physical ocean indicators were related to water temperature and Baker River wild coho had higher survival in years with lower temperatures during the period of ocean entry. Baker River wild coho also had higher survival in years when June trawl surveys returned higher catch per unit effort of juvenile Chinook. Individual regressions predicted a marine survival rate ranging from 5.4% to 10.5%. A marine survival of 5.4% was selected to represent the Skagit River management unit for the 2012 forecast. This rate was also applied to the neighboring Nooksack, Samish River, and Strait of Georgia management units.

Marine survival of South Fork Skykomish natural-origin coho was correlated with 2 of the 11 physical ocean indicators (both SST measures) and 2 of the 7 biological ocean indicators (winter ichthyoplankton, September coho catch densities, Table 7). Survival of South Fork Skykomish natural-origin coho was higher in years with lower SSTs, higher winter ichthyoplankton, and higher juvenile coho catch per unit effort during fall trawl surveys. Individual regressions predicted a marine survival between 8.7% and 11.2%. A marine survival of 8.7% was selected to represent the Snohomish management units for the 2012 forecast. This rate was also applied to the neighboring Stillaguamish River management unit.

Marine survival of Deschutes River natural-origin coho was correlated with 1 of the 11 physical ocean indicators (PDO May – September) and 2 of the 7 biological ocean indicators (winter ichthyoplankton, June Chinook catch densities, Table 8). Survival of Deschutes River natural-origin coho was higher in years with lower PDO values (lower sea surface temperatures), higher winter ichthyoplankton abundance, and higher juvenile Chinook catch per unit effort in the June trawl surveys. Individual regressions based on biological indicators predicted a much lower marine survival (2.3 to 3.8%) than the regression based on physical indicators (10.4%). As only 4 survival data points were available for Deschutes River coho during the ocean sampling time frame, these regressions had little power to detect trends. A marine survival of 4% was selected to represent the Deschutes River management unit for the 2012 forecast. This rate was also applied to the South Sound, Nisqually, and Puyallup management units.

Without additional information or wild indicator groups from central Puget Sound, a 6.5% marine survival (intermediate between South Sound and Whidbey basin MUs) was applied to the Lake Washington, Green River, and East Kitsap management units.

Table 6. Ocean ecosystem indicators of salmon survival as predictors of wild coho marine survival from Baker River (Skagit), Washington, brood year 1996 to 2007. Ocean indicators were provided by NWFSC fish ecology staff and are available online (http://www.nwfsc.noaa.gov/research divisions/fed/oeip/a-ecinhome.cfm). Marine survival predictions for the 2012 coho returns were based on 2011 ocean conditions and were calculated for significant correlations.

Indicator	Regression	$adjR^2$	p	2011 value	2012 Pred
Physical Indicators					
PDO (Sum Dec-March)	---	0.00	0.97	-3.65	---
PDO (Sum May-Sep)	ms =0.0661 - 0.006x	0.29	0.06	-6.45	10.5%
ONI Jan-June (Average)	ms =0.0698 - 0.0296x	0.22	0.09	-0.70	9.1%
SST 46050	---	0.16	0.13	13.06	---
SST NH 05 Summer	ms =0.397 - 0.0287x	0.33	0.05	11.27	7.4%
SST NH 05 Winter Before (Nov-Mar)	---	0.00	0.67	10.04	---
Physical Spring Trans UI Based	---	0.00	0.57	105	---
Upwelling Anom (April-May)	---	0.06	0.25	-36	---
Length of upwelling season (UI Based)	---	0.00	0.45	153	---
NH 05 Deep T (May-Sept)	---	0.00	0.42	7.92	---
NH 05 Deep S (May-Sept)	---	0.00	0.54	33.73	---
Biological Indicators					
Copepod richness anomaly	---	0.02	0.3	-2.41	---
Northern Copepod Biomass	---	0.19	0.12	0.43	---
Biological Transition	---	0.00	0.35	82	---
Copepod Community structure	---	0.05	0.27	-0.70	---
Winter Ichthyoplankton	---	0.06	0.24	0.61	---
June-Chinook Catches	ms = .0384 + 0.0345x	0.37	0.04	0.46	5.4%
Sept-Coho Catches	---	0.12	0.18	0.30	---
Composite Scores					
Mean of ranks of environmental data	---	0.13	0.15	6.9	---

Table 7. Ocean ecosystem indicators of salmon survival as predictors of wild coho marine survival from South Fork Skykomish River, Washington, brood year 1996 to 2007. Ocean indicators were provided by NWFSC fish ecology staff and are available online (http://www.nwfsc.noaa.gov/research divisions/fed/oeip/a-ecinhome.cfm). Marine survival predictions for the 2012 coho returns were based on 2011 ocean conditions and were calculated for significant correlations.

Indicator	Regression	$adjR^2$	p	2011 value	2012 Pred
Physical Indicators					
PDO (Sum Dec-March)	---	0.00	0.99	-3.65	---
PDO (Sum May-Sep)	---	0.06	0.22	-6.45	---
ONI Jan-June (Average)	---	0.13	0.13	-0.70	---
SST 46050	$ms = 0.781 - 0.0514x$	0.30	0.03	13.06	11.0%
SST NH 05 Summer	$ms = 0.642 - 0.0471x$	0.31	0.04	11.27	11.2%
SST NH 05 Winter Before (Nov-Mar)	---	0.00	0.33	10.04	---
Physical Spring Trans UI Based	---	0.08	0.19	105	---
Upwelling Anom (April-May)	---	0.00	0.74	-36	---
Length of upwelling season (UI Based)	---	0.00	0.49	153	---
NH 05 Deep T (May-Sept)	---	0.04	0.25	7.92	---
NH 05 Deep S (May-Sept)	---	0.00	0.34	33.73	---
Biological Indicators					
Copepod richness anomaly	---	0.11	0.15	-2.41	---
Northern Copepod Biomass	---	0.15	0.11	0.43	---
Biological Transition	---	0.00	0.32	82	---
Copepod Community structure	---	0.08	0.19	-0.70	---
Winter Ichthyoplankton	$ms = 0.0457 + 0.0674x$	0.28	0.05	0.61	8.7%
June-Chinook Catches	---	0.00	0.43	0.46	---
Sept-Coho Catches	$ms = 0.0767 + 0.0745x$	0.26	0.05	0.30	9.9%
Composite Scores					
Mean of ranks of environmental data	---	0.07	0.2	6.9	---

Table 8. Ocean ecosystem indicators of salmon survival as predictors of wild coho marine survival from Deschutes River, Washington, brood year 1996 to 2007. Ocean indicators were provided by NWFSC fish ecology staff and are available online (http://www.nwfsc.noaa.gov/research divisions/fed/oeip/a-ecinhome.cfm). Marine survival predictions for the 2012 coho returns were based on 2011 ocean conditions and were calculated for significant correlations.

Indicator	Regression	$adjR^2$	p	2011 value	2012 Pred
Physical Indicators					
PDO (Sum Dec-March)	---	0.46	0.2	-3.65	---
PDO (Sum May-Sep)	$ms = 0.0499 - 0.00840x$	0.82	0.06	-6.45	10.4%
ONI Jan-June (Average)	---	0.55	0.13	-0.70	---
SST 46050	---	0.00	0.43	13.06	---
SST NH 05 Summer	---	0.09	0.37	11.27	---
SST NH 05 Winter Before (Nov-Mar)	---	0.38	0.23	10.04	---
Physical Spring Trans UI Based	---	0.04	0.4	105	---
Upwelling Anom (April-May)	---	0.10	0.37	-36	---
Length of upwelling season (UI Based)	---	0.00	0.75	153	---
NH 05 Deep T (May-Sept)	---	0.00	0.46	7.92	---
NH 05 Deep S (May-Sept)	---	0.25	0.3	33.73	---
Biological Indicators					
Copepod richness anomaly	---	0.00	0.48	-2.41	---
Northern Copepod Biomass	---	0.16	0.33	0.43	---
Biological Transition	---	0.62	0.14	82	---
Copepod Community structure	---	0.07	0.38	-0.70	---
Winter Ichthyoplankton	$ms = -0.0298 + 0.0864x$	0.74	0.09	0.61	2.3%
June-Chinook Catches	$ms = 0.018 + 0.0432x$	0.98	0.006	0.46	3.8%
Sept-Coho Catches	---	0.00	0.96	0.30	---
Composite Scores					
Mean of ranks of environmental data	---	0.37	0.26	6.9	---

Coast

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. In Bingham Creek, coho smolts and spawners are intercepted by a creek-spanning weir during their respective migration periods. Coded-wire tag releases of wild smolts from Bingham Creek are used to estimate marine survival (harvest + escapement) for jack (age-2) and adult (age-3) returns from each brood year. Marine survival of Bingham Creek wild coho has ranged from 0.6% to 11.6% between brood year 1980 and 2007 (Figure 10).

In previous forecasts, marine survival associated with the upcoming fishery has been predicted with a sibling regression, relying on a relationship between return rates of adult and jack coho to Bingham Creek. Between brood year 1980 to 2008, the adult to jack survival ratio averaged 55 adults per jack coho. However, this ratio has varied widely, from 8 to 153 adults per jack coho (Figure 10). Historically, this forecast has derived different sibling regression models for different time periods (Seiler 1996; Volkhardt et al. 2008) based on observed temporal shifts in relative return rates of jack and adult coho. However, recent indications are that the ratio of returning adults per jack is changing once again (Figure 10). For example, 72.4 adults per jack coho survived in the 2010 return whereas just 11.7 adults per jack coho survived in the 2011 return. This variability has led to increased interest in alternate predictors of age-3 survival.

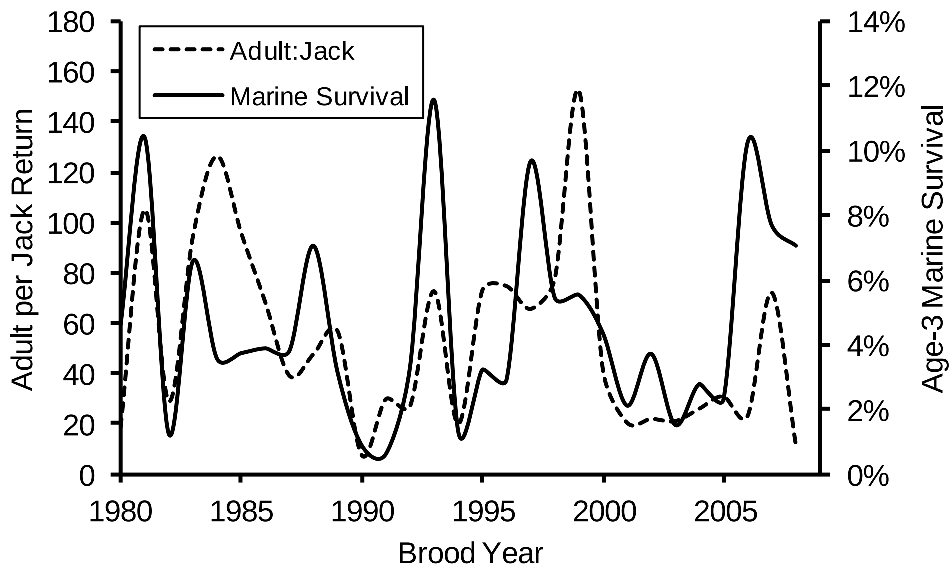


Figure 10. Marine survival and adult (age-3) per jack (age-2) return ratio of wild coho to Bingham Creek, Washington, brood year 1980 to 2007.

Ocean condition indices may have good potential as alternate predictors of coho marine survival. Over the past decade, the ocean sampling program conducted by the Northwest Fishery Science Center fish ecology staff has collected and provided useful metrics of ocean conditions. NWFSC scientists use these indicators to forecast returns of coho and Chinook to the Columbia River and coastal Oregon. Further application of these conditions to wild coho on the Washington coast is plausible given that previous studies have found that hatchery coho stocks from the Columbia River and Washington coast were influenced by similar metrics of ocean conditions (Ryding and Skalski 1999). Therefore, this forecast explores the use of physical and biological ocean indicators for explaining marine survival of

Bingham Creek wild coho salmon and uses statistically significant relationships to predict marine survival of the 2012 coho return (2009 brood year).

In 2011, Bingham Creek wild coho marine survival was predicted to be 10.9% based on a jack-adult sibling regression and 6.1% based on a regression between PDO and age-3 marine survival (Zimmerman 2011). An intermediate value of 8.5% was selected for the 2011 wild coho forecast. The preliminary estimate of marine survival for the 2011 Bingham Creek wild coho return (brood year 2008) is 7.0%. This number may be adjusted upwards as fishery interceptions of additional coded-wire tags are reported in the coastwide RMPC database. In 2012, the jack return rate to Bingham Creek was 0.60% (137 tagged jacks returning from an adjusted tag group of 22,771 smolts). However, an appropriate adult to jack survival rate was questionable based on the recent variability in this ratio (Figure 10).

Therefore, separate linear regressions were conducted for each physical and biological metric of ocean condition to determine which metrics were best correlated with marine survival of Bingham Creek wild coho (Table 9). Of the 11 physical metrics, marine survival of Bingham Creek wild coho was correlated with the Pacific Decadal Oscillation index (PDO, sum December through March and May through December) and the upwelling anomoly between April and May. Higher coho survival was associated with a lower PDO (cooler temperatures) and a more positive upwelling anomoly. Of the 7 biological metrics, marine survival of Bingham Creek wild coho was correlated with copepod richness, date of biological transition, copepod community structure, winter ichthyoplankton densities, and June Chinook catches. Higher coho survival was associated with a lower copepod richness,earlier date of biological transition, a more “cold-water copepod” community structure, and higher densities of winter ichthyofauna and June Chinook catches. Marine survival of Bingham Creek wild coho was also correlated with the composite index of all physical and biological metrics (mean of environmental indicator ranks) calculated by the NWFSC staff (Bill Peterson and Laurie Weitkamp, NWFSC, personal communication). Consistent with results reported for Columbia River coho and Chinook (NWFSC website, address provided above), Bingham Creek wild coho survival was associated with the composite index.

Predicted marine survival for the 2012 returns (brood year 2009) of Bingham Creek wild coho ranged between 3.5 and 8.9%. The physical indicators generally predicted a higher survival than the biological indicators. This forecast uses the intermediate value of 5.3%, predicted by the composite score (mean of ranks of environmental data) as the starting point for forecasting wild coho in the Washington coast management units. A marine survival of 5.3% was applied to the Grays Harbor, Humptulips, and Willapa Bay management units as well as independent tributaries in coastal Washington (Table 1). A marine survival of 6.5% was applied to the Quinault, Queets, and Hoh rivers. A marine survival of 7.5% was applied to the Quillayute River. These upward adjustments for the northern coastal watersheds reflected the general trend of higher marine survival in the northern Washington coastal systems.

Table 9. Ocean ecosystem indicators of salmon survival as predictors of wild coho marine survival from Bingham Creek, Washington, brood year 1996 to 2007. Ocean indicators were provided by NWFSC fish ecology staff and are available online (http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/a-ecinhome.cfm). Marine survival predictions for the 2012 coho returns were based on 2011 ocean conditions and were calculated for significant correlations.

Indicator	Regression[a]	$adjR^2$	p	2011 Value	2012 Pred.
Physical Indicators					
PDO (Sum Dec-March)	ms =0.0513 -0.00566 x	0.45	0.01	-3.65	7.2%
PDO (Sum May-Sep)	ms = 0.0425 - 0.00720 x	0.69	<0.001	-6.45	8.9%
ONI Jan-June (Average)	ms = 0.0472 - 0.0332 x	0.51	0.005	-0.70	7.0%
SST 46050	---	0.11	0.16	13.06	---
SST NH 05 Summer	---	0.01	0.32	11.27	---
SST NH 05 Winter Bef (Nov-Mar)	---	0.11	0.15	10.04	---
Physical Spring Trans UI Based	---	0.01	0.31	105	---
Upwelling Anom (April-May)	ms = 0.0610 + 0.000843 x	0.27	0.04	-36	3.1%
Length upwelling season (UI Based)	---	0.00	0.34	153	---
NH 05 Deep T (May-Sept)	---	0.15	0.11	7.92	---
NH 05 Deep S (May-Sept)	---	0.03	0.27	33.73	---
Biological Indicators					
Copepod richness anomaly	ms = 0.0505 - 0.00742 x	0.36	0.02	-2.41	6.8%
Northern Copepod Biomass	---	0.22	0.07	0.43	---
Biological Transition	ms = 0.0957 - 0.000359 x	0.30	0.04	82	6.6%
Copepod Community structure	ms = 0.0359 - 0.0334 x	0.34	0.02	-0.70	5.9%
Winter Ichthyoplankton	ms= 0.0167 + 0.0356 x	0.30	0.04	0.61	3.9%
June-Chinook Catches	ms = 0.0180 + 0.0370 x	0.56	0.003	0.46	3.5%
Sept-Coho Catches	---	0.03	0.27	0.30	---
Composite Scores					
Mean of ranks of environmental data	ms = 0.104 - 0.00734 x	0.51	0.005	6.9	5.3%

[a]All linear regressions met assumptions of normality and homogeneity of variance, except for copepod community structure.

Lower Columbia River

Wild coho marine survival in the Lower Columbia River Evolutionary Significant Unit was assumed to be comparable to coastal Washington stocks and a 5.3% marine survival rate was also applied to this ESU (Table 1). At a 20% harvest rate, the predicted 5.3% marine survival corresponds to a 4.2% smolt-to-adult return rate. This prediction is slightly higher than the 2.9% smolt-to-adult return rate of coho (hatchery and wild) to Bonneville Dam as forecasted by the NWFSC Ocean Ecosystem Indicator research group (Bill Peterson and Laurie Weitkamp, NWFSC, personal communication)

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 2010 (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 2010 (corresponding to the 2011 outmigration and 2012 returning adults) had an index value of 9.7 or 121% of the long-term average.

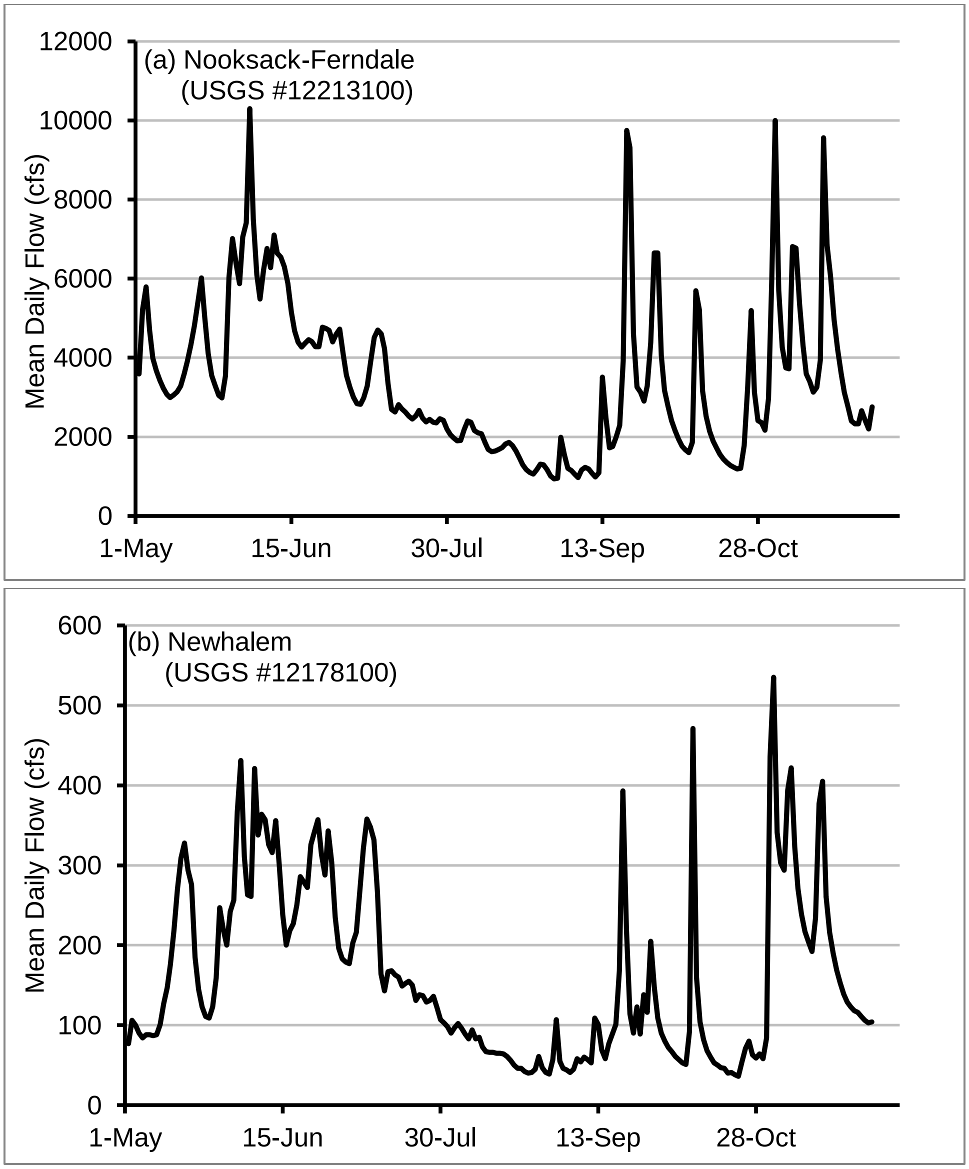
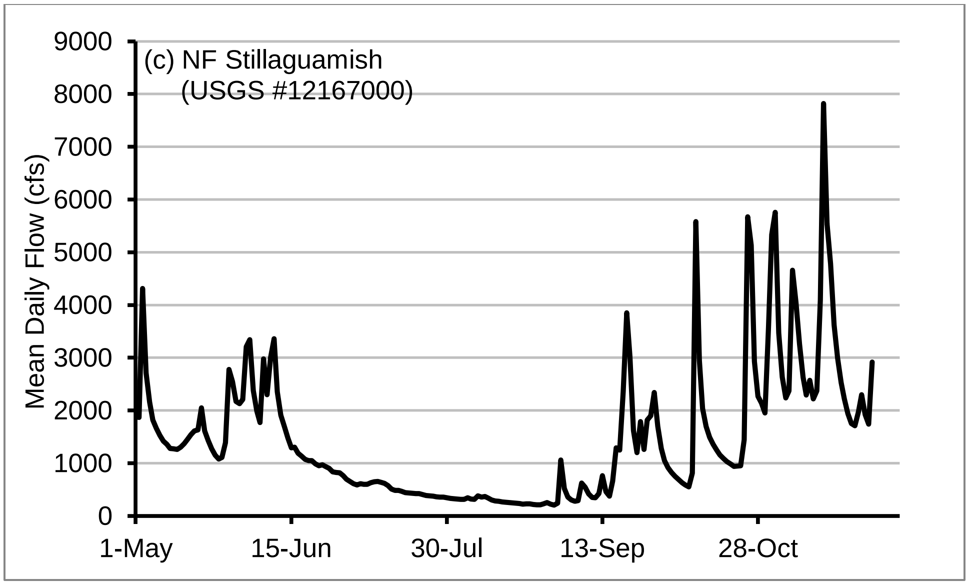


Figure A-1. Mean daily flows at selected stream gages used for Puget Sound Summer Low Flow Index. Flow data for May 1 – November 30, 2010 were provided by the United States Geological Survey for the Nooksack River (*a*), Newhalem Creek (*b*), North Fork Stillaguamish River (*c*), North Fork Snoqualmie River (*d*), Taylor Creek (*e*), Rex River (*f*), Newaukum Creek (*g*), and Skokomish River (*h*). Figure is continued on the next page.



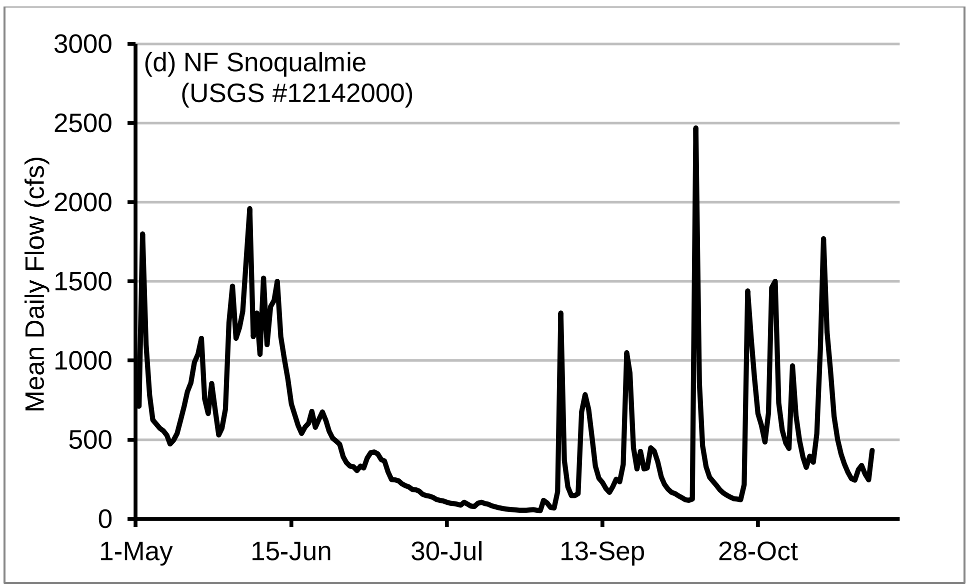


Figure A-1. Mean daily flows at selected stream gages used for Puget Sound Summer Low Flow Index. Flow data for May 1 – November 30, 2011 were provided by the United States Geological Survey for the Nooksack River (*a*), Newhalem Creek (*b*), North Fork Stillaguamish River (*c*), North Fork Snoqualmie River (*d*), Taylor Creek (*e*), Rex River (*f*), Newaukum Creek (*g*), and Skokomish River (*h*). Figure is continued on the next page.

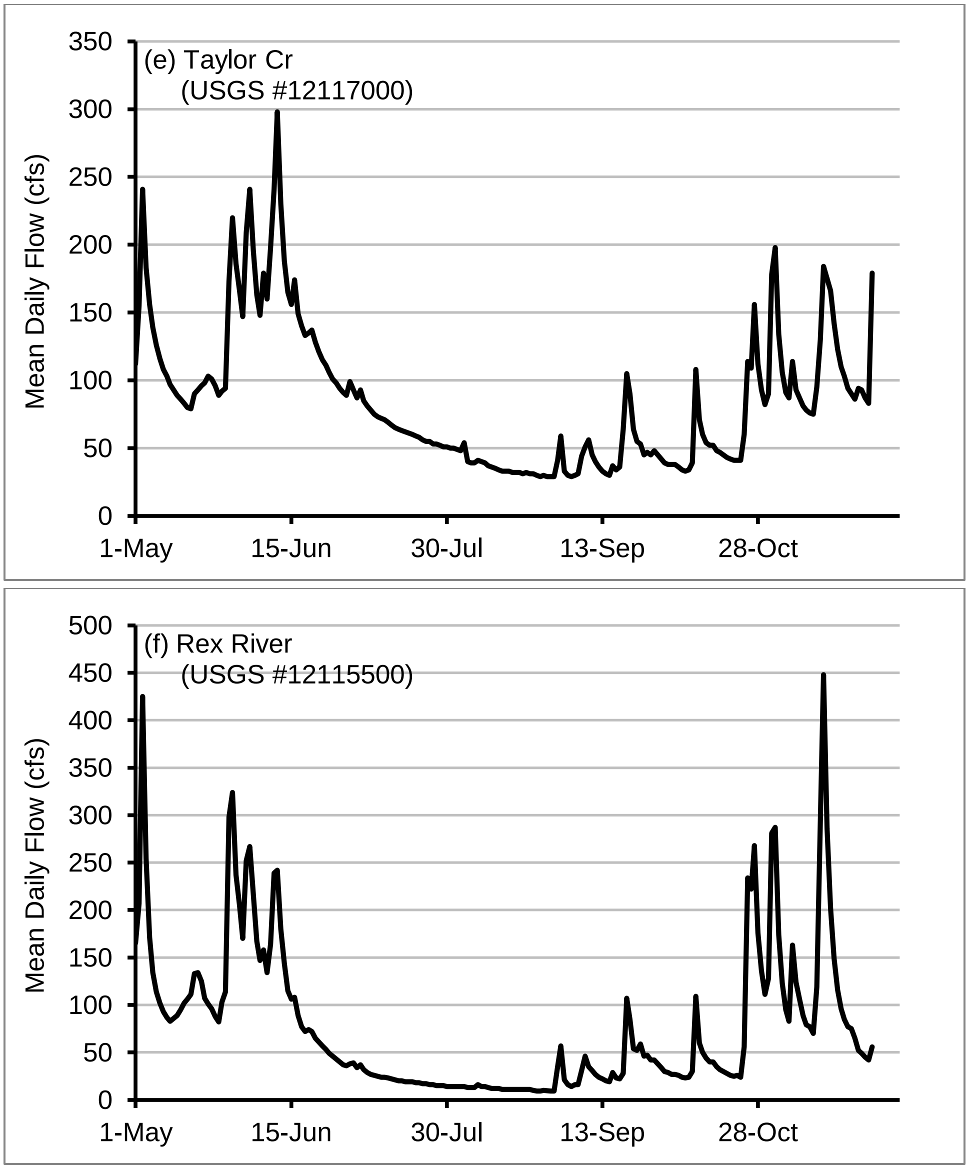
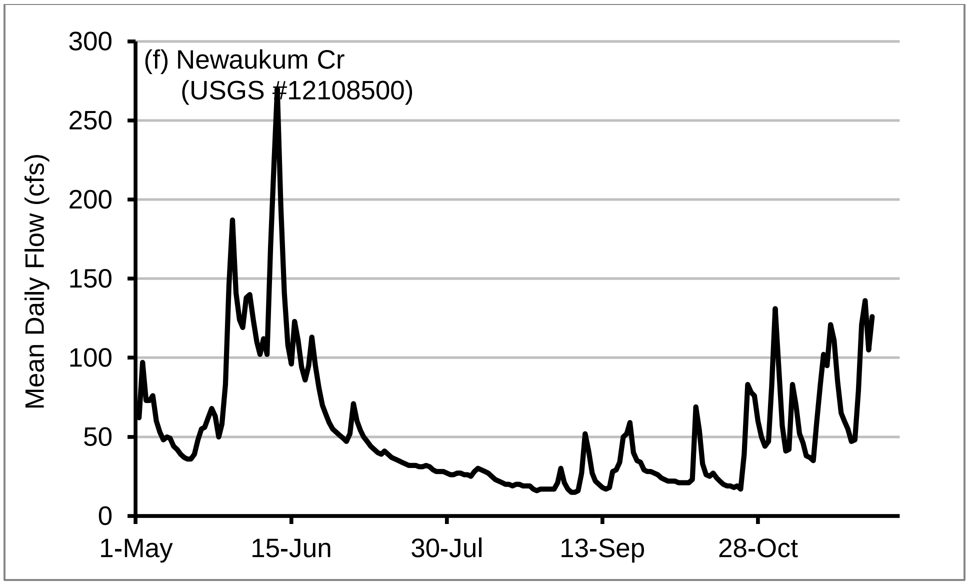
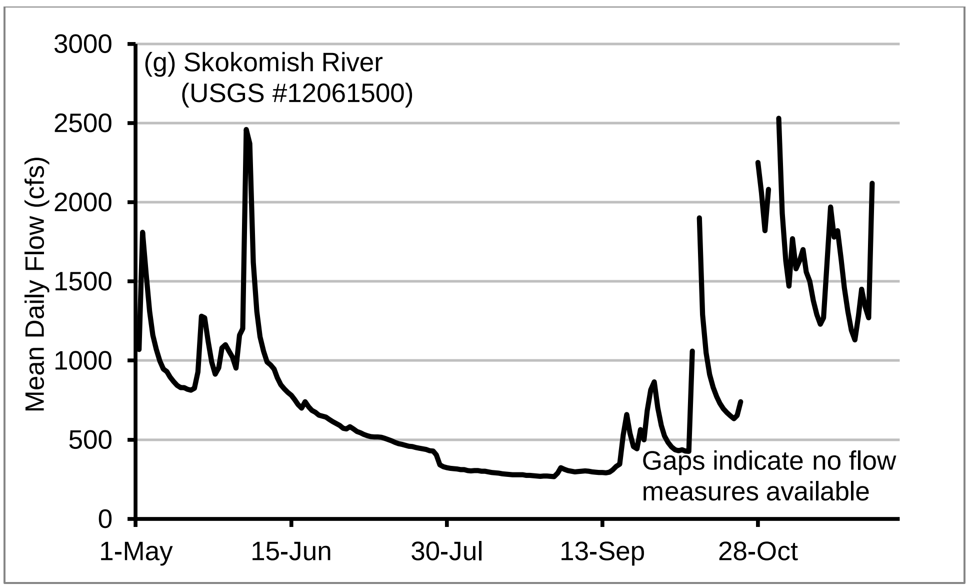


Figure A-1. Mean daily flows at selected stream gages used for Puget Sound Summer Low Flow Index. Flow data for May 1 – November 30, 2010 were provided by the United States Geological Survey for the Nooksack River (*a*), Newhalem Creek (*b*), North Fork Stillaguamish River (*c*), North Fork Snoqualmie River (*d*), Taylor Creek (*e*), Rex River (*f*), Newaukum Creek (*g*), and Skokomish River (*h*). Figure is continued on the next page.





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

	Drainage area (mi^2)	
Watershed	Total	Measured
Quillayute	629	
Dickey		87
Bogachiel		129
Hoh	299	
Queets	450	450
Clearwater	140	140
Quinault	434	
Independent Tributaries		
Waatch River	13	
Sooes River	41	
Ozette River	88	
Goodman Creek	32	
Mosquito Creek	17	
Cedar Creek	10	
Kalaloch Creek	17	
Raft River	77	
Camp Creek	8	
Duck Creek	8	
Moclips River	37	
Joe Creek	23	
Copalis River	41	
Conner Creek	12	
Grays Harbor		
Chehalis	2,114	2,114
Humptulips	250	
Southside tribs*	186	
Willapa Bay	850	

* Southside tributaries below the Grays Harbor terminal fishery

Appendix C. Marine survival of wild coho in selected Puget Sound watersheds. Marine survival is estimated from releases and recoveries of coded-wire tagged wild coho (except where noted).

Year Brood	Year Return	Big Beef Creek	Deschutes River[c]	SF Skykomish[b]	Baker River	Average
1975	1978	13.3%				13.3%
1976	1979	16.7%		22.3%		19.5%
1977	1980	29.2%	21.5%	17.3%		22.6%
1978	1981	16.9%	21.5%	14.5%		17.7%
1979	1982	14.7%	21.0%	7.9%		14.5%
1980	1983	21.7%	27.5%	17.8%		22.3%
1981	1984	17.4%	23.6%	13.2%		18.0%
1982	1985	22.4%	19.0%	13.2%		18.2%
1983	1986	32.0%	26.9%	22.3%		27.1%
1984	1987	28.6%	29.5%	19.0%		25.7%
1985	1988	11.1%	27.2%	17.5%		18.6%
1986	1989	18.0%	10.7%	17.0%		15.2%
1987	1990	22.5%	17.2%	27.6%		22.4%
1988	1991	9.7%	6.5%	10.6%		9.0%
1989	1992	9.1%	13.2%	17.1%	13.9%	13.3%
1990	1993	9.1%	3.2%	9.9%	6.0%	7.0%
1991	1994	23.8%	17.9%	23.7%	10.4%	19.0%
1992	1995	11.0%	6.3%	13.2%	8.5%	9.8%
1993	1996	13.0%	4.7%	16.4%	10.6%	11.2%
1994	1997	17.0%	4.8%	6.9%	6.3%	8.8%
1995	1998	16.1%	2.2%	9.1%	12.5%	9.9%
1996	1999	3.2%	---	5.7%	5.8%	4.9%
1997	2000	11.5%	7.4%	9.2%	10.6%	9.7%
1998	2001	13.1%	---	20.8%	---	17.0%
1999	2002	22.0%	---	17.6%	---	19.8%
2000	2003	20.0%	4.7%	12.5%	6.7%	11.0%
2001	2004	22.2%	---	16.6%	9.9%	16.2%
2002	2005	15.7%	---	9.6%	6.4%	10.6%
2003	2006	4.8%	2.8%	3.6%	1.1%	3.1%
2004	2007	9.2%	---	11.8%	8.6%	9.8%
2005	2008	4.2%	---	3.7%	3.5%	3.8%
2006	2009	13.4%	13.0%	14.1%	12.3%	13.2%
2007	2010	2.0%	---	3.5%	3.4%	3.0%
2008	2011[a]	4.0%	---	15.7%	2.7%	7.5%
	Average	15.3%	14.4%	14.0%	7.7%	13.9%
	Min	2.0%	2.2%	3.5%	1.1%	3.0%
	Max	32.0%	29.5%	27.6%	13.9%	27.1%
	Count	34	23	33	18	34

Continued on next page

Appendix C. Continued.

[a]Brood year 2008 marine survival should be considered preliminary and a lower bound. Estimate will be finalized after expansions of all sampling data have been reported in RMIS.

[b]SF Skykomish River marine survival calculations: brood year (BY) 1978-1984 based on coded-wire tag release and recoveries of wild coho, BY 1985-present based on an average measured smolt production and Sunset Falls escapement expanded for escapement rate. Average smolt production from BY 1976 to 1981 was 276,000 smolts above Sunset Falls. When escapement was experimentally reduced (BY 1982-1984), the average smolt production fell to an average of 198,000 smolts. The lower production is used to estimate marine survival for years when Sunset Falls escapement falls below 9,000 adults. Escapement rate for BY 1985-1995 was calculated from the Wallace hatchery coho coded-wire tag group (CWT/Ad-Clip). Escapement rate for brood year 1996 to present was claculated from the Wallace hatchery coho DIT group (CWT/No Clip).

[c]Since 1995, coded-wire tag groups for Deschutes River natural coho have been limited by low smolt catches (low escapements in 2 of 3 brood years). Marine survival of Dechutes natural coho is reported only for those years when smolt abundance was high enough to release a CWT tag group.

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