2010 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 element of the state and tribal pre-season planning process for Washington State salmon fisheries. Accurate forecasts on a stock-by-stock basis are necessary to ensure adequate spawning escapements, realize harvest benefits, and achieve harvest allocation goals.

Across Washington's coho producing systems, ocean recruits have been predicted using various approaches. 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. Furthermore, escapement-based coho forecasts often have no predictive value because streams become fully seeded with juvenile coho at low spawner abundances (Bradford et al. 2000). The accuracy of coho run size forecasts are improved by partitioning recruitment into freshwater production and marine survival.

Freshwater production, or smolt abundance, is measured as the number of coho smolts leaving the freshwater rearing phase. Natural coho escapement goals throughout the state are based on the projected smolt carrying capacity of each system (Zillges 1977). The Washington Department of Fish and Wildlife (WDFW) and tribal co-managers have made substantial investments in monitoring smolt populations in order to assess these goals and to improve run forecasts.

Marine survival is survival from ocean entry through the ocean rearing phase. Marine survival is measured by summing coho harvest and escapement for a given stock. 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. Survival-to-return at these stations is considered accurate and unbiased because the fate of tag groups are enumerated at upstream trapping structures. Data from these monitoring stations describe patterns in survival among years and between systems.

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 predict hatchery returns where 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 based on rates of smolt production and marine survival rates from neighboring or comparable watersheds. Long-term populations studies have been used to identify environmental variables contributing to freshwater production and regional patterns in marine survival. This forecast directly connects coho production with habitat and should therefore improve stakeholder understanding of fisheries management.

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

Table 1 summarizes the forecasts for 2010 wild coho for Puget Sound, Washington Coast, and Lower Columbia River systems. Estimates 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). December age-2 recruits, which have been included in this table in previous years, are not provided as they are no longer used by resource managers. The following sections provide the approach for and derivation of smolt production and marine survival estimates.

TABLE 1.—2010 wild coho run forecasts for Puget Sound, Coastal Washington, and Lower Columbia based on smolt production and marine survival.

Production Unit	Production X Estimated Smolts Spring 2009	Marine Survival = Adults (Age 3)	Recruits Adults (Age 3)	Recruits Jan. (Age 3)
Puget Sound				
Primary Units				
Skagit River	1,475,000	3.0%	44,300	54,500
Stillaguamish River	370,000	5.0%	18,500	22,800
Snohomish River	1,420,000	5.0%	71,000	87,500
Hood Canal	995,000	3.2%	31,800	39,200
Straits of Juan de Fuca	**see note below**			
Secondary Units				
Nooksack River	226,000	3.0%	6,800	8,400
Strait of Georgia	26,000	3.0%	800	1,000
Samish River	66,000	3.0%	2,000	2,400
Lake Washington	84,000	5.0%	4,200	5,200
Green River	144,000	5.0%	7,200	8,900
Puyallup River	107,600	3.0%	3,200	4,000
Nisqually River	173,000	3.0%	5,200	6,400
Deschutes River	8,000	2.0%	160	200
South Sound	115,000	2.0%	2,300	2,800
East Kitsap	62,000	5.0%	3,100	3,800
Puget Sound Total	5,271,600		200,560	247,100
Coast				
Queets River	429,000	3.0%	12,870	15,900
Quillayute River	497,000	4.0%	19,880	24,500
Hoh River	217,000	3.0%	6,510	8,000
Quinault River	217,000	3.0%	6,510	8,000
Independent Tributaries	212,000	2.0%	4,240	5,200
Grays Harbor				
Chehalis River	1,843,000	2.0%	36,860	45,400
Humptulips River	200,000	2.0%	4,000	4,900
Willapa Bay	510,000	2.0%	10,200	12,600
Coastal Systems Total	4,125,000		101,070	124,500
Lower Columbia Total	395,900	2.0%	7,918	9,800
GRAND TOTAL	9,792,500		309,548	381,400

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

Puget Sound Smolt Production

Approach

The WSPE unit has measured coho production on the Skagit, Stillaguamish, Snohomish, Green, Nisqually, and Deschutes rivers as well as tributaries to Lake Washington and Hood Canal. Wild coho production estimates for each of the primary and secondary management units in Puget Sound are derived from these trapping studies. Results from over thirty years of study demonstrate that wild coho smolt production is limited by a combination of factors including seeding levels (i.e., escapement), environmental effects (flows) and human-caused habitat degradation. In general, streams are fully seeded with juvenile coho at very low spawner abundances and the majority of variation in production is generated by environmental effects (Bradford et al. 2000). Summer rearing flows have been identified as a key environmental variable affecting the freshwater survival and production of Puget Sound coho (Mathews and Olson 1980; Smoker 1955), although localized habitat factors such as woody debris, pool habitat, and road densities also impact smolt production (Quinn and Peterson 1996; Sharma and Hilborn 2001).

Measured production estimates for Puget Sound watersheds are evaluated with respect to potential production predicted by Zillges (1977). 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 number defined in the Washington stream catalog (Williams et al. 1975). For streams less than 6 yards wide, potential production was the habitat area multiplied by 0.42. This approach was based on measured densities of coho in three small Oregon streams (Chapman 1965). For streams wider than 6 yards, potential production was the length of stream multiplied by 2.5, based on measured coho densities in Big Qualicum River, British Columbia (Lister and Walker 1966). This approach assumes that only the margins of these larger rivers are suitable habitat for juvenile coho, an assumption supported by the depth and velocity preferences of juvenile coho identified in a range of Puget Sound and coastal streams (Beecher et al. 2002). Potential production was predicted by summing production potentials of individual streams in watershed.

Zillges (1977) predictions were for potential production under average flow conditions and based on the assumption that habitat was intact and escapement was adequate. Measured production estimates for Puget Sound watersheds have ranged, on average, from 11.2% to 121.2% of the predicted potential production (Table 2). The Zillges technical report provides a reasoned approach to comparing coho smolt production among years and among watersheds, and this forecast uses his predictions as a means to evaluate coho production in Puget Sound watersheds. For watersheds without direct measurements, production was estimated based on the predicted potential for the non-measured watershed (Zillges 1977) adjusted by measured:predicted ratios from comparable watersheds where brood year 2007 production was measured.

TABLE 2.—Wild coho production measured in Puget Sound watersheds. Table includes the average and range of production estimates compared to the potential production predicted by Zillges (1977). Data in these tables are the production estimates and potential production above the trap.

		Smolt production above trap			Zillges (1977) comparison		
Stream	No. Years	Average	Min	Max	Average	Min	Max
Hood Canal							
Big Beef	32	26,992	11,510	47,088	70.0%	29.8%	122.1%
Little Anderson	16	570	45	1,969	11.2%	0.9%	38.6%
Seabeck	16	1,451	626	2,620	13.8%	6.0%	25.0%
Stavis	16	6,092	2,850	9,667	121.2%	56.7%	192.3%
Skagit River	20	1,037,119	426,963	1,884,668	75.6%	31.1%	137.5%
SF Skykomish River*	6	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	7	79,702	22,671	194,393	35.3%	10.1%	86.2%
Lake Washington							
Cedar River**	11	50,759	13,322	82,462	42.0%	11.0%	68.2%
Bear Creek	11	32,834	9,807	52,791	65.6%	19.6%	105.4%
Deschutes	31	49,445	892	133,198	22.5%	0.4%	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.

Puget Sound Primary Units

Skagit River

A total of 1,475,000 wild coho smolts are estimated to have emigrated from the Skagit River in 2009 (Table 1), representing 107.6% of the production potential estimated by Zillges (1977). This estimate is based on wild coho catch 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 wild yearling coho marked and released from an upstream tributary (Mannser Creek) and recaptured at the main stem trap. Total production was calculated using a Petersen estimator with Chapman modification (Seber 1973).

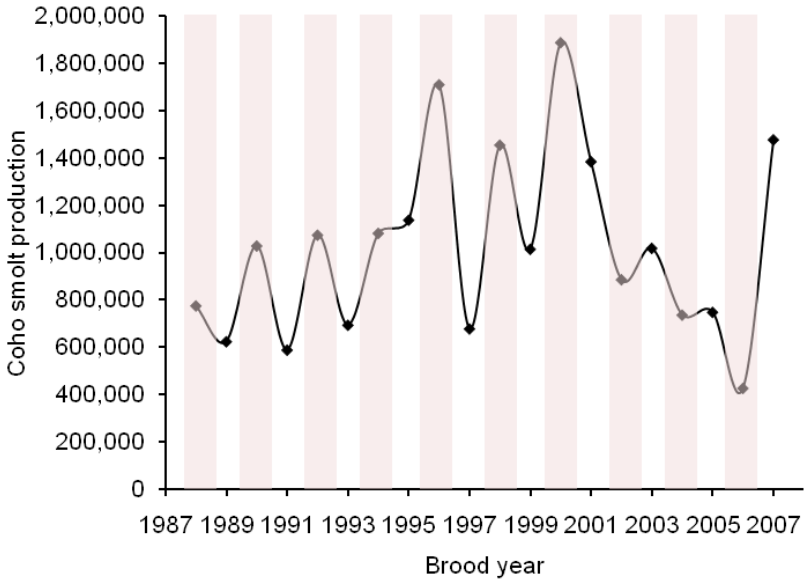

Figure 1. Wild coho smolt production in the Skagit River, brood year 1988 – 2007. Bars represent brood years where the parr rearing period overlaps with pink salmon returns to the river.

Between 1990 and 2009, wild coho production in the Skagit River has averaged 1,037,000 smolts (Table 2). The 2009 production (2007 brood year) was the third highest production observed during this period. Historically, inter-annual variability in coho production has been attributed to at least three variables – incubation flows, summer rearing flows, pink salmon escapement (odd years only). In the initial years of the study, coho production was consistently higher for brood years when the summer parr rearing period overlapped with pink salmon returns to the river (Figure 1). Nutrient inputs from the pink salmon carcasses were hypothesized to increase smolt production for those brood years (Seiler 1997). However, the pink salmon 'effect' has not persisted past the 2000 brood year.

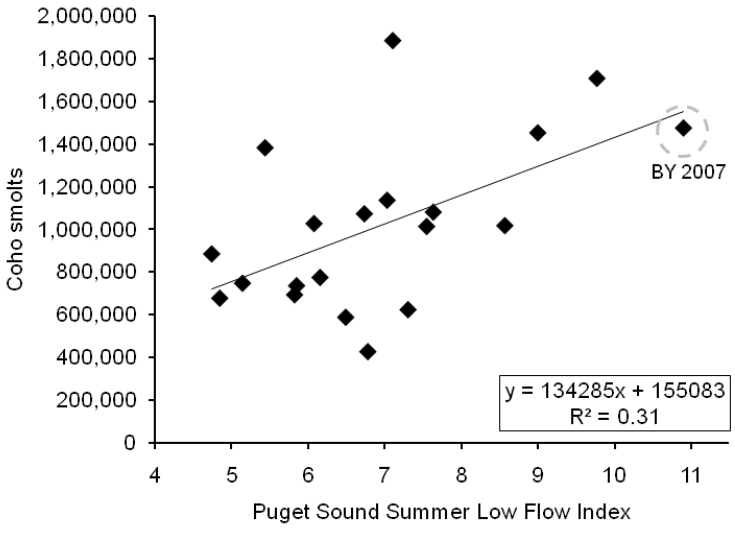

Figure 2. Wild coho smolt production in the Skagit River as a function of the Puget Sound Summer Low Flow Index. Data are for brood years 1988 to 2007. Puget Sound Summer Low Flow Index in an index of 60-day summer low flow periods in major Puget Sound watersheds.

Smolt production in the Skagit River is correlated with low flows during the

summer (parr) rearing period (Figure 2). Summer low flows were represented by the Puget Sound Summer Low Flow Index (PSSLFI), a composite measure of coho rearing flows in Puget Sound rivers (Appendix A). Ability to predict coho production was not improved by adding peak incubation flows (October to March) or presence of pink salmon as variables in this linear model. For the 2007 brood year, the Puget Sound Summer Low Flow Index was the highest observed over the period of time that wild coho smolt production has been estimated for this basin. Therefore, high summer rearing flows were likely to be a key factor contributing to the high coho production for the 2007 brood year.

Stillaguamish River

A total of 370,000 coho smolts are estimated to have emigrated from the Stillaguamish River in 2009 (Table 1). Production was not directly measured in 2009; therefore, 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.

Historical data provide an average coho production for the Stillaguamish River for the 1979 to 1981 brood years. During these years, the watershed was considered to be adequately seeded. A juvenile trap was operated on the Stillaguamish River 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 between 1979 and 1981 was estimated to be 370,000 smolts.

Smolt production for the 2007 brood year was based on a comparison of rearing flows between the 1979-1981 brood years (when coho production was measured) and the 2007 brood year. This comparison was made with the assumption that Stillaguamish coho production is positively influenced by rearing flows, as observed in the Skagit River. Stillaguamish rearing flows for the 1979 to 1981 brood years were high and comparable to those of the 2007 brood year (see Appendix A for explanation of the low flow index). Between brood year 1979 and 1981, the average of the low flow indices for the Stillaguamish basin was 128% of the long-term average (USGS gage #12167000), suggesting that average production measured for these years represented watershed capacity under good rearing conditions. The low flow index for the 2007 brood year was 135% of the long-term average average. Based on this information, smolt production for the 2007 brood year was estimated to be 370,000 smolts. The smolt production estimate was not increased from the historical average as a precautionary measure, reflecting the inherent uncertainty of the flow-production correlation in the Stillaguamish basin.

Snohomish River

A total of 1,420,000 coho smolts are estimated to have emigrated from the Snohomish River in 2009 (Table 1). Production was not directly measured in 2009; therefore, this estimate is based on historical measures of smolt production in the South Fork Skykomish River expanded to the entire Snohomish watershed. Adult spawners enumerated at Sunset Falls in 2007 (28,581 adult coho) were adequate to fully seed the watershed.

Average coho production for the South Fork Skykomish River is based on historical data from the 1976 to 1984 brood years. For these brood years, a juvenile trap was operated below Sunset Falls and production estimates were generated with a back-calculation method (Petersen-Chapman estimator). For a given brood year, the back-calculation applied the incidence of coded-wire tag returns to the Sunset Falls adult trap to the catch of coho smolts in the juvenile trap. The back-calculation method accounts for South Fork Skykomish coho production above and below the trap. For the 1976-1981 brood years, average production was 276,000 smolts (range = 212,000 to 354,000 smolts). Smolt production during this period was not correlated with spawner abundance (Figure 3). Escapement was experimentally reduced for the 1982-1984 brood years 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) did reduce coho production to an average of 198,000 smolts.

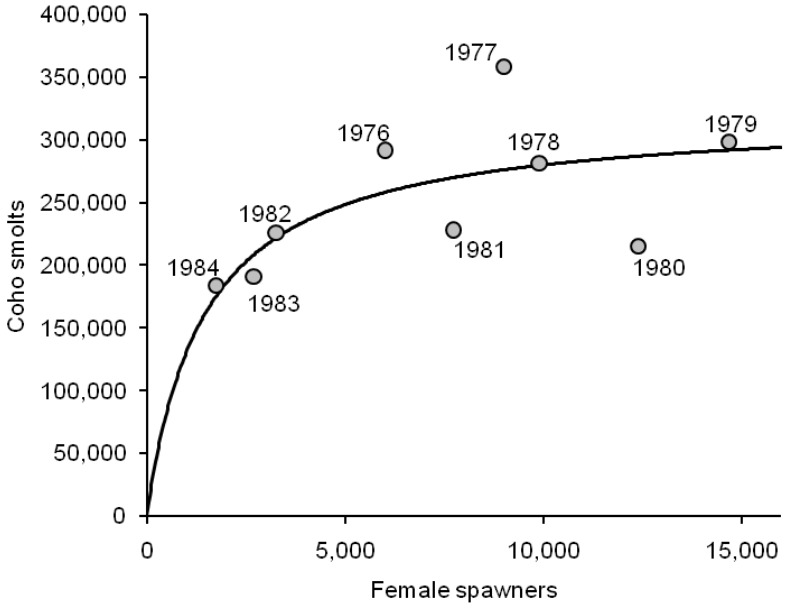

Figure 3. Wild coho production as a function of female spawners in the South Fork Skykomish River. Dates are brood years.

Two approaches were used to estimate average production for the entire Snohomish basin. The first approach, used in previous forecasts, expanded the average South Fork Skykomish coho production by 20.7%, the portion of the Snohomish system's drainage area represented by this South Fork Skykomish sub-basin. With this method, average coho production for the Snohomish basin is 1,333,000 smolts (Seiler 1996). Previous forecasts subsequently reduced this estimate 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). The second approach was based on Zillges production potential for the Snohomish basin and therefore comparable to estimates made for other Puget Sound watersheds. Average production for the South Fork Skykomish River (276,000 smolts) was 90.8% of the predicted production potential (304,000) for this sub-basin (Zillges 1977). When this percentage is applied to the production potential for non-trapped portions of the Snohomish basin (1,723,000), average production for the Snohomish basin outside of the South Fork Skykomish River is estimated to be 1,564,000 smolts. Using this second method, average coho production for the entire Snohomish basin is estimated to be 1,840,000 smolts. Due to the large discrepancy between these methods and the lack of empirical data necessary for validation, an average of the two basin-wide estimates was adopted (1,420,000 smolts).

Smolt production for the 2007 brood year was based on a comparison of rearing flows between the 1976-1981 brood years and the 2007 brood year. This approach assumes that rearing flows limit coho production in the Snohomish basin, as observed in the Skagit River. Between brood year 1976 and 1981, the average of the 60-day low flow indices for the Snohomish basin was 124% of the long-term

average (USGS gage #12142000), suggesting that average production measured for these years represented watershed capacity under good rearing conditions. The 60-day low flow index for the 2007 brood year was 156% of the long-term average average. Based on this information, smolt production for the 2007 brood year was estimated to be 1,420,000 smolts. Smolt production was not increased from the historical average as a precautionary measure, reflecting the inherent uncertainty of the flow-production relationship in the Snohomish basin.

Hood Canal

A total of 995,000 coho smolts are estimated to have emigrated from Hood Canal tributaries in 2009 (Table 1). Production was not directly measured in all tributaries; therefore this estimate is based on an expansion of the measure production.

Three approaches have been used to estimate wild coho smolt production in Hood Canal. The approaches are similar in that they expand measured production at Big Beef Creek and neighboring tributaries to a Hood Canal-wide estimate, but differ in how measured production is expanded. The first approach assumes that coho production from four tributaries (Little Anderson, Big Beef, Seaback, and Stavis creeks) was 5.9% that of the entire Hood Canal (Zillges 1977). A subsequent review by the Hood Canal Joint Technical Committee (HCJTC) estimated that coho production from these same four tributaries was 7.6% that 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% that of Hood Canal.

Wild coho production in 2009 was estimated to be 45,392 smolts from Big Beef Creek, 1,101 smolts from Little Anderson Creek, 626 smolts from Seabeck Creek, and 3,474 smolts from Stavis Creek. These estimates include smolts captured in fan traps (BBC) and fence weirs. Catch was extrapolated for early and late migrants using historical migration timing data. Actual catch was greater than 95% of each estimate. In total, these estimates represent 85.5% of the production potential estimated by Zillges (1977) and 118.9% of the production potential estimated by the HCJTC revision.

Coho smolt production has been estimated for each of these four tributaries since 1993 (Big Beef estimates date back to 1978). In 2009, Big Beef coho production was 96% of the maximum production observed during the 1993 – 2009 period. This was consistent with the favorable summer low flow conditions in Hood Canal as measured with the Big Beef Department of Ecology gage (Station ID 15F150) and the Skokomish USGS gage (#12061500). However, coho production from the three neighboring tributaries were much lower with respect to historical observations (24 – 56% of maximum production observed).

The three approaches described above estimated that wild coho production in Hood Canal ranged between 668,000 and 995,000 smolts. Using the Zillges approach, the total of 50,593 smolts from the four tributaries were expanded to an estimated 860,349 Hood Canal smolts. Using the second approach (HCJTC 1994 revision), the total of 50,593 smolts from the four tributaries were expanded to 668,013 Hood Canal smolts. The third approach expanded the 45,392 smolts from Big Beef Creek to a total of 995,429 Hood Canal smolts. This forecast is based on the expansion provided by the third approach.

Puget Sound Secondary Units

Nooksack River

A total of 226,000 coho smolts are estimated to have emigrated from the Nooksack River in 2009 (Table 1). Production was not directly measured in 2009. Although coho rearing conditions were generally good throughout Puget Sound, additional factors are thought to limit smolt production in the Nooksack River, including high harvest rates and habitat degradation (Seiler 1996). Previous forecasts have estimated that Nooksack wild coho production to be 20% and 50% of its predicted potential production of 451,275 smolts (Zillges 1977). Based on the relatively high production of Skagit River wild coho and the good rearing conditions indicated by the PSSLFI (Appendix A), the 2009 production of Nooksack wild coho is estimated to be 226,000 (50% of potential production).

Strait of Georgia

A total of 26,000 coho smolts are estimated to have emigrated from the Straits of George streams in 2009 (Table 1). Production was not directly measured in 2009. This estimate is based on the smaller nature of these tributaries and the condition of spawning and rearing habitat. Seventy-nine percent of the potential production in the Strait of Georgia management unit comes from tributaries less than 6 yards in width (Zillges 1977). Although Puget Sound rearing flows were good for the 2007 brood year, production from these small watersheds is assumed to be influenced by localized factors (e.g., agriculture, urbanization) in addition to rearing flows, similar to that observed in small Hood Canal tributaries. Previous forecasts have estimated that wild coho production in the Straits of Georgia was 20% to 50% of its potential. A total production of 26,000 smolts represents 50% of the total production potential for these watersheds (51,821 smolts per Zillges 1977).

Samish River

A total of 66,000 coho smolts are estimated to have emigrated from the Samish River in 2009 (Table 1). Production was not directly measured in 2009; therefore this estimate is based on adult escapement and an assumed number of smolts per spawner.

Production potential of the Samish River was estimated to be 169,489 (Zillges 1977). This includes 57,923 smolts below and 111,566 smolts above the Samish River hatchery rack. Since hatchery supplementation ended in the 1980s, Samish River coho have continued a self-sustaining run of nearly 10,000 spawners. Juvenile production of at least 100,000 smolts are needed to produce this number of spawners under conditions favorable to survival (i.e., 20% marine survival and 50% harvest; Seiler 1996)

In recent years, coho returns to the Samish River have declined. A total of 1,500 spawners were estimated in 2005 and 345 spawners in 2006. Estimated escapement in 2007 was 1,765 spawners. This estimate was based on the number of fish enumerated at the Samish hatchery weir. The Samish Hatchery weir is currently operated for the collection of Chinook broodstock (late September to early November) and misses the latter portion of the coho run. Therefore, catch at this weir (September 20 to October 22) was expanded based on coho run timing at Sunset Falls (South Fork Skykomish River). The 1,428 coho handled at the weir were assumed to be 81% of the run, resulting in a total escapement

estimate of 1,765 coho. Assuming a 1:1 sex ratio and a high production rate of 75 smolts/female spawner, a total of 66,000 smolts are estimated to have emigrated from the Samish River in 2009.

Lake Washington

A total of 84,000 coho smolts are estimated to have entered Puget Sound from the Lake Washington basin in 2009 (Table 1). This estimate is based on measured production for two major tributaries to Lake Washington (Cedar River and Bear Creek), historical production data (2000) for Issaquah Creek, and an estimate of survival through Lake Washington. Juvenile traps operated in each of these watersheds were calibrated using recaptures of marked coho released above the trap. Wild coho production was estimated with a Petersen estimator with Chapman modification (Seber 1973).

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 2009, coho production in Cedar River and Bear Creek was estimated to be 52,691 and 33,395 smolts respectively. Unlike 2008, where poor trapping conditions reduced the accuracy of wild coho estimates, trap efficiency was greatly improved in 2009 and estimates for this year are believed to be accurate (Kiyohara and Zimmerman In review). The 2009 coho production from Issaquah Creek was estimated by scaling the 2000 estimate for this creek (measured through trapping study) by the 2009 to 2000 production ratios in the Cedar River and Bear Creek. In 2009, coho smolt production in Cedar River and Bear Creek was 164% and 103% of that measured in 2000, respectively (average = 133%). Therefore, 2009 coho production from Issaquah Creek was estimated to be 25,512 smolts, 133% of the measured 2000 production (19,182 smolts). Combined coho abundance entering Lake Washington was rounded to 112,000 smolts.

The total production of 84,000 smolts assumed 75% survival through Lake Washington. This 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 144,000 coho smolts are estimated to have emigrated from the Green River in 2009 (Table 1). This estimate is based on the two major rearing areas of the watershed – accessible areas upstream of river mile 34 and Big Soos Creek.

In 2009, coho production above river mile 34 was estimated with a juvenile trap. The juvenile trap was calibrated based on recapture rates of marked wild coho. Production above the trap was estimated to be 65,250 smolts using a Petersen estimator with Chapman modification (Seber 1973). This represents 28.9% of the 225,546 production potential estimated for this portion of the watershed (Zillges 1977).

Big Soos Creek enters the Green River downstream of the juvenile trap. In 2000, a juvenile trap was operated in Big Soos Creek and wild coho production was estimated to be 64,341 smolts (Zillges 1977). Coho production in Big Soos Creek, a low gradient stream, is likely to be impacted by the amount of low flow habitat. Therefore, 2009 production from this creek was based on the ratio of PSSLFI values between the 2009 and 2000 outmigrant years (see Appendix A for explanation of PSSLFI). This ratio (10.3/8.4 = 122%) was applied to the 2000 production estimate (64,341 smolts) yielding an estimate of 78,551 coho smolts in 2009.

The total 2009 coho production estimate for the Green River was the sum of production for these two regions of the watershed, 144,000 smolts. This estimate assumes that little to no rearing occurs in the lower Green River.

Puyallup River

A total of 107,600 coho smolts are estimated to have emigrated from the Puyallup River in 2009 (Table 1). This estimate is based on unmarked coho production above a juvenile trap expanded to untrapped portions of the watershed. The Puyallup River trap is operated by the Puyallup Tribes just upstream of the confluence with the White River. A total of 54,051 coho are estimated to have migrated past the juvenile trap in 2009 (Berger et al. 2009), 19.3% of the production potential for this portion of the watershed (Zillges 1977). Total emigration for untrapped portions of the watershed was estimated by applying this production rate (19.3%) to the potential production (276,824 smolts) for the untrapped reaches. Total production of 107,600 smolts was the sum of measured (54,051 smolts) and expanded (53,549 smolts)

Nisqually River

A total of 173,000 coho smolts are estimated to have emigrated from the Nisqually River in 2009 (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 Petersen estimator with Chapman modification (Seber 1973).

Wild coho production above the trap (river mile 12) was estimated to be 135,512 smolts, 117.3% of the 115,554 smolt potential predicted by Zillges (1977). Production below the trap was estimated to be 37,118, which is 117.3% of the potential production predicted for this portion of the watershed (Zillges 1977). Total watershed production was the sum of these two estimates (135,512 + 37,118 = 172,630).

Of note, the 2009 production level is substantially higher than the production estimated in previous forecasts when no trap was operated (range 10,000 to 60,000).

Deschutes River

A total of 8,000 coho smolts are estimated to have emigrated from the Deschutes River in 2009 (Table 1), representing 3.7% of the production potential estimated by Zillges (1977). This estimate is based on wild coho catch in a juvenile trap operated below Tumwater Falls. Final smolt production estimates for this brood will be derived from a back-calculated Petersen estimator and based on returns

of tagged and untagged wild coho to the adult trap in 2010. The preliminary estimate was derived by expanding catch in the juvenile trap (total catch = 1,734) by average trap efficiency (21.5%).

Over the last two decades, coho production in the Deschutes River has become severely depressed. A combination of variables may have contributed to this trend - habitat degradation in the upper watershed, high incubation flows, and low escapement. In addition, extremely low marine survival was likely a major factor driving the current status of this stock. In the 1990s, marine survival for Deschutes coho was lower than any other Puget Sound stock for which survival is measured. As a result, two of the three brood lines are virtually extinct. The 2007 brood is one of the severely depressed brood lines.

South Sound

A total of 115,000 coho smolts are estimated to have emigrated from South Sound tributaries in 2009 (Table 1). This estimate is based on production estimates from representative creeks in the southern extent of this management unit (Cranberry, Mill, Goldsborough, and Sherwood creeks) and on historical information from a representative creek (Minter Creek) in the northern extent of this management unit. Production in the southern tributaries is expected to be lower than northern tributaries due to higher terminal harvest rates in deep South Sound.

In 2009, coho production in Cranberry Creek was 2,072 smolts from Cranberry Creek and 5,824 smolts from Mill Creek (Scott Steltzner, Natural Resources Department, Squaxin Island Tribe, personal communication). Production from these creeks was 10.0 and 10.4% of the production potential predicted by Zillges (1977). Production from Goldsborough (40,191 smolts) and Sherwood creeks (10,003), where natural production was supplemented, was 56.1% and 14.8% of the predicted production potential. Minter Creek was not trapped in 2009. Historical smolt production from this creek averaged 10,000 smolts (Brandt Boeltz, Fish Program, WDFW). This production is 34.2% of the 29,272 smolt potential estimated above the hatchery rack (Zillges 1977).

Given the wide disparity in production within South Sound, we applied 20% of potential production to the 573,770 smolt potential (including production above Minter hatchery rack) predicted by Zillges (1977). Based on this approach, total coho production is estimated to be 115,000 smolts in 2009.

East Kitsap

A total of 62,000 coho smolts are estimated to have emigrated from East Kitsap tributaries in 2009 (Table 1). This estimate was based on an expansion of measured production in a single East Kitsap tributary. In 2009, Steele Creek coho production was measured with fence weirs operated on the North and South Forks of the creek. A total of 347 and 1,919 coho smolts were caught emigrating from the north and south forks of Steele Creek, respectively (Steele Creek Organization for Resource Enhancement; www.bougan.com/SCORE). These catches represent a minimum production as the weir panels were blown out several times during the season. The 2009 production represents 54.7% of the potential 4,140 smolts predicted for this creek (Zillges 1977).

Total production for all East Kitsap tributaries was estimated to be 62,000 based on applying 40% to the 154,973 smolt potential predicted for East Kitsap streams (Zillges 1977). This percentage was selected because the Steele Creek restoration efforts are expected to result in higher coho

productivity in Steele Creek than other East Kitsap watersheds. A lower overall production rate (than that measured in Steele Creek) was also a precautionary measure to account for localized factors likely to influence these small streams, similar to that observed in small Hood Canal tributaries.

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 drainages (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. Smolt production per unit drainage area has averaged 400 and 900 smolts/mi^2 (Table 3). Low-gradient systems, such as the Chehalis River (Grays Harbor) or Dickey River (tributary to the Quillayute), have consistently had a higher production rate than high-gradient systems, such as the Clearwater River (Queets tributary) or Bogachiel River (Quillayute tributary).

In 2009, wild coho production was measured in the Chehalis and Clearwater/Queets river systems. Historical production data is also available from the Dickey and Bogachiel rivers in the Quillayute watershed. In coastal watersheds where production was not estimated in 2009, 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 rage (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	66,811	27,314	101,820	477.2	195.1	727.3
Queets (no Clearwater)	9	247,497	163,450	355,000	550.0	363.2	788.9
Chehalis (Grays Harbor)	26	1,888,988	502,918	3,592,275	893.6	237.9	1699.3

Queets River

A total of 429,000 wild coho smolts are estimated to have emigrated from the Queets and Clearwater rivers in 2009 (Table 1). This estimate is based on measured production in the Clearwater River and estimated production for the remainder of the basin. The 2009 coho production for the Clearwater River was estimated to be 101,820 smolts (Jim Jorgeson, Quinault Tribe, personal communication). This corresponds to 727 smolts/mi^2, the highest production rate estimated for this system in 31 years of study (Table 3). Estimates for the entire basin will be finalized by the Quinault tribe based on a mark-recapture study, releases from tributary and scoop traps, and a nighttime seining

project on the lower Queets River. Because the final 2009 estimate was not available at the time of this forecast, a preliminary estimate was derived by WDFW. Annual production rates (smolts/mi^2) for the Queets River (excluding the Clearwater) have ranged from 0.5 to 1.2 times that of the Clearwater. Wild coho production for the Queets River in 2009 was estimated by applying the Clearwater production rate (727 smolts/mi^2) to the 450 mi^2 drainage area for the Queets (excluding the Clearwater). In total, wild coho production was estimated to be 429,000 smolts, the sum of 101,820 smolts from the Clearwater and 327,279 smolts from the Queets (excluding the Clearwater).

Quillayute River

A total of 497,000 coho smolts are estimated to have emigrated from the Quillayute River system in 2009 (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 actually measured in 2000.

Smolt production has been measured in the Bogachiel and Dickey rivers, two sub-basins of the Quillayute River. Between 1992 and 1994, coho production above the Dickey River trap averaged 71,189 coho (818 smolts/mi^2). Over three years (1987, 1988, and 1990), Bogachiel coho production averaged 53,751 smolts (417 smolts/mi^2). Higher production rates in the Dickey than Bogachiel River are hypothesized to result from the lower gradient in the Dickey than the Bogachiel river system (Seiler 1996). Lower gradients should increase available summer and winter rearing habitats.

Average production of the Quillayute system was estimated to be 306,000 coho smolts. This estimate was the sum of Dickey River production and production for 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 an estimate of 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 an estimate of 217,257 smolts. The sum of these estimates is 306,000 smolts.

The 2009 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 rate between the Dickey and Bogachiel rivers, the two regions of the watershed were estimated separately. The 2009 coho production in the Dickey River sub-basin was estimated to be 147,534 smolts (1.67*88,344 smolts). The 1.67 expansion factor was the ratio of Clearwater production in 2009 (101,820 smolts) to average Clearwater production in 1992-1994 (101,820/61,000 = 1.67). The 2009 coho production in the Quillayute (excluding the Dickey sub-basin) was estimated to be 349,784 smolts (1.61*217,257 smolts). The 1.61 expansion factor was the ratio of Clearwater production in 2009 to average production in 1987, 1988, and 1990 (101,820/63,333 = 1.61). A total 2009 coho production of 497,000 was the sum of these estimates.

Hoh River

A total of 217,000 wild coho smolts are estimated to have emigrated from the Hoh River in 2009 (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 many similar characteristics as well as regional proximity. The production rate of 727 smolts/mi^2 from the

Clearwater was applied to the 299-mi^2 of the Hoh watershed, resulting in an estimated 217,000 smolts from the Hoh River system.

Quinault River

A total of 217,000 wild coho smolts are estimated to have emigrated from the Quinault River in 2009 (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, low escapement, and degraded habitat. In 2009, a production rate of 500 smolts/mi^2 was applied to the 434-mi^2 Quinault River system, resulting in an estimated 217,000 smolts.

Independent Tributaries

A total of 212,000 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 2009, an average production rate of 500 smolts/mi^2 was applied to the total watershed area (424 mi^2; Appendix C), resulting in an estimated 212,000 smolts.

Grays Harbor

A total of 2,043,000 coho smolts are predicted to have emigrated from the Grays Harbor system in 2009 (Table 1). This estimate was produced n 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 back-calculation method. Smolts are coded-wire tagged on a main-stem juvenile trap (RM 52) and at the Bingham Creek juvenile trap (right bank tributary to the East Fork Satsop River at RM 17.4) during the outmigration period. This catch is 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. Smolt production is estimated after adults have passed through the fishery and returned to the river. Between 1980 brood and present, Chehalis River wild coho production has ranged from 503,000 to 3.6 million smolts.

Because the back-calculation method does not provide a production estimate in the year that coho are entering into the fishery, an alternative approach has been used for forecasting purposes. This alternative approach is based on a spawning flow-production regression. Historically, there was a strong predictive relationship between minimum spawning flows and coho smolt production in the Chehalis basin (Seiler 1996). Spawning flows were represented by mean daily flows at the Grand Mound USGS gage (#12027500) between November 2 and December 15. Over time, this regression relationship has lost some of its predictive capacity. At present (BY 1980 to 2005), minimum spawning flows explained just 41% of the variation in coho production (Figure 4). Adding additional variables to this model, such as minimum rearing flows (60-day average) did not improve the relationship. The spawning flow regression estimated that 2009 coho production from the Chehalis River was 1,693,985 smolts. This prediction is based on a minimum spawning flow (November 9, 2007) of 464 cfs at the Grand Mound gage.

Four brood years (1990, 1994, 1997, and 2000) have been excluded from the spawning flow versus production regression. The 1990 brood was excluded because tagging on this brood was limited, few wild, tagged adult coho were recovered in the terminal fishery, and low tag incidence (0.29%) among returning spawners resulted in an unlikely production estimate of six million smolts. The 1994 and 1997 brood years were excluded from the regression because low spawner abundance of these broods was likely the dominant factor limiting smolt production. Spawner abundance for these years was less than 7,000 coho and productivities were greater than 100 smolts/female. The 2000 brood year was excluded from the regression analysis because productivity was unusually high (156 smolts/female). The high productivity of this brood year is less likely due to escapement, which was comparable to other years and may be explained by favorable incubation and rearing conditions. The 2000 brood experienced the lowest peak winter flow and third highest summer low flow since trapping began.

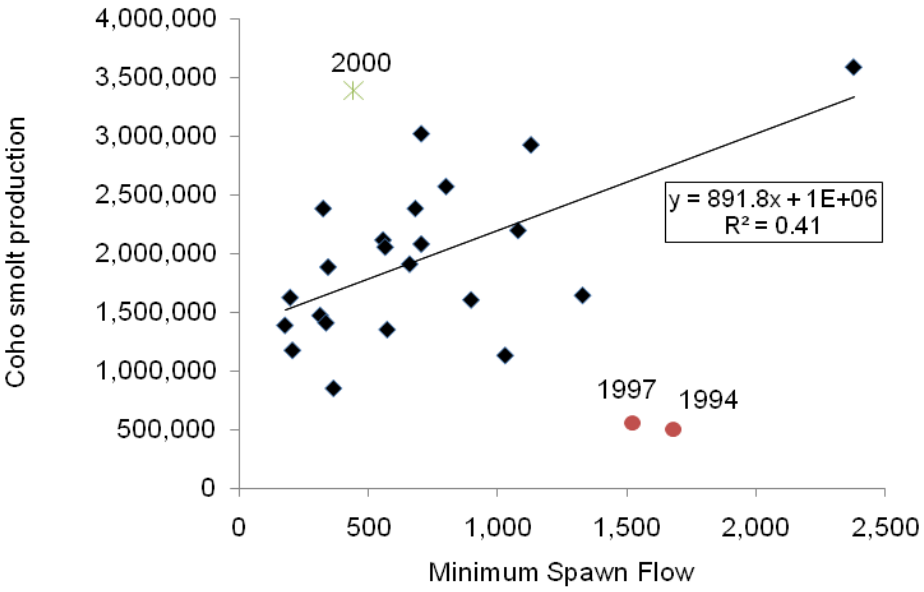

Figure 4. Production of wild coho smolts in the Chehalis River basin as a function of minimum spawning flow, brood year 1980 - 2005. Minimum spawning flow was the minimum of mean daily flows measured at the Grand Mound USGS gage (#12027500) between November 2 and December 15. Brood years 1990, 1994, 1997 and 2000 were excluded from the analysis.

Production for other portions of the Grays Harbor management unit was estimated by applying the production per unit area for the Chehalis River basin. Production per unit area for the Chehalis basin including the Wishkah River was 801 smolts/mi^2 (1,693,985 smolts per 2,114 mi^2). A total of 1,843,030 wild 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 200,329 smolts (801 smolts/mi^2*250 mi^2). After summing production estimated for these regions of the Grays Harbor management unit, total wild coho production was estimated to be 2,043,000 smolts.

Willapa Bay

A total of 510,000 coho smolts are estimated to have emigrated from the Willapa Bay basin in 2009 (Table 1). As production was not directly measured, this estimate is based on production per unit area of the Chehalis Basin. The Willapa Basin 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. Given these impacts, wild coho production per unit area is likely to be somewhat lower than observed in the Chehalis Basin. Wild coho production from the 2007 brood year (510,000 smolts) was calculated by applying 600 smolts/mi^2 production rate to the total basin area (850 mi^2).

Lower Columbia Smolt Production

A total of 395,900 natural-origin coho smolts are estimated to have emigrated from the Lower Columbia region in 2009 (Table 1). Derivation of this estimate was prepared by Dan Rawding of WDFW and is provided in Appendix C.

Marine Survival

Approach

Marine survival of wild coho has been measured over thirty years at four long-term monitoring stations in Puget Sound and one station in coastal Washington. Wild coho smolts are coded-wire tagged during the outmigration period and recaptured as jack and adult coho in upstream weir traps. The smolt tag group is adjusted downward by 16% for tag-related mortality (Blankenship and Hanratty 1990) and 4% for tag loss (WSPE, unpubl. data). Jack return rate is the harvest (minimal to none) and escapement of tagged jacks divided by the adjusted number of tagged smolts. Adult marine survival is the sum of all tag recoveries (harvest + escapement) divided by the adjusted number of tagged smolts. Coast-wide tag recovery data were accessed through the Regional Mark Information System database (RMIS, http://www.rmpc.org/).

Marine survival has ranged twenty-fold among the years of study. Conditions prior to and upon ocean entry (e.g., sea surface temperature and timing of the spring upwelling transition) have been shown to correlate with coho marine survival (Logerwell et al. 2003; Ryding and Skalski 1999). Differences in marine survival are dramatic among years and differ among regions (Coronado and Hilborn 1998). As a result, marine survival in one year is an inconsistent predictor for the next year and marine survival in one region is a poor proxy for a distant region.

Evaluation of the long-term datasets from Puget Sound and coastal Washington demonstrate a correlation between jack return rates and adult (age-3) marine survival. In this forecast, marine survival is predicted based on current jack returns and a predictive relationship between jack returns and adult (age-3) marine survival. The observed correlations between jack and adult returns are consistent with the hypothesis that conditions upon ocean entry (experienced by both age classes) is a primary driver of coho marine survival. The jack-adult survival regression from Big Beef Creek (Hood Canal) is applied to Puget Sound watersheds and the jack-adult survival regression from Bingham Creek (Grays Harbor basin) is applied to watersheds in coastal Washington and the lower Columbia.

Puget Sound

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 (Appendix D). In this forecast, these populations are assumed to represent the different regions of Puget Sound. In Big Beef Creek (Hood Canal), marine survival has varied more than ten-fold (3 to 32%) between brood years 1975-2006. At Sunset Falls (South Fork Skykomish River, southern Whidbey Basin), marine survival ranged between 8% and 22% over nine broods (1976 to 1984 brood). For brood year 1985 and later, marine survival has been estimated from adult escapement at the Sunset Falls trap, the historical average production (276,000 smolts), and the assumption that escapement has been 85% of the total run (1995-present). Since the 1995 brood year, escapement has been assumed to be 85% of the total run. At Baker River (Skagit River, northern Whidbey Basin), marine survival has ranged between 1.1% and 13.8% over thirteen brood years (1989-1997, 2003-2006). In the Deschutes River (South Sound), marine survival has ranged between 0.1% and 29% between brood years 1977 to 2006.

Marine survival of Puget Sound coho has declined since the long-term studies began in the late 1970s (Figure 5). This decline was most dramatic in South Sound (indicated by Deschutes River stock), but observed across the sound by the mid-1990s. Marine survival has differed among populations, and the relative differences among populations have changed over time. Marine survival estimates for the 2003-2005 brood years were low and nearly identical among populations. As a result, the 2009 forecast applied a single marine survival (9.3%) prediction for all regions of the sound. Across the four wild stocks, preliminary marine survival estimates for the 2006 brood year averaged 9.4%, very close to the predicted survival. These preliminary estimates represent a lower bound to marine survival as many tag recoveries from the 2009 fishery are not yet reported in RMIS. Preliminary estimates suggest that marine survival differed substantially among regions, ranging from 4.5% in South Sound (Deschutes River) to 14.9% in the southern Whidbey basin (SF Skykomish River).

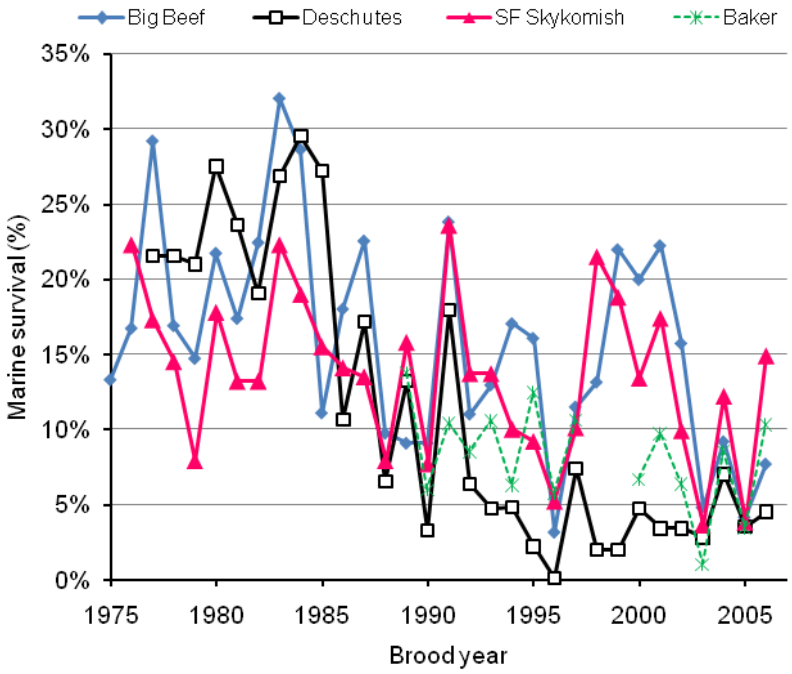

Figure 5. Long-term marine survival of wild coho in four Puget Sound watersheds.

Marine survival for the 2007 brood year was predicted based on jack returns. A marine survival prediction was first derived for Big Beef Creek coho and then extrapolated to other regions of Puget Sound based on assumed differences in survival among regions. Between 1977 and 1996, the adult:jack return ratio of Big Beef Creek wild coho averaged 11.3 (range = 6 to 18) and was remarkably consistent among years. During these years, 76% of the variation in age-3 coho marine survival could be predicted from jack return rates. Over the past decade, the ratio of adult to jack returns has

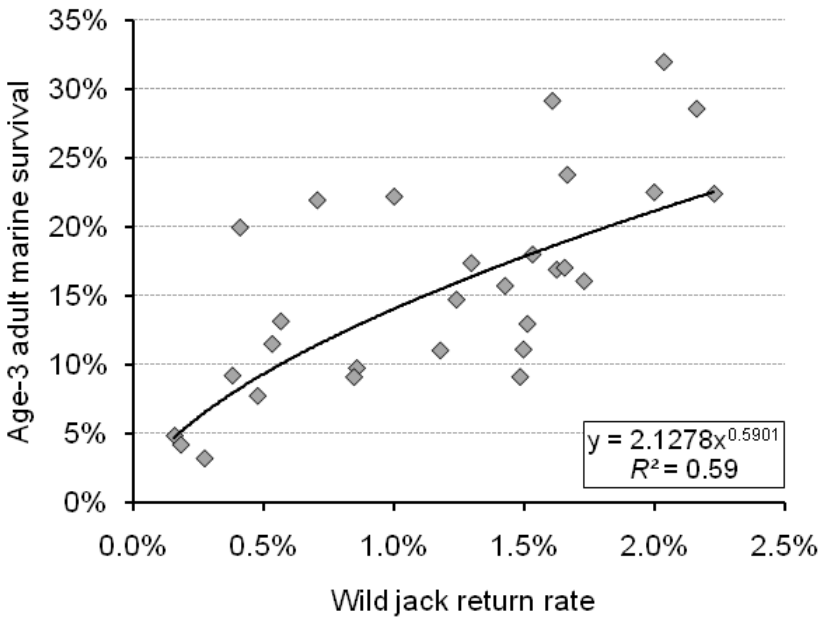

Figure 6. Marine survival of wild coho adults as a function of jack return rates, Big Beef Creek brood years 1977-2006.

increased (average = 26.8) and oscillated more dramatically among years (range = 12 to 49). Currently, jack return rates explain 59% of the variation in age-3 marine survival of Big Beef coho (Figure 6). This change has resulted in greater uncertainty about the predicted marine survival, especially at under high jack return rates. However, the difference between estimated and predicted survival has been less than 2.5% over the past five brood years (Figure 7). Acknowledging the potential uncertainty, this model remains appropriate for predicting coho marine survival.

In the fall of 2009, 26 tagged wild jacks (estimated) returned to Big Beef Creek from the adjusted tag group of 31,249 coho smolts released in spring of 2009 (tag group was adjusted for mortality and tag retention as described in approach). Marine survival of the 2007 brood is predicted to be 3.2% based on the jack return rate of 0.08% (Table 1). Marine survival of South Sound coho (Puyallup to Deschutes) is predicted to be slightly lower than Hood Canal, 2.0-3.0%, reflecting the chrononically poor survival in this region. Marine survival is predicted to be 5.0% for the central sound region (Stillaguamish to Green) and 3.0% for northern region of Puget Sound (Skagit and north).

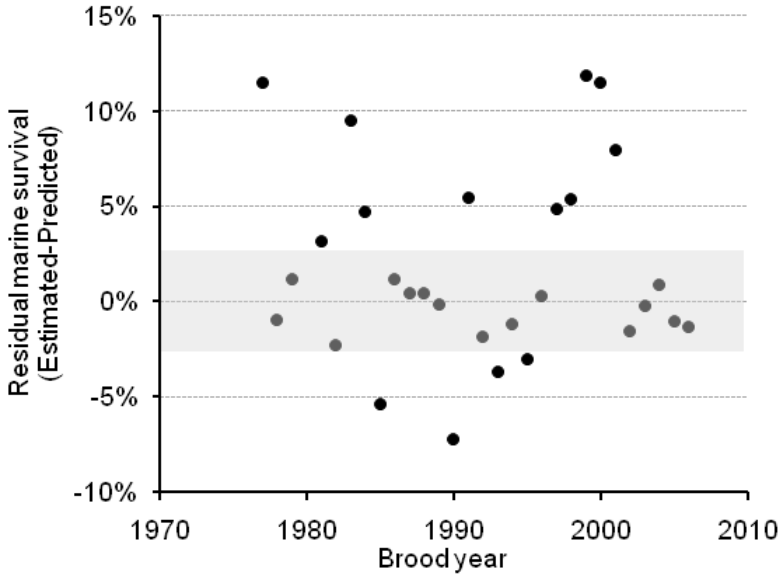

Figure 7. Residual error (estimated-predicted) for jack-adult marine survival regression, Big Beef Creek coho brood years 1977-2006. Parameters for regression model ($a*x^b$) were were calculated for the 1977-1996 brood years and then updated with each additional year. Shaded region represents years for which prediction was within 2.5% of actual marine survival estimate.

Coast

Marine survival of Bingham Creek wild coho has ranged from 0.6% to 11.6% between brood year 1980 and 2006 (Figure 8). The relationship between Bingham Creek jack returns and adult marine survival is predictive when data are divided into three times periods: brood year 1981-1986, 1987-2000, and 2001-2006 (Figure 9). Historically, multiple regression models were derived because marine survival predictions were biased high over multiple brood years (Seiler 1996; Volkhardt et al. 2008). Both adjustments to the regression model involved a lower slope value, indicating that fewer adults returned per jack. Two El Niño broods (1980 and 1990) were outliers and excluded from the analysis.

The 2009 forecast predicted that marine survival of the 2006 brood year would be 8.6% (Zimmerman 2009). Based on 2009 tag returns and estimated harvest, the preliminary estimate of marine survival for this brood year is 9.3%. The 2006 brood year had the highest jack return rate observed for Bingham Creek and among the highest adult marine survival estimated for this population. When the 2006 brood year data were added to the third regression model (BY 2001-2006), jack return rates predicted 99% of the variation in adult marine survival. Therefore, this model remains appropriate for predicting adult returns.

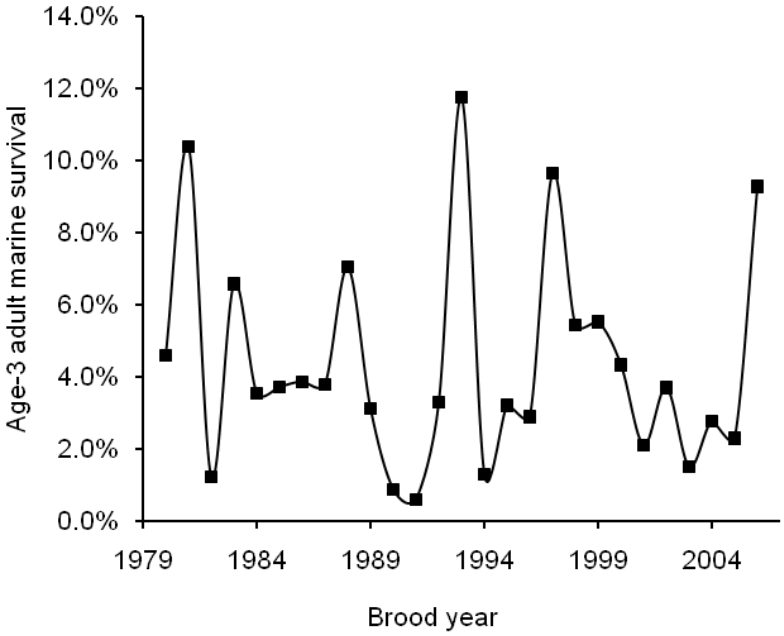

Figure 8. Adult marine survival for Bingham Creek wild coho, brood year 1980-2006. Data are based on recoveries of coded-wire tagged wild coho in harvest and escapement.

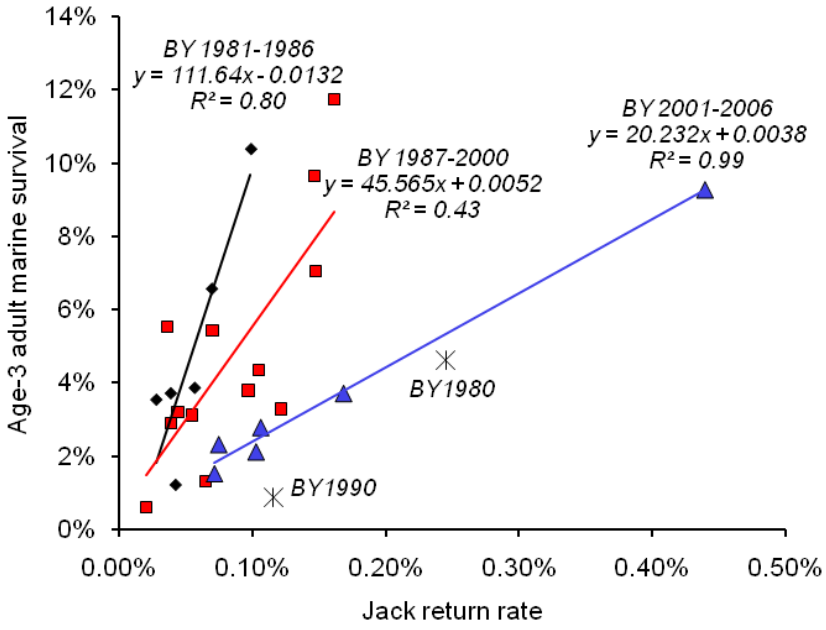

Figure 9. Adult marine survival as a function of jack return rate for Bingham Creek wild coho, brood year (BY) 1980-2006. Data are based on recoveries of coded-wire tagged wild coho. Three regression models have been fit to these data and reflect a shift in the predictive relationship over time. Brood year 1980 and 1990 were El Niño years and were treated as outliers.

Marine survival for 2007 brood year Bingham Creek wild coho is predicted to be 2.61%. This estimate is based on a 0.11% jack return and the regression between jack returns and adult marine survival for the 2001 to 2006 brood year (Figure 9). This prediction should be considered with caution because of the El Niño conditions that developed in the Pacific by mid-2009. For two brood years (1980 and 1990) previously exposed to El Nino conditions, adult marine survival was much lower than predicted from jack return rates (Figure 9).

In consideration of the uncertainty caused by El Niño conditions, a more conservative 2.0% marine survival was applied to the Grays Harbor, Willapa Bay, coastal tributaries, and Quinault River (Table 1). A marine survival of 3% was applied to the Queets and Hoh rivers and a marine survival of 4% was applied to the Quillayute River. These upward adjustments to marine survival predictions for the northern coastal watersheds reflected the general trend of higher marine survival in the northern Washington coastal systems.

Lower Columbia River

Lacking any indicators for wild coho survival in the Lower Columbia River, a 2.0% marine survival rate was also applied to this system.

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). However, for the 2008 rearing year (brood year 2007), the index was based on just seven gauges as no data were available for the South Fork Nooksack in this year. Comparison of inter-annual flow indices used in the 2010 forecast is based on all historical gages except the South Fork Nooksack.

The Puget Sound Low Flow Index is calculated each year and is the sum of each site-specific flow index. Site-specific indices were calculated from minimum 60-day average flow (mean daily) between late March and November. Typically, the minimum 60-day average flow occurs during late August or early September. For each year, the index for each site was the 60-day average low flow converted to a proportion of the inter-annual average for that site (data are available for brood year 1962 to present).

Between brood year 1962 and present, the PSSLFI has ranged from 3.8 to 11.1 with an average of 7.0 (based on seven gauging stations and without the S Fork Nooksack). During this period, site-specific indices were closely correlated with each other (Table A1) supporting the concept that summer rearing flows are coordinated among Puget Sound basins.

TABLE A1.—Pearson correlations among 60-day low flow metrics at representative USGS stream gages in Puget Sound.

Gage name	Gage No.	SFNook	Newhal	NFStill	NFSnoq	Taylor	Rex	Newauk	Skok
SF Nooksack	#12209000	1							
Newhalem (Skagit)	#12178100	0.65***	1						
NF Stillaguamish	#12167000	0.89***	0.57***	1					
NF Snoqualmie	#12142000	0.83***	0.53***	0.84***	1				
Taylor (Cedar)	#12117000	0.67***	0.54***	0.68***	0.70***	1			
Rex (Cedar)	#12115500	0.71***	0.34*	0.79***	0.89***	0.76***	1		
Newaukum (Green)	#12108500	0.58***	0.45**	0.60***	0.60***	0.80***	0.63***	1	
Skokomish	#12061500	0.69***	0.56***	0.66***	0.58***	0.65***	0.61***	0.50***	1

***p < 0.001, **p < 0.01, *p < 0.05

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. Wild coho smolt production estimates for the Lower Columbia River

January 18, 2010

To: Mara Zimmerman

From: Dan Rawding

Subject: Smolt population estimates for the Washington portion of the Lower Columbia River ESU

In 2009, WDFW monitored a total of eight streams for coho salmon smolt abundance in the Lower Columbia River ESU. These trapping locations included the mouths of independent tributaries to the Lower Columbia River including Grays River (RM 6), Mill Creek, Abernathy Creek, Germany Creeks, the Cowlitz River at Mayfield and Cowlitz Falls Dams, and the Wind River near Little Wind River at RM 1. The Coweeman River, a tributary to the Cowlitz River, has been monitored near the gauge station (RM 7.5) through 2008 but was not monitored in 2009. Individual population estimates are not finalized but preliminary estimates were developed from capture-mark-recapture data using a stratified Petersen estimate (Schwarz and Taylor 1998) for periods with and without panels. Panels were installed at the Grays, Mill, Abernathy, and Germany trap sites in 2009 as water flows dropped to improve the precision of the estimate by diverting a greater proportion of flow and presumably smolts through the trap.

At the Cowlitz Falls dam site, a pooled Petersen estimate was used to estimate seasonal trap efficiency and this was applied to the seasonal catch of smolts. It should be noted that a small number of adults were hauled to the upper basin for a productivity test in 2007, which resulted in low smolt yield in 2009. Therefore, due to the low number of adults this estimate was not used to estimate the density for hatchery streams. At the Mayfield site, collection efficiency was estimated to be 66.4% for coho salmon smolts (Paulik and Thompson 1967). It was assumed a release of 1000 smolts and a recapture of 664 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, so no smolt estimates were calculated for this subbasin. Since the Coweeman River was not monitored in 2009, a four-year average was used to estimate the coho smolt production.

A Bayesian approach, using binomial mark-recapture model, was used to calculate smolt outmigration estimates using in WinBUGS (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. It should be noted that the priors for population size were truncated at approximately between 150% and 200% of the maximum smolt population estimate from previous trapping. This truncation had minimal influence on the all smolt estimates. 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 and after the installation of panels. The posterior predictive distribution for Grays River was influence by the trap efficiency 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. Preliminary smolt production estimates are found in Table 1.

Bradford et al. (2000) indicated that coho salmon smolt production was correlated to habitat. They 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. Estimates of smolts per square mile of drainage area are also found in Table 1.

In Cedar Creek, a Remote Site Incubation (RSI) program has been in place since 2004. All RSI embryos were thermally marked and a subsample of smolts were collected during outmigrant trapping. Natural origin smolt abundance was estimate by multiply the natural origin proportion, based on the otolith decoding of the subsample, by the annual smolt estimate. Since the 2007 and 2009 otoliths have not been decoded, the mean natural origin proportion from 2004 to 2006 was applied to the 2009 outmigration estimate.

The natural origin coho salmon smolts in Cedar Creek were estimated to be 1154 smolts per square mile of drainage area. Historically, Cedar Creek density estimates are greater than twice as high as the next best estimate due to the abundance of low gradient habitat in this subwatershed, seeding of this habitat with hatchery and wild spawners, and on going recovery activities including placement of surplus hatchery carcass and habitat restoration. It was felt that this density is not likely approached in other subwatersheds. Therefore, this estimate was not used to develop average smolt densities from unsampled areas.

The Grays and Tilton watersheds had densities of 91 and 256 smolts per square mile, respectively. Other watersheds with hatcheries had high levels of spawning escapement in 2007, including Grays, Elochoman, Green, and Kalama Rivers since surplus hatchery coho salmon were recycled or released above hatchery. It was also assumed that the escapement of hatchery coho salmon was high on the Lower Cowlitz, Lewis, and Washougal Rivers, which also have hatcheries. Therefore, the median density of coho salmon smolts from the Grays and Tilton Rivers was applied to all watersheds with hatcheries. The square miles of drainage area in these watersheds was estimated to be 805 square miles, and the resulting smolt production was predicted to be 139,900 smolts (90% CI 125,700 – 170,700) and can be found in Table 2.

The Coweeman, Germany, Abernathy, and Mill subwatersheds have no operating coho hatcheries but hatchery coho salmon do stray and spawn in them. The coho smolt densities ranged from a low of 103 to a high of 216 smolts per square mile. The median density of smolts per square mile (141) from these watersheds was multiplied by 620 square miles to predict smolt production from non-monitored streams

without hatchery releases. These abundance estimates are listed in Table 2 and the smolt estimate from unmonitored wild streams was predicted to be 87,170 smolts (90% CI 81,800 - 92,700).

The 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. The smolt production form 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. The monitored smolt abundance was estimated to be 168,400 (90% CI 162,900 – 174,200). The total abundance estimate for the Washington portion of the LCR ESU is found in Table 2 and was estimated 395,300 smolts (90% CI 377,200 – 429,400).

These coho smolt estimates are believed to be relatively unbiased because estimates are obtained from a census or mark-recapture programs, where care is 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 Germany Cr. to 1042 square miles in the Upper Cowlitz River. Habitat in monitored subwatershed 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 mainstems, 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.

It should also be noted that coho parr are observed emigrating past the trap sites. Some of these parr are likely continue rearing in freshwater below the traps and in the mainstem Columbia River and if they survive would emigrate 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 LCR should be considered a minimum number.

These coho smolt predictions would not be possible without funding from numerous federal, state, and private sources and dedicated WDFW employees. Special recognition goes to the following crew supervisors and their staff including Todd Hillson (WDFW) for providing Grays River data, Pat Hanratty (WDFW) for providing Mill, Abernathy, and Germany Creeks data, Julie Henning (WDFW) provided Mayfield trap catches, John Serl (WDFW) for providing Cowlitz Falls data, Cam Sharpe (WDFW) for the Coweeman River data, Josua Holowatz (WDFW) for the Cedar Creek data, and Charlie Cochran (WDFW) for the Wind River data. Jeff Grimm (WDFW) provided otolith decoding for the Cedar Creek samples and Steve VanderPloeg provided estimates of Grays River watershed size.

Table 1. Estimated smolt production and density from monitored coho salmon streams in the Lower Columbia River ESU during 2008. The Coweeman River was not monitored in 2009 but the 4-year average was used.

	Smolt Abundance			Smolt Density (Smolts/Sq. Mile)		
node	5.00%	median	95.00%	5.00%	median	95.00%
Mill	5901	6283	6697	203.5	216.6	230.9
Abernathy	3450	3761	4119	119	129.7	142
Germany	2321	2576	2902	100.9	112	126.2
Grays	1504	2377	4365	57.84	91.44	167.9
Tilton	39190	40640	42240	246.5	255.6	265.6
Upper Cowlitz	116800	123800	131400	112	118.8	126.1
Coweeman	9012	12290	15610	75.73	103.3	131.1
Cedar	57190	61140	65590	1079	1154	1237

Table 2. Estimated smolt production from streams with hatcheries, streams without hatcheries, minimum abundance from monitored streams, and predicted smolt abundance for the LCR ESU.

	Smolt Abundance			Smolt Density (Smolts/Sq. Mile)		
node	5.00%	median	95.00%	5.00%	median	95.00%
Unmonitored H_Streams	125700	139900	170700	156.1	173.8	212.1
Unmonitored W_Streams	81800	87170	92700	131.9	140.6	149.5
Monitored Streams	162900	168400	174200			
Nat. Origin Smolt Prediction	377200	395900	429400			

Appendix D. Marine survival of wild coho in selected Puget Sound watersheds. Marine survival is estimated from releases and recoveries of coded-wire tagged wild coho. Tagged coho are recovered in fisheries and at the upstream trap.

Year		Big Beef	Deschutes	SF	Baker	
Brood	Return	Creek	River	Skykomish[b]	River	Average
1975	1978	13.3%				
1976	1979	16.7%		22.3%		19.5%
1977	1980	29.2%	21.5%	17.3%		22.7%
1978	1981	16.9%	21.5%	14.5%		17.6%
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%		18.1%
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%	15.5%		17.9%
1986	1989	18.0%	10.7%	14.1%		14.3%
1987	1990	22.5%	17.2%	13.5%		17.7%
1988	1991	9.7%	6.5%	7.9%		8.0%
1989	1992	9.1%	13.2%	15.8%	13.8%	13.0%
1990	1993	9.1%	3.2%	7.7%	6.0%	6.5%
1991	1994	23.8%	17.9%	23.6%	10.4%	18.9%
1992	1995	11.0%	6.3%	13.7%	8.5%	9.9%
1993	1996	13.0%	4.7%	13.7%	10.6%	10.5%
1994	1997	17.0%	4.8%	10.0%	6.3%	9.5%
1995	1998	16.1%	2.2%	9.2%	12.5%	10.0%
1996	1999	3.2%	0.1%	5.2%	5.8%	3.6%
1997	2000	11.5%	7.4%	10.1%	10.6%	9.9%
1998	2001	13.1%	2.0%	21.5%		12.2%
1999	2002	22.0%	2.0%	18.8%		14.3%
2000	2003	20.0%	4.7%	13.4%	6.7%	11.2%
2001	2004	22.2%	3.4%	17.4%	9.7%	13.2%
2002	2005	15.7%	3.4%	9.9%	6.4%	8.9%
2003	2006	4.8%	2.8%	3.6%	1.1%	3.1%
2004	2007	9.2%	7.0%	12.2%	8.6%	9.2%
2005	2008	4.2%	3.5%	3.8%	3.5%	3.7%
2006	2009	7.7%[a]	4.5%[a]	14.9%[a]	10.32%[a]	9.4%[a]
	Average	16.1%	11.7%	13.6%	8.0%	13.7%
	Min	3.2%	0.1%	3.6%	1.1%	3.1%
	Max	32.0%	29.5%	23.6%	13.8%	27.1%
	Count	31	29	30	15	30

[a]Brood year 2006 marine survival estimates are preliminary and should be considered a lower bound to the final estimate.

[b]Marine survival for the South Fork Skykomish River stock has been estimated from estimated smolt production and total adult returns since the 1985 brood year.

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