2009 Wild Coho Forecasts for Puget Sound, Washington Coast, and Lower Columbia

Washington Department of Fish & Wildlife

Science Division

by

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Introduction

Run size forecasts for wild coho stocks are an important element of the joint state and tribal pre-season planning process for Washington State salmon fisheries. Accurate forecasts on a stock basis are necessary to ensure adequate spawning escapements while realizing harvest benefits and achieving allocation goals.

The ability to manage wild coho runs will be improved by understanding variables that cause variation in abundance for each major system. Across Washington's coho producing systems, ocean recruits have been predicted using various approaches. Methods that rely on the relationship between adult escapement estimates and resulting run sizes are problematic due to inaccurate escapement estimates and difficulty allocating fishery catches by stock. Furthermore, coho forecasts based solely on estimated escapement have no predictive value in systems that are adequately seeded and do not account for survival rates associated with freshwater and marine rearing phases.

Freshwater production is measured by smolt abundance. In recognition of this, natural coho escapement goals throughout the state are based on the projected smolt carrying capacity of each system. The Washington Department of Fish and Wildlife (WDFW) and tribes have made substantial investments in monitoring smolt populations in order to assess these goals and to improve run forecasts.

Marine survival rates for wild coho stocks have also been measured at several stations in Puget Sound and at one station in the Grays Harbor system. Survival-to-return at these stations is considered accurate and unbiased because tag groups are enumerated at a 100%-capture trapping structure. Data from these monitoring stations describe patterns of inter-annual and inter-system survival within broods.

Adult recruits are the product of smolt production and marine survival and can be expressed in a matrix that combines these two components. This approach is similar to that used to understand hatchery returns because the starting population (number of smolts released) is known. For stocks where smolt abundance or marine survival is not measured, adult ocean recruits can be forecasted from extrapolated smolt production rates and marine survival rates of neighboring or comparable watersheds. Long-term data sets, such as those that contribute to this forecast, have been used to identify environmental variables contributing to freshwater production and regional patterns in marine survival. In addition, the life history approach adopted by this forecast directly connects coho production with habitat and should therefore improve stakeholder understanding of fisheries management.

Forecasts of ocean recruits are important for Washington fisheries managed for escapement as well as those focused on recovery of stocks listed under the Endangered Species Act (ESA). Fisheries are managed to achieve escapement goals for wild coho stocks returning to eight production areas in Puget Sound and the Washington coast: Skagit, Stillaguamish/Snohomish, Hood Canal, Straits, Quillayute, Hoh, Queets, and Grays Harbor. Forecasts for these “primary” wild coho management units are to determine the extent and shape of fisheries. In addition, forecasts for Lower Columbia natural-origin coho are increasingly important for the management of Columbia River fisheries because harvest impacts on Lower Columbia coho are restricted in order to rebuild this Evolutionary Significant Unit (ESU).

The Wild Salmon Production Evaluation (WSPE) Unit within the WDFW Fish Program Science Division has developed wild coho run-size forecasts for the last fourteen years. Beginning in 1996, a wild coho forecast for all primary and most secondary management units in Puget Sound and the Washington coast was developed by the WDFW Science Division (Seiler 1996). A forecast for Lower Columbia wild coho was added in 2000 (Seiler 2000). Forecast methodology for the Lower Columbia continues to evolve (Volkhardt et al. 2007) in response to listing of Lower Columbia coho under the Endangered Species Act in 2005.

Table 1 presents forecasts for 2009 wild coho run sizes for Puget Sound, Coastal, and Lower Columbia River stream systems. Estimates of three-year old ocean recruits were adjusted to both December age-2 and January age-3 recruits in order to provide appropriate coho management model inputs. The following sections provide rationale for each smolt production and marine survival estimate.

Table 1. Wild coho run forecasts for 2009 based on smolt production estimates and marine survival predictions.

Production Unit	PRODUCTION X Estimated Smolt Production: Spring 2008	MARINE SURVIVAL = Adults (Age 3)	Dec. (Age 2)	RECRUITS Adults (Age 3)	Dec. (Age 2)	Jan. (Age 3)
Puget Sound						
Primary Units						
Skagit River	426,963	9.3%	12.4%	39,700	52,900	48,880
Stillaguamish River	144,000	9.3%	12.4%	13,400	17,900	16,540
Snohomish River	720,000	9.3%	12.4%	67,000	89,300	82,510
Hood Canal	601,293	9.3%	12.4%	55,900	74,500	68,840
Straits of Juan de Fuca	**see note below**					
Secondary Units						
Nooksack River	113,000	9.3%	12.4%	10,500	14,000	12,940
Strait of Georgia	16,000	9.3%	12.4%	1,500	2,000	1,850
Samish River	23,000	9.3%	12.4%	2,100	2,900	2,680
Lake Washington	37,500	9.3%	12.4%	3,500	4,600	4,250
Green River	56,048	9.3%	12.4%	5,200	6,900	6,380
Puyallup River	146,556	9.3%	12.4%	13,600	18,200	16,820
Nisqually River	20,000	9.3%	12.4%	1,900	2,500	2,310
Deschutes River	43,074	9.3%	12.4%	4,006	5,340	4,930
South Sound	163,000	9.3%	12.4%	15,200	20,200	18,660
East Kitsap	110,000	9.3%	12.4%	10,200	13,600	12,570
Puget Sound Total	2,620,434			243,706	324,840	300,160
Coast						
Queets River	278,018	7.0%	9.3%	19,461	25,942	23,970
Quillayute River	269,000	7.0%	9.3%	18,830	25,100	23,190
Hoh River	119,000	7.0%	9.3%	8,330	11,104	10,260
Quinault River	163,000	7.0%	9.3%	11,410	15,210	14,050
Independent Tributaries	159,000	7.0%	9.3%	11,130	14,836	13,710
Grays Harbor						
Chehalis River	1,657,937	7.0%	9.3%	116,056	154,702	142,940
Humptulips River	180,211	7.0%	9.3%	12,615	16,815	15,540
Willapa Bay	510,000	7.0%	9.3%	35,700	47,588	43,970
Coastal Systems Total	3,336,166			233,532	311,297	287,630
Lower Columbia Total	380,100	7.0%	9.3%	26,607	35,467	32,770
GRAND TOTAL	6,336,700			503,845	671,604	620,560

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

Smolt Production

Coho smolt production has been measured in each of the eight major natural production systems except the Hoh. Skagit River smolt production has been estimated annually since 1990. Smolt production from the Chehalis River basin has been estimated annually since 1986. The Chehalis River is the largest Washington watershed accessible to anadromous fish outside of the Columbia River. Smolt production has also been measured from portions of the Snohomish, Stillaguamish, Hood Canal, Quillayute, and Queets systems as well as the Lower Columbia River. In aggregate, this work has produced a body of information describing wild coho carrying capacity as a function of habitat quality and quantity. Seeding levels, environmental effects (flows), and human-caused habitat degradation explain much of the inter-system and inter-annual variations in smolt production that have been measured (Table 2).

In currently unmeasured systems, production can be approximated using available production data. Within Puget Sound, Washington Department of Fisheries Technical Report 28 (Zillges 1977) has been used to transfer smolt production measurements to other basins. The Zillges report projects potential coho smolt production for each stream in Puget Sound (east of Cape Flattery) based on wetted habitat area during summer low flows. For coastal systems, smolt production in unstudied watersheds can be approximated by extrapolating production per square mile of drainage basin measured in the study streams. For Lower Columbia systems, smolt production in unstudied watersheds was also approximated using production rates of study streams with and without hatchery releases of coho.

Table 2. Summary of coho smolt production evaluations and sources of inter-annual variation in sixteen western Washington streams.

Stream	Number of Years	Watershed Area (mi^2)	SMOLT PRODUCTION Range Low	High	Ratio Hi/Lo	Average Production	Average Prod/mi^2	Identified Sources of Variation (see key)
Hood Canal								
Big Beef Creek	31	14	11,510	47,088	4.1	26,422	1887	1,2,3,4,5
Stavis	15	5	2,850	9,667	3.4	6,267	1253	1,2,3,4,5
Seabeck	15	5.4	787	2,725	3.5	1,513	280	1,2,3,4,5
Little Anderson	15	5	45	1,969	43.8	534	107	1,2,3,4,5
Bingham Creek	27	35	15,233	70,342	4.6	30,533	872	2,3
Deschutes River	30	160	892	133,198	149.3	49,197	307	1,2,4,5
SF Skykomish River	9	362	181,877	353,981	1.9	249,442	689	7
Dickey River[a]	3	87	61,717	77,554	1.3	71,189	818	6
Bogachiel River[a]	3	129	48,962	61,580	1.3	53,751	417	6
Clearwater River	28	140	27,314	99,354	3.6	68,709	491	1,4,5
Stillaguamish River	3	540	203,072	379,022	1.9	275,940	511	6
Green River	7		12,553	191,000	15.2	59,156		1,2,5
Lake Washington								
Cedar River	10	188	13,382	84,000	6.3	52,017	277	1,5
Bear Creek	10	50	3,170	64,100	20.2	36,024	720	
Skagit River[b]	19	1,918	426,963	1,884,668	4.4	1,014,069	529	1,2,3,8
Chehalis River	25	2,114	502,918	3,592,275	7.1	1,902,207	900	1,2,3,4
Total		5,752						
Mean							671	
Weighted Mean[c]							667	

[a] Dickey and Bogachiel River watersheds are estimated areas above trap locations.
[b] Skagit River total drainage area – 3,093 mi^2, of which 1,175 mi^2 are inaccessible above dams.
[c] Weighted by watershed
[d] All data above trap at R.M. 34.

Key	
1. Winter flows – gravel scour/egg survival	5. Habitat damage
2. Summer flows – rearing habitat	6. No factors identified
3. Fall flows – spawner distribution	7. Experimental escapement reduction

Puget Sound Primary Units

Skagit River

A total of 426,963 coho smolts are estimated to have emigrated from the Skagit River in 2008. This estimate is based on capture of emigrants in floating scoop and screw traps located in the lower main stem river. Traps are calibrated based on recaptures of natural-origin yearling coho trapped and marked in a 100%-capture upstream tributary. Total production estimate is calculated using a pooled Petersen estimate with a Chapman modification (Appendix 1- 1; Volkhardt et al. 2007).

Production from the 2006 brood was 61% below average production of the 1990-2006 brood years and the lowest production observed in nineteen years of study on the Skagit River (Figure 1; Table 2). Low spawner abundance was the most likely contributor to low smolt production as the 2006 escapement was also the lowest on record (Brett Barkdull, WDFW Region 4, personal communication).

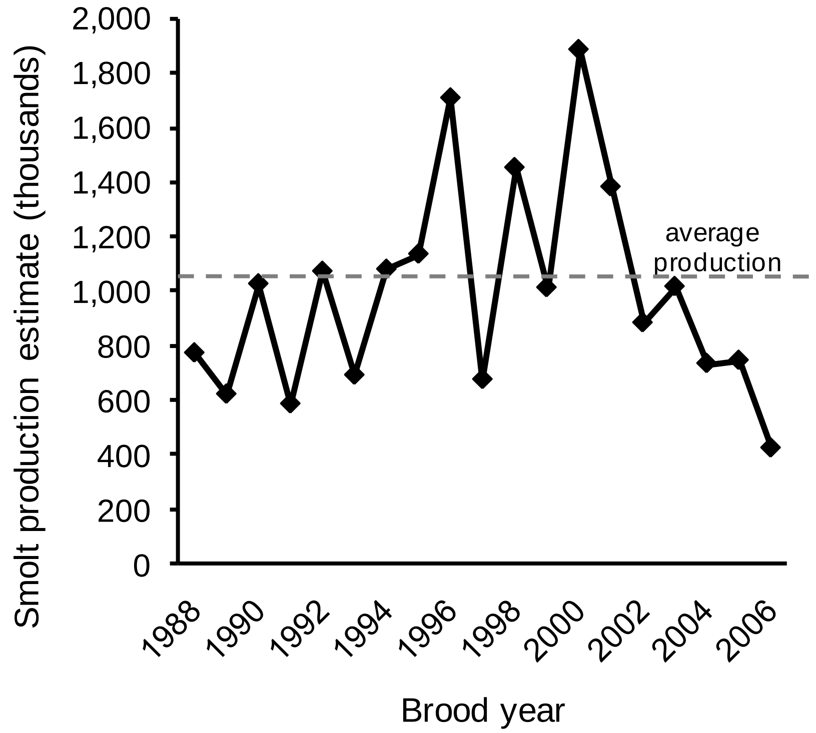

Figure 1. Production of natural-origin coho smolts in the Skagit River

In addition to escapement, at least three variables contribute to inter-annual variability in Skagit River coho production: peak winter flows, summer low flows, and species interactions. Peak winter flows were high (125,000 cfs at the Mt Vernon Gage on November 8, 2006), a 106% increase over the median peak incubation flow of 60,600 cfs for the 1988 – 2006 brood years that correspond to trap operations. The timing of this peak, early in the coho spawning season, was more likely to have a positive effect of increasing access to spawning habitat than a negative effect of decreasing survival of incubating eggs. Low flows during summer months decrease rearing space, thus summer low flows are expected to negatively influence coho production. A metric of summer low flows is the Puget Sound Summer Low Flow Index (PSSLFI). The 2007 PSSLFI was 7.1, just 8% lower than the long-term average from previous years.

In addition to flows, even-numbered brood years have historically produced substantially more smolts compared to odd-numbered years. This pattern may be attributed to a positive interaction with adult pink salmon, which primarily spawn in odd years. However, the bi-annual oscillations in coho production have been less evident over the last four years.

Stillaguamish River

A total of 144,000 coho smolts are estimated to have emigrated from the Stillaguamish River in 2008. This estimate is based on juvenile trapping conducted on the Stillaguamish River upstream of river mile (R.M.) 16 between 1981 and 1983. Average production of these broods, which received sufficient spawners to attain carrying capacity, was 276,000 coho smolts (range 203,000 to 379,000). This number was expanded to 360,000 by the 23% smolt production projected to occur downstream of the trap location (Zillges 1977).

Spawner abundance of the 2006 brood was among the lowest estimated for the Stillaguamish River (WDFW Salmonid Stock Inventory database). Therefore, production was estimated to be144,000 smolts in 2008. This estimate is a 60% reduction from average Stillaguamish production, similar to the lower production observed from the Skagit River.

Snohomish River

A total of 720,000 coho smolts are estimated to have emigrated from the Snohomish River in 2008. This estimate is based on measured smolt production and adult spawners above Sunset Falls (South Fork Skykomish River) over nine brood years (1976-1984) and on spawner escapement above Sunset Falls in 2006. Production estimates were generated with a back-calculation method. The back-calculation method applies coded-wire tag (CWT) ratios of adult returns to the number of tagged juveniles and therefore includes production that reared in the sub-basin downstream of Sunset Falls. Trap-based estimates indicated that 75% of the South Fork Skykomish production originated above Sunset Falls.

Production of the 1976 to 1981 brood years ranged between 212,039 and 353,981 smolts. During these years, no correlation existed between smolt production and spawner abundance (range = 6,000 to 14,761 female coho; Figure 2). Average production of the entire South Fork Skykomish sub-basin was 276,000 smolts. Production above Sunset Falls was estimated to be 207,000 smolts (assuming 75% production originated above the falls).

Production of the 1982 to 1984 brood years ranged from 184,584 to 226,366 smolts. Reduced production during these years resulted from an intentional reduction of spawners passed above Sunset Falls. In years when escapement was reduced (1,747 to 3,255 female coho), average production for the entire South Fork Skykomish sub-basin was estimated to be 198,412 smolts. Production above Sunset Falls was estimated to be 149,000 smolts (assuming 75% production originated above the falls).

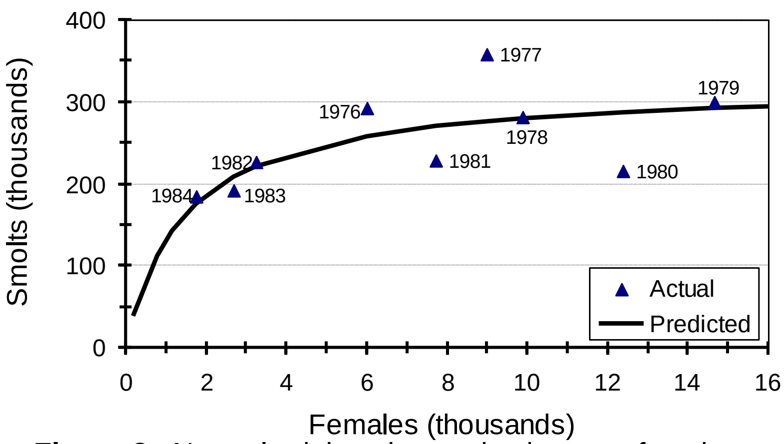

Figure 2. Natural-origin coho production as a function of female spawners in the South Fork Skykomish River.

Productivity (smolts/female) was a decreasing function of female spawners and exceeded 100 smolts/female at low spawner abundances (Figure 3).

In 2006, escapement at Sunset Falls was just 8,521 coho. Escapement has dropped below 9,000 only five times between 1966 and the present. The 2006 female spawner abundance (4,261 assuming 50% female) was intermediate in value between historical escapements that yielded an average production of 207,000 smolts and reduced escapement that yielded a reduced average production of 149,000 smolts (Figure 2). For the purposes of this forecast, the lower production rate was extrapolated to the entire basin based on the assumption that spawner abundance limited production of the 2006 brood.

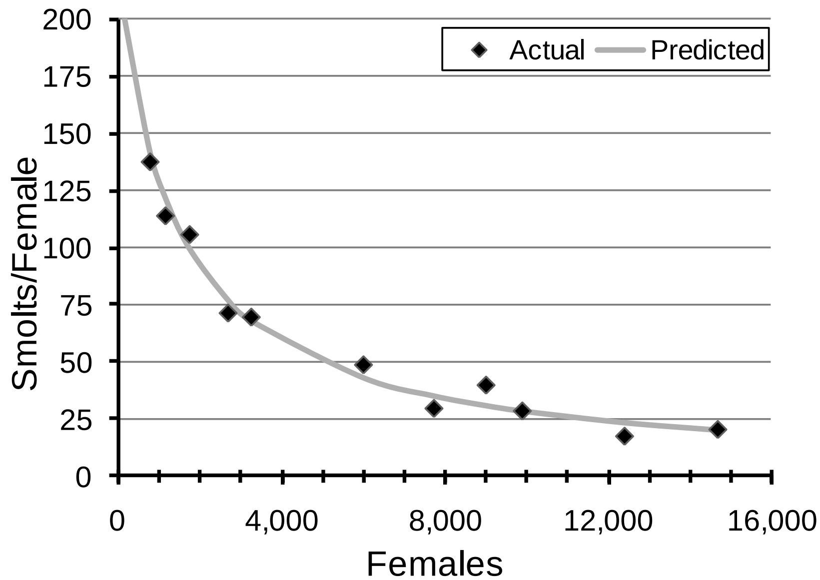

Figure 3. Productivity as a function of spawner abundance in the South Fork Skykomish River.

The South Fork Skykomish sub-basin comprises 20.7% of the Snohomish River system's drainage area. However, 26% (450 mi^2) of the 1,714 mi^2 Snohomish Basin is inacessible to anadromous fish, including the Snoqualmie Basin above Snoqualmie Falls (375 mi^2) and the Sultan Basin above the dam (75 mi^2). To account for the unavailability of this basin-wide habitat to coho, production for the entire basin was projected based on production above Sunset Falls (reduced production estimate = 149,000 smolts) rather than that of the entire South Fork Skykomish River.

Hood Canal

A total of 27,419 coho smolts are estimated to have emigrated from Big Beef Creek in 2008. In addition, 2,850, 828, and 96 coho smolts emigrated from Stavis, Seabeck, and Little Anderson creeks, respectively. These estimates are based on capture of coho smolts at 100%-capture fence weirs operated on each creek between March and June.

Production trends among creeks have not been consistent over time (Figure 4). Whereas coho production in Big Beef Creek was slightly (4%) higher than average in 2008 (Table 2), production from the remaining three creeks were near all time lows. Production from Stavis Creek was 54% below average production for this creek. Production from Seabeck Creek was the second lowest we have observed in 15 years of trapping with the lowest production occurring in 2007. Coho production from Little Anderson Creek was also extremely low, 82% below average. Over the 15 years of trapping, production from Little Anderson has been the most variable of the Hood Canal streams we study and oscillated by a ratio of 43.8 (Table 2).

In earlier years of this forecast, one of two habitat-based estimates were selected to predict total smolt production in Hood Canal. Production potential was originally estimated to be 1,006,577 smolts (Zillges 1977). The Hood Canal Joint Technical Committee (HCJTC) subsequently revised this estimate downward to 561,631 smolts. Both approaches assume adequate seeding and average environmental conditions. These projections predict that the combined capacity of Big Beef, Stavis, Seabeck, and Little Anderson creeks account for 5.9% and 7.6% of Hood Canal's coho smolt production potential, respectively. If the combined smolt production from these four streams (31,193) is expanded by these rates, production for the entire Hood Canal is estimated to be between 528,695 (Zillges 1977) and 410,434 (HCJTC) in 208.

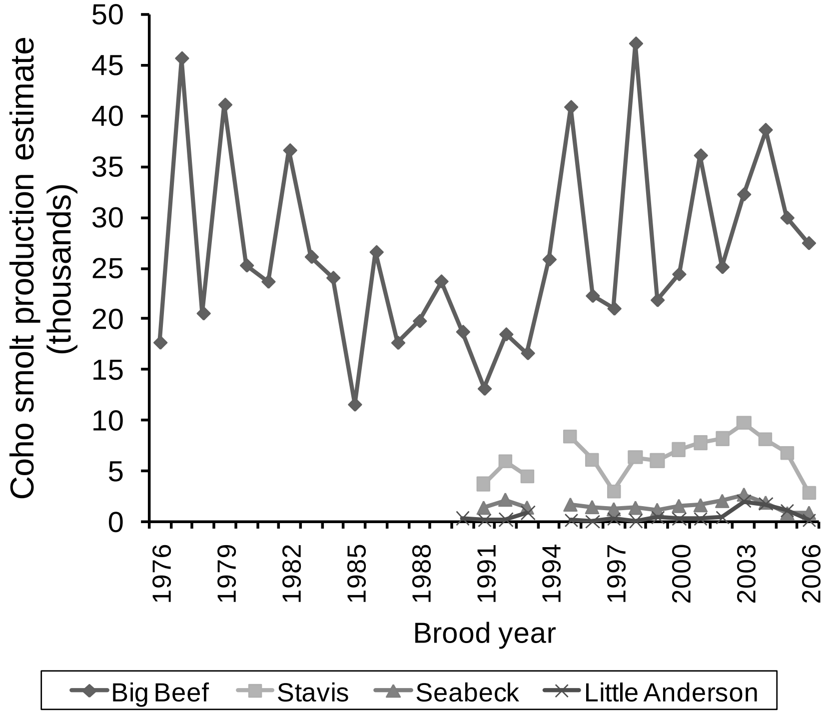

Figure 4. Production of natural-origin coho smolts in four creeks to Hood Canal.

Beginning with the 1999 brood, a new approach was adopted based on the summer 2001 HCJTC forecast review that compared predicted cohorts with computed post-season via run reconstruction. This review predicts that Big Beef Creek represents 4.56% of the total Hood Canal run. Inherent in this analysis are two main assumptions:

(1) Marine survival as estimated with tagging Big Beef Creek wild coho represents survival for the entire Canal's production; and

(2) Run reconstruction accurately represents total Hood Canal recruits.

Based on this revised approach, a total of 601,293 coho smolts are estimated to have emigrated from Hood Canal tributaries in 2008.

Puget Sound Secondary Units

Nooksack River

Coho smolt production has not been directly assessed on the Nooksack River. Considering the extent of habitat degradation and high harvest rates, natural production in 2008 is expected to be far below production potential identified by Zillges (1977). A total of 113,000 natural-origin coho smolts (25% of the projected potential) are estimated to have emigrated from the Nooksack River in 2008.

Strait of Georgia

Coho smolt production has not been directly assessed in the Straits of Georgia. A total of 16,000 natural-origin coho smolts (30% of the projected potential) are estimated to have emigrated from this drainage in 2008.

Samish River

Coho production has not been directly assessed on the Samish River. Coho have continued a self-sustaining run in the Samish River since hatchery supplementation ceased in the 1980s. During the period of hatchery supplementation, scale analysis indicated that virtually all adult coho returning to the weir at the Samish Hatchery were of natural origin. In recent years, natural-origin coho spawners have been enumerated and passed upstream at the Samish Hatchery. Between 2001 and 2004, coho escapements averaged over 10,000 adult coho per year. Smolt production would need to exceed 100,000 to produce this escapement, even at a low harvest rate and a high marine survival.

Coho escapement in 2005 and 2006 was far below that of previous years. The 2005 escapement was 1500 spawners; the 2006 escapement declined even further to 345 spawners. To estimate the 2006 escapement, coho spawners enumerated at the Samish River hatchery between late September and early November (247 spawners between statistical week 40 through 45) were expanded by the proportion of the run (72%) occurring during this time in the South Fork Skykomish River. Low escapement in 2006 was consistent with low region-wide returns (i.e., Skagit and Snohomish River systems discussed above). Assuming a 1:1 sex ratio and a high production rate of 130 smolts/female spawner (Figure 3), a total of 23,000 smolts are estimated to have emigrated from the Samish River in 2008.

Lake Washington, Green River, Puyallup River, and Nisqually River

Coho production in each of these systems is impacted to various degrees by habitat degradation, diking and water withdrawals. Each of these systems also contains a main stem dam that blocks access to the upper watershed. Hatchery fry are planted in some of these systems in an attempt to mitigate for presumed underseeding by natural spawners. As available healthy habitat in each area is already seeded, these plants probably contribute very little to production.

Lake Washington

A total of 37,500 coho smolts are estimated to have entered Puget Sound from Lake Washington in 2008. This estimate is based on capture of emigrants in floating screw traps in two of the major tributaries to Lake Washington, Cedar River, Bear Creek, and Issaquah Creek. Cedar River and Bear Creek traps were operated in 2008; Issaquah Creek was trapped in 2000. Traps are calibrated based on recaptures of natural-origin yearling coho that are marked and released upstream of the trap. Total production estimates and their confidence intervals are calculated using a Darroch maximum likelihood estimator for stratified populations (Appendix 1- 2 and 1-3; Bjorkstedt 2005).

Coho production in Cedar River and Bear Creek was estimated to be 13,382 and 5,404 smolts in 2008. However, traps in both creeks may have undersampled the larger coho due to poor trapping conditions in 2008, and these estimates are likely to be lower than actual production.

Therefore, we selected the upper confidence interval (95%) for both creeks, 20,313 and 14,609 respectively.

Issaquah Creek, the other major coho producing tributary in the Lake Washingon system, was trapped in 2000. In 2000, production in Issaquah Creek was estimated to be 19,182 coho smolts. To estimate production in 2008, we scaled the production in Issaquah Creek by the mean 2008 to 2000 production ratio for Cedar River and Bear Creek. In 2008, coho smolt production in Cedar River and Bear Creek was 63% and 52% of that measured in 2000, respectively (average = 58%). Therefore, 2008 production in Issaquah Creek was estimated to be 11,126 smolts. Given that these three systems contain most of the coho habitat in the basin, their combined production was rounded up to 50,000 smolts for the entire Lake Washington basin.

The 50,000 coho smolts emigrating into Lake Washington were adjusted for survival through Lake Washinton. A 75% survival between the traps and the Ballard Locks (i.e., through Lake Washington) was estimated from Passive Integrated Transponder (PIT) tagging of emigrating coho smolts caught in our traps.

The 2006 brood in Cedar River and Bear Creek was the lowest production observed over the time juvenile coho have been trapped in these systems (Figure 5). Although trapping conditions may have contributed a low bias to our production estimate, these data are the best available for these watersheds. Two additional variables – spawner abundance and winter flows – were unlikely to have negatively influenced 2008 smolt production. Spawner surveys conducted on the Cedar River are conducted on just a few tributaries and not considered adequate to derive an escapement estimate. However, coho spawners accessing the upper watershed are counted by Seattle Public Utilities at the Landsburg Dam. Coho spawners passed above Landsburg Dam in 2006 were slightly higher than that observed 2003-2005 (http://www.seattle.gov/util/About_SPU/Water_System/ Habitat_Conservation_Plan--HCP/Landsburg_Mitigation/index.asp). Peak winter flow associated with the 2006 brood year occurred on November 9, 2006 (5190 cfs at Renton USGS gage) and was a 157% increase over the median peak winter flow of 3170 cfs for the 1997 to 2006 brood years. This peak flow was timed early in the spawning season and thus likely to enhance, not decrease, production by increasing access to spawning habitat.

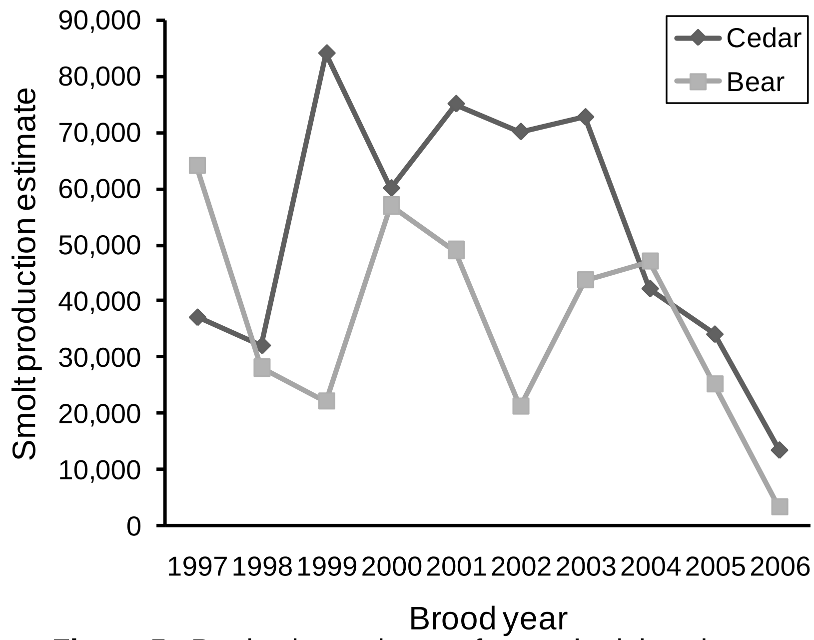

Figure 5. Production estimate of natural-origin coho smolts in the Cedar River and Bear Creek.

Green River

A total of 56,048 coho smolts are estimated to have emigrated from the Green River in 2008. This estimate is based on production above a floating screw trap in the main stem Green River and from historical information on coho production in Big Soos Creek. The main stem Green River trap is operated at R.M. 34, just above the confluence with Big Soos Creek. The main stem trap is calibrated using recaptures of natural-origin yearling coho that are marked and released upstream of the trap. Typically total production estimates are calculated using a pooled Petersen estimate with a Chapman modification (Volkhardt et al. 2007). However, 2008 recapture rates were so low that an alternate method was selected to estimate production.

A total of 12,553 coho smolts are estimated to have passed main stem trap in 2008. This estimate expanded the catch of coho based on a 3.8% trap efficiency (trap efficiency of sub-yearling Chinook during the 2008 coho outmigration period). In previous years, seasonal trap efficiency for coho has consistently averaged between 5.0 and 5.8%. However, few released coho were recaptured in 2008 suggesting that trap efficiencies were lower than those previously measured.

Big Soos Creek, the other major production area in this system, enters the Green River downstream of the screw trap. Production of Big Soos Creek was estimated to be 64,341 coho smolts in 2000. As with many small, low-gradient Puget Sound streams, coho production is expected to be regulated by the amount of low flow habitat available in the late summer and early fall months. Therefore, 2000 smolt production was adjusted by the ratio of PSSLFI values between the 2000 and 2006 brood years ($7.1 \div 10.5 = 67.6\%$) and 43,495 coho smolts were estimated to have been produced from Big Soos Creek in 2008.

The production estimate and actual catch from the Green River in 2008 were the lowest observed since we began trapping in 2000. Peak winter flows (October – February) were the highest observed since trapping operations have occurred on the Green River (11,300 cfs at Auburn USGS gage), a 36% increase over median flow experienced by the preceding eight broods. This high flow event occurred early in the coho spawning migration (November 9, 2006). Whereas an early winter high flow event might enhance production in other systems, the run timing of the Green River brood stock is relatively early. Therefore, during this peak flow event, more coho eggs should have been in the gravel in the Green River than for other Puget Sound stocks. Scour during incubation will decrease egg-to-migrant survival and is a potential explanation for low production.

Puyallup River

A total of 146,556 coho smolts are estimated to have emigrated from the Puyallup River in 2008. This estimate is based on production estimates provided by the Puyallup Tribe. In 2008, the Puyallup Tribe operated a rotary screw trap on the Puyallup River just upstream of the mouth of the White River. An estimated migration of 83,608 coho smolts passed their trap in 2008 (Andrew Berger, Puyallup Tribe Natural/Environmental Resources, personal communication). This production represents 26.3% of the projected potential for this portion of the Puyallup drainage (Zillges 1977). The total 2008 emigration was calculated by applying this rate to the production potential projected for the entire Puyallup Basin by Zillges (1977).

The 2006 brood is the strongest of the three brood lines spawning in the Puyallup and White rivers (Andrew Berger, Puyallup Tribe Natural/Environmental Resources, personal communication).

Nisqually River

Coho smolt production has not been directly assessed on the Nisqually River. We believe that Nisqually River coho production is affected by the same influences affecting other deep South Sound streams (see Deschutes River below). A total of 20,000 natural-origin coho smolts (10% of the potential projected by Zillges 1977) are estimated to have emigrated from the Nisqually River in 2008.

Deschutes River

Over the last two decades, a number of variables have combined to severely depress production in the Deschutes River: habitat degradation in the upper watershed, extreme high flows during egg incubation, low reproductive potential due to small spawner size, and low escapement. While these factors affect freshwater survival, extremely poor marine survival is the primary reason that this stock's status is so low. In the 1990s, marine survival for Deschutes coho has declined lower than that of the other Puget Sound stocks for which survival is measured. As a result, two of the three brood lines are virtually extinct.

A total of 43,074 coho smolts are estimated to have emigrated from the Deschutes River in 2008. This estimate is based on production above a floating screw trap on the lower main stem river. Catch in the trap is expanded to total migration using average trap efficiency. Trap efficiency was calculated using a back-calculation method. The back-calculation method is based on the total number of adults returning to the 100%-capture fish ladder and recapture of adults that were coded-wire tagged as emigrating smolts.

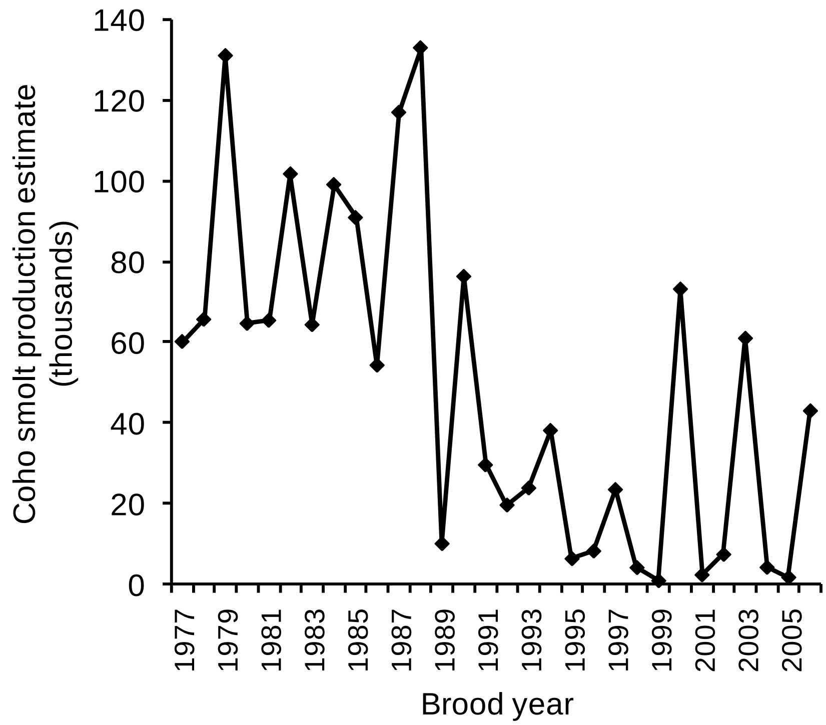

Figure 6. Production of natural-origin coho smolts in the Deschutes River.

The 2006 brood represents the strongest of the three coho brood lines in the Deschutes River (Figure 6). Whereas production of the 2006 brood represented 19.7% of potential production predicted for the Deschutes River (Zillges 1977), the 2004 and 2005 broods represented just 1.9% and 0.8% of potential production, respectively.

South Sound

This production area includes all independent tributaries to Puget Sound south of Area 10 (Seattle), excluding Lake Washington and the Green, Puyallup, Nisqually, and Deschutes rivers.

Tributaries in deep South Sound have incurred declining conditions similar to that of the Deschutes River. More northern tributaries in this region, while impacted by increasing urbanization, have probably experienced higher seeding levels than deep South Sound tributaries as a result of lower terminal harvest rates.

A total of 163,000 coho smolts are estimated to have emigrated from South Sound tributaries in 2008. This estimate is based on production estimates from deep South Sound tributaries (Cranberry, Skookum, and Johns creeks) and from historical information on smolt production from Minter Creek, a proxy for northern tributaries in South Sound. In 2008, coho production in the three deep South Sound creeks (Scott Steltzner, Natural Resources Department, Squaxin Island Tribe, personal communication) averaged 1.7% of the potential projected by Zillges (1977). In comparison, coho smolt production from Minter Creek has averaged 10,000 smolts (Brandt Boeltz, Fish Program, WDFW). This production is 59% of the potential for this creek (using approach of Zillges 1977). Given the wide disparity in production within South Sound, we applied 30% of potential production to the 544,498 smolts projected by Zillges (1977).

East Kitsap

We estimate that 110,000 coho smolts emigrated from East Kitsap tributaries in 2008. This estimate is based on production estimates from a 100%-capture weir operated on Steele Creek by the SCORE volunteer group (Steele Creek Organization for Resource Enhancement; www.bougan.com/SCORE). In 2008, 1,039 and 1,919 coho smolts emigrated from the north and south forks of Steele Creek, respectively. The 2008 production represents 71% of the production potential projected for this creek (Zillges 1977). Total production for all East Kitsap tributaries was estimated by applying this rate to the potential production projected for these drainages (154,973 smolts; Zillges 1977).

Coastal Systems

Queets River

Quinault tribal biologists estimate that 278,018 coho emigrated from the Queets River in 2008 (Rob Rhoads, Quinault Tribal biologist, personal communication). This estimate is calculated with a linear programming model based on data from tributary and scoop traps operated in the Clearwater River and a night-seining project in the lower Queets River. Production estimated for the Clearwater River alone was 55,602 coho smolts. Production rates in the Clearwater and Queets basins were 397 smolts/mi^2 and 494 smolts/mi^2, respectively.

Quillayute River

A total of 269,000 coho smolts are estimated to have emigrated from the Quillayute River system in 2008. This estimate is based on historical measures of smolt production in two sub-basins of the Quillayute River and relative production between these sub-basins and the Clearwater drainage, where smolt production was actually measured in 2008.

Smolt production has been measured in two sub-basins of the Quillayute River — the Bogachiel and Dickey Rivers. Production above the trap in the Bogachiel River averaged 53,751 coho smolts over three years (1987, 1988 and 1990) or 417 smolts/mi^2. Production above the trap in the Dickey River averaged 71,189 coho smolts (1992-1994) or 818 smolts/mi^2. High production in the Dickey River, compared to the Bogachiel River, may be explained by the low gradient of the

Dickey River system. Low gradients should increase the available summer and winter rearing habitats. Prior work in these systems also evaluated smolt production in response to hatchery fry plants and concluded that the system was already seeded to capacity by natural spawners.

Average production of the entire Quillayute system (629 mi^2) was estimated from production/area values measured in the two sub-basins. Based on relatively high gradient streams in most of the Quillayute watershed, the Bogachiel average production/area value was applied to 521 mi^2 of the Quillayute watershed (excluding the Dickey River sub-basin). An average production of 217,257 coho smolts was estimated for the Quillayute system outside of the Dickey River sub-basin. An average production of 88,344 coho smolts was estimated for the 108 mi^2 of the Dickey River's drainage area. In total, average production of the Quillayute system was estimated to be 306,000 coho smolts.

The 2008 smolt production from the Quillayute was estimated by adjusting the previously measured average production of this system by current and previously measured smolt production from the Clearwater River in the Queets basin. Over the three years that smolt production was concurrently measured in the Bogachiel and Clearwater rivers, production in the Clearwater River averaged 63,333 coho smolts. In 2008, production in the Clearwater River was 55,602 coho smolts, 88% of production when the Bogachiel and Clearwater rivers were concurrently measured. In 2008, average production/area measured for the Bogachiel (417 smolts/mi^2) was decreased to 367 smolts/mi^2 and a total of 191,207 coho smolts are estimated for the 521mi^2 of the Quillayute system outside the Dickey River sub-basin. The 2008 production for the Dickey River is estimated to be 77,743, 88% of the average production for this sub-basin.

Hoh River

Coho smolt production has not been directly measured on the Hoh River. Due to the similarity and proximity of the Hoh and Clearwater watersheds, production/area of the Clearwater system (397 smolts/mi^2) was applied to the 299-mi^2 drainage area of the Hoh River system. A total of 119,000 coho smolts are estimated to have emigrated from the Hoh River in 2008.

Quinault River

Coho smolt production has not been directly measured on the Quinault River. A combination of high harvest rates, low escapement, and degraded habitat has likely limited natural smolt production rates in the Quinault system when compared with the Clearwater River (397 smolts/mi^2). In 2008, a production rate of 375 smolts/mi^2 was applied to the 434-mi^2 Quinault River system, and a total of 163,000 coho smolts are estimated to have emigrated.

Independent Tributaries

Coho smolt production has not been directly measured in any of the independent coastal tributaries. In 2008, an average production rate of 375 smolts/mi^2 was applied to the total watershed area (424 mi^2; Table 3). A total of 159,000 coho smolts are estimated to have emigrated from these systems.

Table 3. Drainage areas of fourteen independent tributaries on the Washington coast.

Stream	Drainage area (mi^2)	Stream	Drainage area (mi^2)
Waatch River	13	Raft River	77
Sooes River	41	Camp Creek	8
Ozette River	88	Duck Creek	8
Goodman Creek	32	Moclips River	37
Mosquito Creek	17	Joe Creek	23
Cedar Creek	10	Copalis River	41
Kalaloch Creek	17	Conner Creek	12
Subtotal	218	**Subtotal**	206
		TOTAL	424

Grays Harbor

A total of **1,838,148** coho smolts are predicted to have emigrated from the Grays Harbor system in 2008. This estimate is based on measured production in the Chehalis River system and application of the Chehalis production rate to Hoquiam, Johns, and Elk rivers as well as the Humptulips River.

Coho smolt production in the Chehalis River is estimated using a back-calculation method that relies on capture of coded-wire tagged and untagged adult coho in the Quinault Tribe's terminal fishery in Gray's Harbor. The tagged to untagged ratio is applied to the total number of smolts tagged and released from a scoop trap operated on the main stem Chehalis and a 100%-capture weir operated on Bingham Creek, a tributary below the main stem trap. Using the back-calculation analysis, coho smolt production for a given year is not measured until adults return to spawn a year later. For example, coho from the 2005 brood year returned in the fall of 2008 and were used to estimate smolt production in 2007. Using the back-calculation method, a total of 1,641,823 coho smolts are estimated to have emigrated from the Chehalis River in 2007 (Appendix 1- 4).

The Chehalis system is characterized by low-gradient, rain-fed streams. Coho smolt production has been measured in the Chehalis River system for twenty-five years, beginning with the 1980 brood. Magnitude of flow during spawning is apparently an important determinant of natural coho production. During this period, flow during spawning (November 1 – December 15) has predicted a substantial percentage of inter-annual variation in smolt production, provided that spawner abundances were adequate (Figure 7). For example, the 2007 smolt production estimate was just 0.2% positive deviation from the 1,638,863 smolts predicted in the 2008 coho forecast (Volkhardt et al. 2008). The most plausible hypothesis for this observation is that increased flows provide access to the upper portions of streams and increase the quantity of spawning habitat in the watershed. If fry emerging from redds distribute downstream, the proportion of the watershed available for rearing juveniles is largely determined by the upstream extent of the spawning population regardless of favorable flow conditions during rearing phases of coho life history.

Five brood years have been excluded from the production versus flow regression because additional variables are considered to have substantially contributed to production of these brood classes.

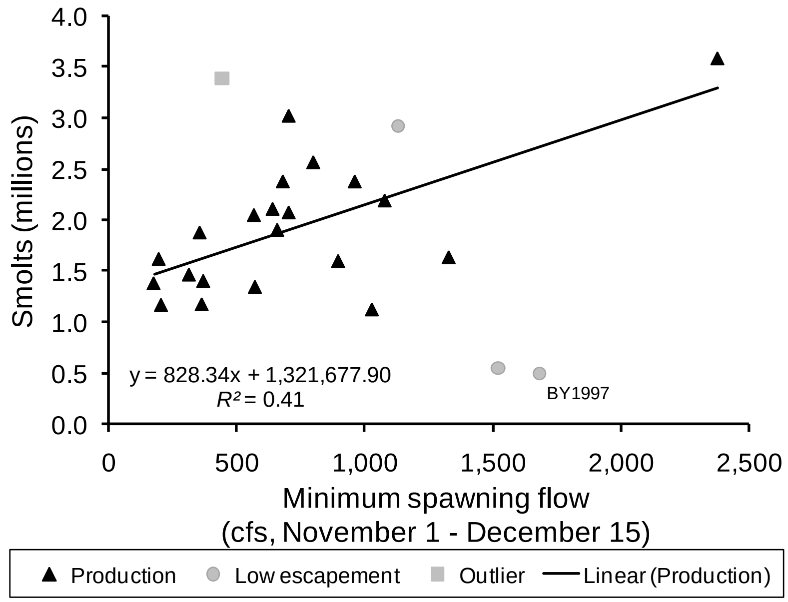

Figure 7. Chehalis River coho smolt production as a function of minimum spawning flow (November 1 through December 15) at the Grand Mound gage, brood years 1980-2005.

• **The 1990 brood** was excluded because tagging on this brood was limited and just six wild, tagged adult coho were recovered in the terminal fishery. This low recovery corresponded to a 0.29% incidence of tagged fish among returning spawners and resulted in an estimated production of over six million smolts, 1.6-fold higher than the maximum observed any other year. For other brood years, incidence of tagged fish in the terminal fishery has ranged from 1.52 to 11.1%. The low tag rate likely precluded making a valid estimate for the 1990 brood class.

• **The 1985, 1994, and 1997 brood years** were excluded from the regression because smolt production was likely limited by spawner abundance in these years. High productivity (smolts/female) at very low escapements is indicative of an underseeded system (Figure 3). Escapement of the 1985, 1994, and 1997 brood classes was less than 10,000 spawners and corresponded to productivities exceeding 100 smolts/female.

• The 2000 brood year was excluded from the regression analysis because productivity was unusually high (156 smolts/female). Escapement contributing to this brood class was comparable to other years; however, this brood experienced the lowest peak winter flow and third highest summer low flow since trapping began. Unusually favorable winter peak flows and summer rearing flows likely overrode the effects of spawning flows on smolt production for this brood year.

Coho production in 2008 was predicted from the regression relationship between smolt production and minimum spawning flows. Minimum spawning flow associated with brood year 2006 was 244 cfs at the Grand Mound USGS gage. Based on the regression relationship, a total of 1,523,860 coho smolts are predicted to have emigrated during spring of 2008. If this production is applied to the 2,114-mi^2 Chehalis Basin (including the Wishkah River), the 2008 production rate was 721 smolts/mi^2. A total of 1,657,937 coho smolts are estimated for the entire Chehalis Basin (2,300-mi^2, including the Hoquiam, Johns, and Elk Rivers and other southside tributaries below the terminal fishery).

In addition to the Chehalis River watershed, the 2,550-mi^2 Grays Harbor Basin includes the 250-mi^2 Humptulips River. No direct estimates were measured on the Humptulips River; therefore, production rate in the Chehalis River (721 smolts/mi^2) was applied to this drainage area and resulted in an estimate of 180,211 coho smolts emigrating from the Humptulips River basin.

Willapa Bay

The Willapa Basin, with a total watershed area of 850 mi^2, is drained by four main river systems and a number of smaller tributaries. Willapa Bay has a presumed high harvest rates and a somewhat degraded freshwater habitat.

Little empirical smolt production evaluation work has been conducted in this system. However, given the mentioned impacts, coho production/area is likely to be somewhat lower than observed in the Chehalis Basin. Production of the 2006 brood year was calculated by applying 600 smolts/mi^2 production rate to the total basin area. Based on this rate, a total of 510,000 coho smolts are estimated to have emigrated from Willapa Bay basin in 2008.

Lower Columbia River

In 2008, WDFW monitored coho salmon smolt abundance in a total of eight streams in the Lower Columbia River ESU. Trapping locations at the mouths of independent tributaries to the Lower Columbia River were Mill Creek, Abernathy Creek, Germany Creek, the Cowlitz River at Mayfield and Cowlitz Falls Dams, the Coweeman River near the lower stream gauge station (River Mile, R.M. 7.5), and the Wind River near Little Wind River at R.M. 1. The Grays River near R.M. 6 was monitored for the first time in 2008. Cedar Creek, a tributary to the North Fork Lewis River, was monitored near the Grist Mill fish ladder (R.M. 2) through 2007 but was not monitored in 2008. Individual population estimates are not finalized but preliminary estimates were developed from capture-mark-recapture data using a pooled Petersen estimate (Schwarz and Taylor 1998) for periods with and without panels.

Approaches to estimating smolt production differed slightly among sites in response to different trapping conditions. In 2008, panels were installed at the Grays, Mill, Abernathy, Germany, and Coweeman trap sites as water flows dropped. Panels should improve precision of the estimate by diverting a greater proportion of flow and smolts through the trap. At the Cowlitz Falls dam site, two different screening configurations were used during the early and late periods and two separate estimates were made for these different collection configurations. In addition, high flows from melting snow pack caused trapping at the Cowlitz Falls Facility to cease for a four day period in May. To estimate passage during this period, the passage for the day before facility closed and day after the facility was opened were estimated and the mean passage for these two days was expanded by four to account for the lost days. Using these assumptions an estimated 27,190 coho salmon smolts (90% CI 22,060 – 36,510) were missed. At the Mayfield site, Paulik and Thompson (1967) estimated a 66.4% collection efficiency for coho salmon smolts. Therefore, a release of 1,000 smolts and a recapture of 664 smolts were assumed in order to include a measure of uncertainty in the smolt production estimates for the Tilton River. All coho salmon juveniles captured in the Wind River were classified as parr; therefore, no smolt estimates were calculated for this sub-basin. Since Cedar Creek was not monitored in 2008, a five-year average was used to estimate the coho smolt production.

A Bayesian approach, using binomial mark-recapture model, was used to calculate the estimates with WinBUGS software (Spiegehalter et al. 2003). Non-informative priors were used for trap efficiency and the population size, which allowed posterior predictive distribution to be determined by the likelihood function with minimal influence from the prior. Priors for population size were truncated at approximately 150% and 200% of the maximum smolt population estimate from previous trapping. This truncation had some influence on the Abernathy and Germany Creek estimates because few fish were recaptured during the early trapping period without panels. Also, few coho smolts were captured prior to the installation of panels on the Grays River. However, there was not a significant difference between hatchery and wild coho trap efficiency, so the trap efficiency from the Grays River hatchery coho release was used as a prior for trap efficiency for wild smolts before the installation of panels. The posterior predictive distribution for Grays River was influence by this prior due to the magnitude of the hatchery release. Two chains were run and after the burn-in period, simulations were run until MC error was less than 5% of the posterior SD. Simulations were thinned to reduce autocorrelation. Convergence was monitored using Gelman and Ruben diagnostics. It is assumed the reported results obtained through Gibbs sampling are representative of the underlying stationary distribution and the Markov Chains have converged. Results are displayed as the median and the 90% Credible Interval (Table 4).

Cedar Creek estimates of smolt production estimates were available from 2003 to 2007. However, a Remote Site Incubation (RSI) program has been in place since 2004. All RSI embryos were thermally marked and a subsample of smolts was collected during outmigrant trapping. Natural-origin smolt abundance was estimated by multiply the natural-origin proportion, based on otolith decoding of the subsample, by the annual smolt estimate. Since the 2007 otoliths have not been decoded, the mean natural-origin proportion from 2004 to 2006 was applied to this outmigration estimate

Coho production per unit area from measured streams was extrapolated to waterways where no measurements were available. Systems with and without major hatchery influence were considered separately. This approach is supported by the Bradford et al. (2000) study which indicated that coho salmon smolt production was correlated with habitat. This study used a distance (km) of spawning and rearing habitat as metric of habitat quantity. WDFW has observed coho smolt production is also correlated to drainage area. Since WDFW estimates of lower Columbia River tributaries spawning and rearing habitat were not readily available, drainage area was used as a surrogate for spawning and rearing habitat quantity.

The 5-year mean density of natural-origin coho salmon smolts in Cedar Creek was estimated to be 305 smolts per square mile of drainage area. Historically, Cedar Creek density estimates were approximately twice as high as the next best estimate. High densities are due to high quantities of low-gradient habitat, seeding with hatchery and wild spawners, and ongoing recovery activities. Recovery activities include placement of surplus hatchery carcasses and habitat restoration. This density is not likely approached in other sub-watersheds. Therefore, this estimate was not used to develop average smolt densities from unsampled areas.

Escapement of hatchery coho salmon was assumed to be high on the Lower Cowlitz, Lewis, and Washougal Rivers, each of which are associated with hatcheries. In these rivers, surplus hatchery coho salmon were recycled or released above hatchery. Other watersheds with hatcheries had high levels of spawning escapement in 2006, including Grays, Elochoman, Green, and Kalama Rivers. In hatchery systems where smolt production was measured, densities were 171 (Grays), 229 (Tilton), and 108 (Upper Cowlitz) smolts per square mile, respectively. The median density of coho smolts from the Grays, Cowlitz, and Tilton Rivers was applied to all watersheds with hatcheries. The square miles of drainage area in these watersheds were estimated to be 805 square miles, and the resulting smolt production was predicted to be 136,500 smolts (90% CI 128,900 – 146,000; Table 5).

Coweeman, Germany, Abernathy, and Mill sub-watersheds have no operating coho hatcheries; however, hatchery coho salmon do spawn in these creeks. Median coho smolt density was 195 smolts per square mile (range = 102 - 313 smolts per square mile). Smolt production from non-monitored streams with no hatchery releases was predicted using a density of 195 smolts per square mile multiplied by 620 square miles. Production from unmonitored wild streams was estimated to be 120,600 smolts (90% CI 111,600 -143,900; Table 5).

Smolt production for the monitored systems was the sum of Grays River, Cedar Creek, Coweeman River, Mill Creek, Abernathy Creek, and Germany Creek production plus the number of coho smolts transported from the Upper to the Lower Cowlitz River and released. Smolt production from the Tilton River was the number trapped at Mayfield Dam plus the number estimated to pass through the turbine multiplied by an assumed 85% survival. The Tilton estimate was added to the sum of the estimates from the other sites. Monitored smolt abundance was estimated to be 122,000 (90% CI 119,200 – 126,100). Total abundance estimate for the Washington portion of the Lower Columbia River ESU was estimated 380,100 smolts (90% CI 364,600 – 407,300; Table 5).

These coho smolt estimates are believed to be relatively unbiased because estimates are obtained from a census or M-R programs, where care is taken to meet the assumptions required for unbiased population estimates. The smolt monitoring sites were not randomly chosen but are representative of coho production in the Washington portion of the ESU. They include streams that include a high percentage of hatchery spawners and streams 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 Germany Creek to 1042 square miles in the Upper Cowlitz River. Habitat in monitored sub-watershed 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 stem, which is still recovering from the eruption of Mt. St. Helens, was excluded.

Coho parr were also observed emigrating past the trap sites. Some of these parr likely continue rearing in freshwater below the traps and in the main stem Columbia River. If they survive, these parr will emigrate to the ocean as smolts in subsequent years. The number of coho smolts emigrating from areas below these traps is unknown. Therefore, the coho salmon smolt abundance estimates for the Lower Columbia River ESU should be considered a minimum number.

Table 4. Preliminary estimates of smolt production and density (smolts/mi^2) from monitored coho salmon streams in the Lower Columbia River ESU during 2008. Cedar Creek was not monitored in 2008 and the 5-year average was used for this drainage.

	Smolt Abundance			Smolt Density (smolts/mi^2)		
Node	5.00%	median	95.00%	5.00%	median	95.00%
Coweeman	10,780	12,170	13,910	90.6	102.3	116.9
Mill	8,359	9,097	10,130	288.2	313.7	349.5
Abernathy	4,156	5,077	7,585	143.3	175.1	261.5
Germany	3,591	3,976	7,063	156.1	172.9	307.1
Grays	3,848	4,453	5,156	148.0	171.3	198.3
Upper Cowlitz	99,410	113,000	134,900	95.4	108.5	129.4
Tilton	34,930	36,240	37,720	219.7	227.9	237.2
Cedar	35,440	36,340	37,170	297.8	305.3	312.3

Table 5. Preliminary estimates of smolt production from streams with hatcheries, streams without hatcheries, minimum abundance from monitored streams, and total predicted smolt abundance for the Lower Columbia River ESU.

	Smolt Abundance			Smolt Density (smolts/mi^2)		
Node	5.00%	median	95.00%	5.00%	median	95.00%
Unmonitored H_Streams	128,900	136,500	146,000	160.1	169.6	181.3
Unmonitored W_Streams	111,600	120,600	143,900	180.0	194.5	232.1
Monitored Streams	119,200	122,000	126,100			
Natural-Origin Smolt Prediction	364,600	380,100	407,300			

Marine Survival

Puget Sound

Background

Marine survival rates of wild coho stocks have been measured in four geographic regions of Puget Sound: Big Beef Creek, Deschutes River, South Fork Skykomish River, and Baker River (Table 6). Measurements of marine survival, decoupled from coho survival in freshwater, began with the 1975 brood year in Big Beef Creek. Survival rates are calculated from a known number of coded-wire tagged smolts, returns of coded-wire tagged adults to upstream migrant trapping facilities, and coast-wide recoveries of coded-wire tagged, age-3 wild coho. Coast-wide recoveries data were accessed through Regional Mark Information System database (RMIS, http://www.rmpc.org/). Coded-wire tag releases were adjusted for 84% mortality (Blankenship and Hanratty 1990) and 96% tag retention.

Marine survival of age-3 coho returning to Big Beef Creek has varied more than ten-fold (3 to 32%) over brood years 1975-2006. Prior to 1998, marine survival rates measured at Big Beef Creek underestimated the total number of adult recruits because many coho caught in Hood Canal net fisheries were unreported and unsampled. Marine survival of the 2005 brood (3.3%) was calculated based on 722 coded-wire tagged adult returns from 21,715 tagged and released smolts. Return of tagged adults was measured at the Big Beef Creek weir and in the Hood Canal terminal fishery.

Marine survival of age-3 coho returning to the Deschutes River has ranged between 0.1% and 29% over brood years 1977 to 2006. For the first eleven broods (1977-1985), average survival of this southern-most Puget Sound stock (22%) was the highest of all monitored Puget Sound stocks. However, average survival of the eleven broods between 1992 and 2002 (3.4%) was the lowest of all monitored stocks. For the last three Deschutes broods (2003-2005), marine survival has been comparable to other Puget Sound stocks. Marine survival of the 2005 brood (3.5%) was calculated based on 48 adult returns in 2008, an estimated harvest rate of 25%, and the 1,726 smolt estimated to have emigrated in 2007.

Marine survival of age-3 wild coho returning to Sunset Falls (South Fork Skykomish River) ranged between 8% and 22% over nine broods (1976 to 1984 brood). Marine survival after 1985 has been estimated from actual adult escapement at the Sunset Falls trap, projected relationship between escapement and total run size, and historical average production (276,000 smolts; Figure 2). Marine survival of the 2005 brood was calculated under the assumption that the 8,982 adult coho returning to the trap represented 85% of the run. Total run size for the 2005 brood was estimated to be 10,567 coho and corresponds to a marine survival of 3.8%.

Marine survival of Baker River coho has ranged between 1.1% and 13.8% over thirteen brood years (1989-1997, 2003-2006). Marine survival of the 2005 brood (4.6%) was calculated based on 662 coded-wire tagged adult returns from 15,756 tagged and released smolts. Return of tagged adults was measured at the Baker River fish trap (Doug Bruland, Puget Sound Energy, personal communication) and estimated for fishery interceptions. Fishery interceptions were estimated from the average tagged coho reported for BY2000 to 2004 (RMIS database).

Marine survival rates have declined in Puget Sound over the measured period (Figure 8). Prior to the 1988 brood year, marine survival averaged 20%. During these years, marine survival of the South Fork Skykomish stock was consistently lower than the Big Beef or Deschutes stocks. Earlier forecasts attributed this trend to the smaller body size of smolts produced from the colder, higher-elevation Skykomish system. However, marine survival of Puget Sound coho declined beginning with the 1988 brood and relative survival of the four monitored stocks has not been consistent. Between the 1994 and 2004 brood classes, lowest marine survival occurred in the Deschutes coho stock, which dropped to less than 5% survival. Over this same period, the South Fork Skykomish stock had among the highest marine survival rates.

Table 6. Marine survival of wild coho in Big Beef Creek, Deschutes River, South Fork Skykomish River, and Baker River.

Year Brood	Year Return	Big Beef	Deschutes River	South Fork Skykomish	Baker River	Average
1975	1978	13.3				
1976	1979	16.7		22.3		19.5
1977	1980	29.2	21.6	17.3		22.7
1978	1981	16.9	21.5	14.5		17.6
1979	1982	14.7	20.9	7.9		14.5
1980	1983	21.7	27.4	17.8		22.3
1981	1984	17.4	23.5	13.2		18.0
1982	1985	22.4	19.1	13.2		18.2
1983	1986	32.0	26.9	22.3		27.1
1984	1987	28.6	29.3	19.0		25.6
1985	1988	11.1	28.3	15.5		18.3
1986	1989	18.0	10.3	14.1		14.2
1987	1990	22.5	17.0	13.5		17.7
1988	1991	9.7	6.6	7.9		8.1
1989	1992	9.1	13.6	15.8	13.8	12.8
1990	1993	9.1	3.2	7.7	6.0	6.7
1991	1994	23.8	19.8	23.6	11.1	22.4
1992	1995	11.0	6.4	13.7	8.3	10.4
1993	1996	13.0	5.0	9.8	10.6	9.2
1994	1997	17.0	5.0	10.0	6.3	10.7
1995	1998	16.1	2.2	9.2	12.5	9.2
1996	1999	3.2	0.1	5.2	5.8	2.8
1997	2000	11.5	7.2	10.1	10.6	9.6
1998	2001	13.1	2.0	21.5		12.2
1999	2002	21.4	2.0	18.8		14.1
2000	2003	19.7	5.0	13.4	6.7	12.7
2001	2004	24.4	3.4	17.4	9.7	15.1
2002	2005	11.0	2.4	9.9	6.4	7.8
2003	2006	4.8	2.4	3.6	1.1	3.6
2004	2007	9.2	7.0	12.2	8.5	9.5
2005	2008	3.3	3.5	3.8	4.2	3.5
	Average	16.0	11.8	13.5	8.1	5.4
	Min	3.2	0.1	3.6	1.1	2.8
	Max	32.0	29.3	23.6	13.8	27.1
	Count	31	29	30	15	30

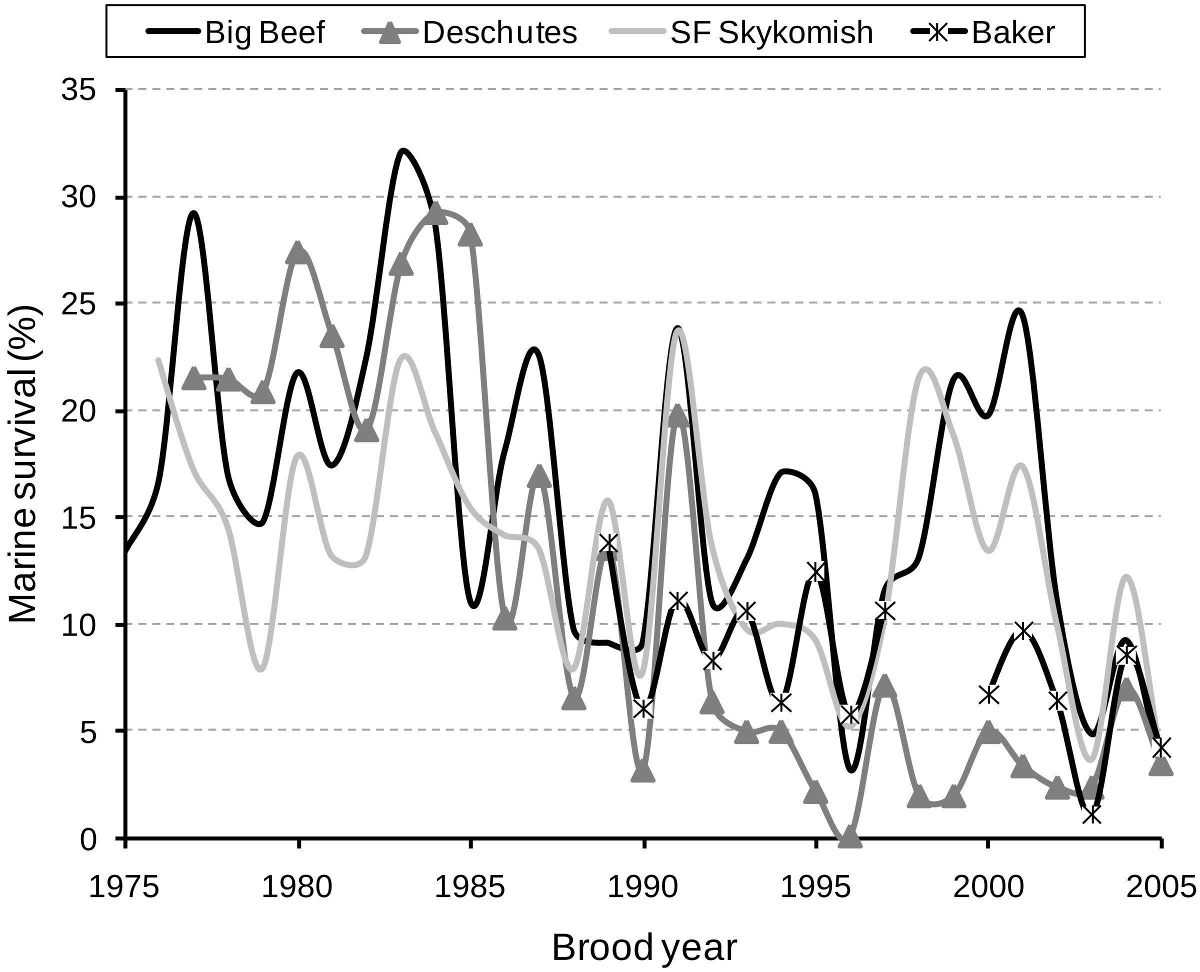

Figure 8. Marine survival of natural-origin coho in four Puget Sound streams.

Predicting 2006 Brood Marine Survival

Marine survival of Puget Sound coho stocks can be predicted from return rates of jacks in the corresponding brood class. Big Beef Creek and Deschutes River have both been sources of adult and jack data. However, recent production has been so low in the Deschutes River that coded-wire tags were not applied to outgoing smolts. Therefore, marine survival rates measured in Big Beef Creek are used to estimate marine survival in other areas of Puget Sound.

In Big Beef Creek, adult:jack return rate ratio averaged 11.3 (range = 6 to 18) and was remarkably consistent between 1977 and 1996 (Figure 9). During these years, 76% of the variation in age-3 coho marine survival could be predicted from jack return rates. Over the past decade, adult to jack return rates have oscillated more dramatically (range = 12 to 49). During this period, ratios of adult:jack return rates were higher than previously observed (average = 26.8). Large variability in this ratio has decreased the accuracy with which age-3 adult coho can be predicted from jack returns. Currently, jack return rates explain 59% of the variation in age-3 marine survival of Big Beef coho (Figure 10).

In the fall of 2008, 93 coded-wire tagged wild jacks (estimated) returned to Big Beef Creek from the 20,029 coho smolts tagged in spring of 2008. Marine survival of the 2006 brood is predicted to be 9.3% based on the jack return rate of 0.46%.

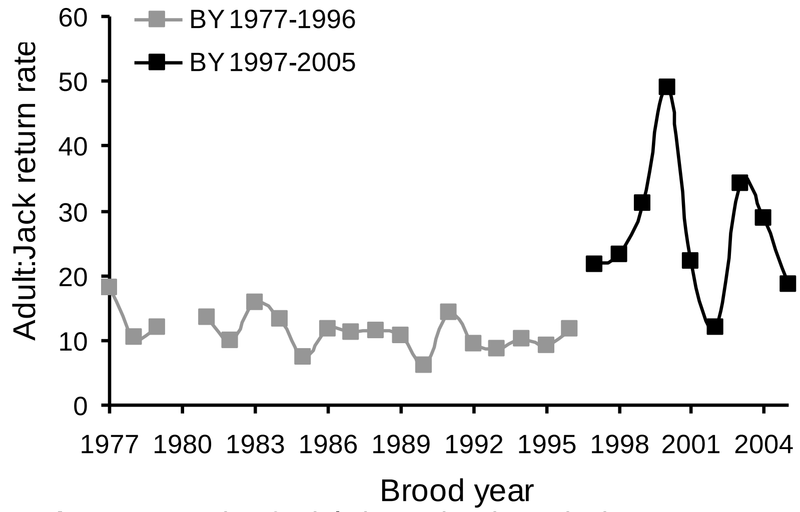

Figure 9. Ratio of adult (age-3) coho to jack return rates for coded-wire tagged wild coho in Big Beef Creek.

A marine survival of 9.3% is a moderate value when compared to survival over the last decade (Figure 8). Ocean indicators, such as the sea surface temperatures or coastal upwelling, suggest that conditions were favorable for the 2008 coho emigration (http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/g-forecast.cfm). However, coho sampling along the Washington coast, conducted in June and September 2008 by the National Marine Fisheries Service (NMFS), yielded moderate abundance estimates compared to other years (http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/a-ecinhome.cfm). These results suggest that "favorable" conditions have not translated into increased coho abundance in ocean waters. Assuming that Puget Sound coho were represented in the NMFS samples, two possible explanations for the observed moderate coho abundance are (1) freshwater production in 2006 was low, driven by poor marine survival in 2006 and low 2006 escapement in many watersheds or (2) conditions within Puget Sound have a larger impact on coho survival than ocean conditions.

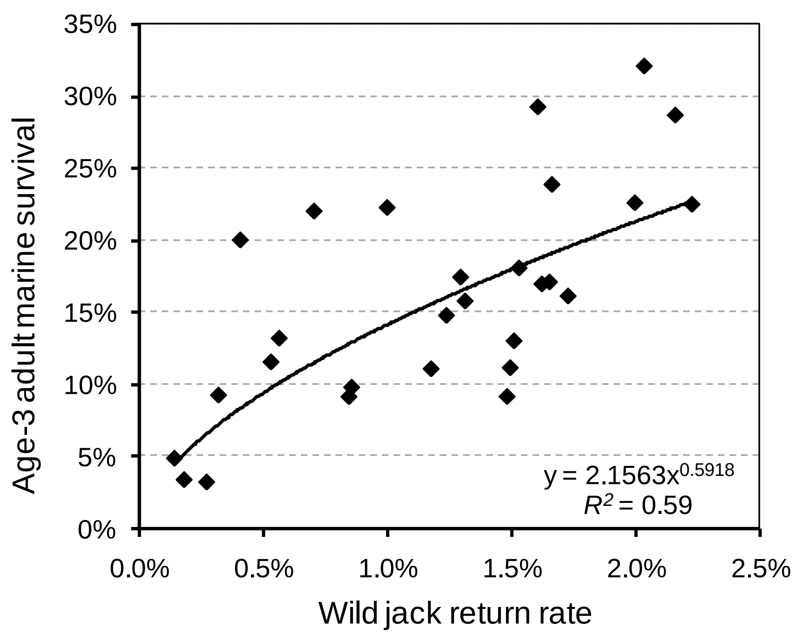

Figure 10. Natural-origin adult marine survival as a function of same-brood jack return rates in Big Beef Creek, brood years 1977-2005.

Historically, this forecast has applied marine survival rates to regions of Puget Sound based on jack return rates to Big Beef Creek and relative differences in measured return rates among regions. Over the past three years, all four monitored Puget Sound stocks have had consistently low survival and similar inter-annual variability. This observation suggests that geographic differences in survival may not currently apply to Puget Sound stocks (Figure 8). Therefore, a marine survival rate of 9.3% was applied to all Puget Sound stocks.

Coast

Annual trapping and tagging of wild coho at Bingham Creek (Grays Harbor) began with the 1980 brood and represents the only direct measurement of jack versus adult coho marine survival on the Washington Coast. Marine survival (age-3) of wild Bingham Creek coho has ranged between 0.6% and 11.6% (average = 4.2%) over 25 years (Figure 11). Over this period, the relationship between jack returns and adult marine survival has been poor. However, correlations between jack and adult returns improve when data are divided into three times periods: 1981-1986, 1987-2000, and 2001-2004 (Figure 12). Two El Niño broods (1980 and 1990) were outliers and excluded from these correlations. Low adult returns for a given jack return in El Niño years has also been observed in the Oregon Production Index.

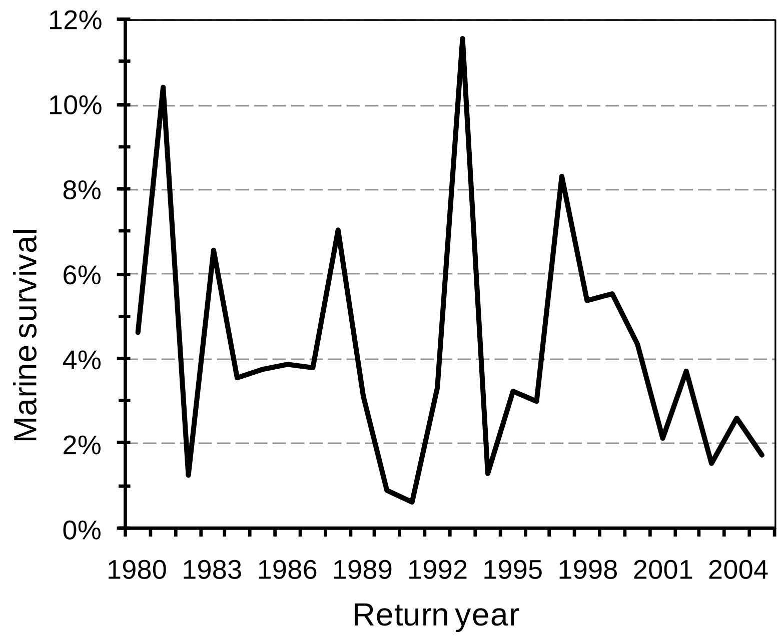

Figure 11. Wild coho marine survival from Bingham Creek.

Marine survival of the 2008 brood was estimated to be 1.7%, a value just 0.1% above the return predicted by the 2001-2004 model. When 2008 return data were added to this model, jack return rates predict 98% of the variation in adult marine survival (Figure 12). Therefore, this model remains appropriate for predicting adult returns.

Jack return rate in fall of 2008 was the highest ever observed in Bingham Creek. Sixty-one jacks (0.38%) returned of the 16,165 coho smolts tagged and released from the Bingham Creek site in spring of 2008. Based on this jack return rate, marine survival is predicted to be 8.6%. This prediction should be considered with caution as marine survival has exceeded 8% just 3 times over 25 years of study at Bingham Creek. High marine survival for the Bingham Creek stock is consistent with favorable ocean conditions measured by the Northwest Fisheries Science Center; however, high survival is not consistent with the moderate number of coho caught in the NWFSC coastal surveys in September 2008. Furthermore, this high survival prediction is based on extrapolation of the regression relationship beyond previously observed data ranges.

In consideration of these issues, a more conservative 7.0% marine survival was applied to the Chehalis River and other coastal streams.

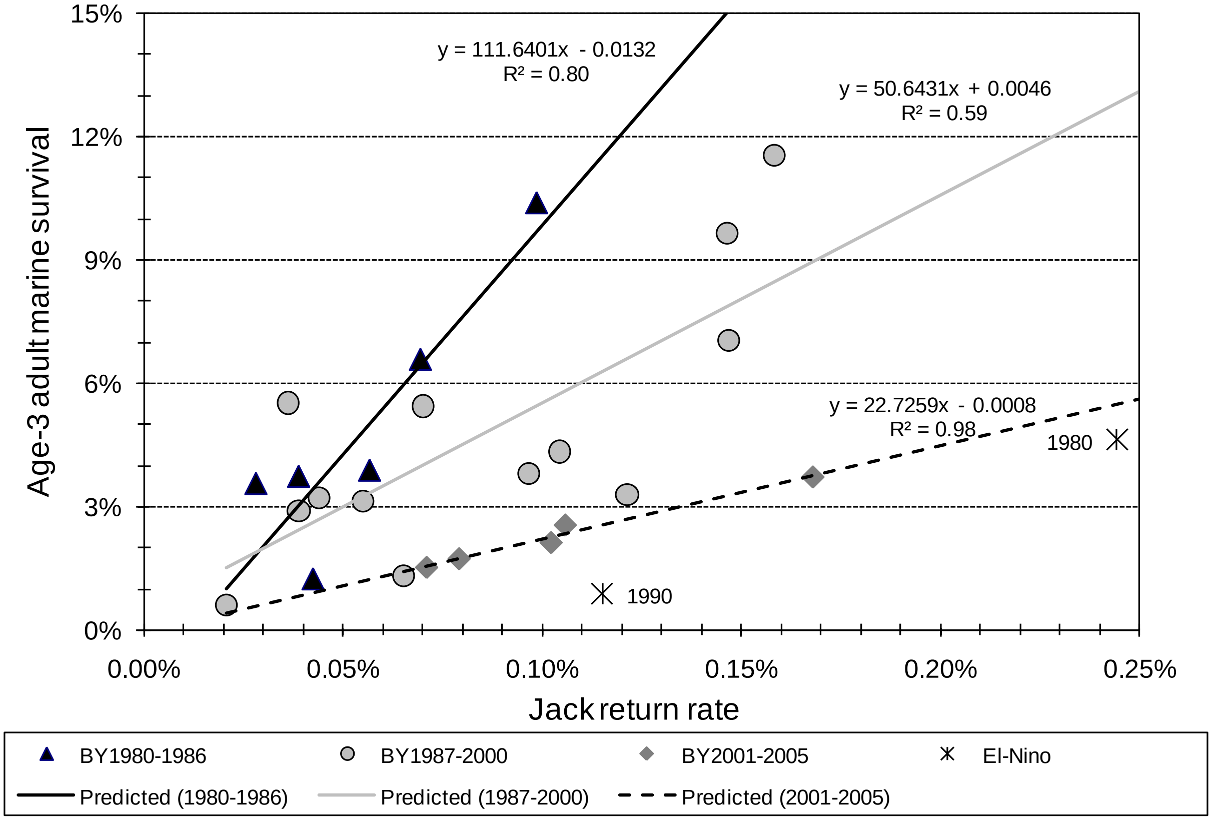

Figure 12. Adult coho marine survival as a function of jack return rates in Bingham Creek, brood years 1980-2005.

Lower Columbia River

Lacking any indicators for wild coho survival in the Lower Columbia River, a 7.0% marine survival rate was also applied to this system.

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Appendix 1- 1. Natural-origin coho smolt production in the Skagit River, 2008. Production was estimated using a pooled Petersen estimator with a Chapman correction.

	Number	Formula
Total mainstem trap catches	5,335	
Skagit Hatchery/Lake Shannon	-722	
Wild coho captured (c)	**4,613**	
LVs recaptured (r)	109	N = (m+1)(c+1)
LVs released (m)	10,178	(r+1)
Total production (N)	**426,963**	
Variance (Var)	1.59E+09	Var = (m+1)(c+1)(m-r)(c-r)
Standard Deviation (sd)	39,823	(r+1)^2(r+2)
Coefficient of Var (CV)	9.33%	CV = sd/N
Confidence Interval (CI)	78,052	CI = +/- 1.96(sd)
Estimated coho production		
Skagit River	426,963	
Upper CI (95%)	505,015	
Lower CI (95%)	348,910	

Notes: Baker River coho smolts are included in the total main stem trap catches (144 total recaptured). Skagit Hatchery (ad-marked and unmarked) counts are made by visual identification and CWT-tag detection at the main stem traps.

Appendix 1- 2. Natural-origin coho smolt production in the Cedar River, 2008. Production was estimated using Darroch's maximum likelihood estimator for stratified populations.

	Date		Total	Recapture	Estimated	
Stratum	**Begin**	**End**	**Catch**	**Rate**	**Migration**	**Variance**
1	04/13/08	05/03/08	50	9.60%	583	1.03E+05
2	05/04/08	05/15/08	158	1.80%	8,795	2.53E+07
3	05/28/08	05/31/08	47	11.80%	400	7.01E+04
4	06/01/08	06/07/08	31	7.30%	424	5.51E+04
5	06/08/08	07/19/08	29	14.30%	203	1.75E+04
		Total	**315**		**10,405**	**2.56E+07**

Note: Total production was estimated to be 13,382 coho smolts. An additional 2,962 coho are estimated to have migrated during a 10-day trap outage and 15 are estimated to have migrated prior to the trapping season.

Appendix 1- 3. Natural-origin coho smolt production in Bear Creek, 2008. Production was estimated using Darroch's maximum likelihood estimator for stratified populations.

	Date		Total	Recapture	Estimated	
Stratum	**Begin**	**End**	**Catch**	**Rate**	**Migration**	**Variance**
1	04/16/08	05/10/08	534	7.80%	4	1.22E+06
2	05/11/08	05/17/08	371	21.50%	1,728	4.84E+04
3	05/18/08	05/24/08	159	10.70%	1,483	1.63E+05
4	02/25/08	05/31/08	59	14.30%	413	2.89E+04
5	06/01/08	06/07/08	246	23.40%	1,051	2.47E+04
6	06/08/08	06/14/08	182	28.70%	634	5938
7	06/15/08	07/09/08	21	24.00%	91	903
		Total	**182**		**5,404**	**1.50E+06**

Appendix 1- 4. Wild coho smolt production in the Chehalis River, 2007. Production was estimated using a back-calculation method. Estimate assumes expanded tag recoveries from terminal fishery samples accurately reflect numbers of hatchery and wild tags caught.

Calculation	Formula	Number
Brood year (i)	i	2005
Tag year (i+2)	i+2	2007
Return year (i+3)	i+3	2008
Wild tag rate		
Total catch (A)		5,517
Estimated hatchery catch (B)		1,784
Wild catch (C)	A-B	3,733
Estimated # wild CWT tags (D)		117
Wild smolt tagging		
Tag incidence (E)	D/C	3.13%
Number tagged (F)		63,851
Mortality adjustment* (G)		0.84
Tag retention adjustment (H)		0.96
Adjusted tag group (I)	FGH	51,489
Estimated smolt production		
Total smolts (J)	I/E	1,641,823
Variance (K)	$[(I+1)(C+1)(I-C)*(C-D)]/[(D+1)^2*(D+2)]$	20,037,817,622
Standard error [L]	sqrt(K)	141,555
Low 95% confidence interval	J-1.96*L	1,364,375
High 95% confidence interval	J+1.96*L	1,919,270
CV	L/J	8.6

* Mortality adjustment for coded-wire tag application based on Blankenship and Hanratty (1990).