2011 Wild Coho Forecasts for Puget Sound, Washington Coast, and Lower Columbia

Washington Department of Fish & Wildlife

Science Division, Fish Program

by

Mara Zimmerman

Contributors: This coho forecast was made possible through funding from numerous federal, state, and local sources. Dan Rawding compiled and analyzed smolt data from the Lower Columbia ESU. The following WDFW employees, listed in alphabetical order, provided field data used in the 2011 forecast: Mike Ackley (Chehalis River and Sunset Falls), Charlie Cochran (Wind River), Pat Hanratty (Bingham Creek and Mill, Abernathy, and Germany creeks), Julie Henning (Mayfield trap catches), Todd Hillson (Grays River), Josua Holowatz (Cedar Creek), Clayton Kinsel (Skagit River and Big Beef Creek), Kelly Kiyohara (Lake Washington), Matt Klungle (Nisqually River), John Serl (Cowlitz Falls), Cameron Sharpe (Coweeman River), and Pete Topping (Green River, Deschutes River). Jeff Grimm (WDFW) provided otolith decoding for the Cedar Creek samples and Steve VanderPloeg provided estimates of Grays River watershed size. Contributions from tribal biologists and local community groups are cited within the document. Dave Seiler and Greg Volkhardt have made substantial contributions to this forecast since its inception in 1996.

Introduction

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

Ocean recruits of wild coho have been predicted using various approaches across Washington's coho producing systems. Methods that rely on the relationship between adult escapement and resulting run sizes are problematic due to inaccurate escapement estimates and difficulty allocating fishery catches by stock. Furthermore, escapement-based coho forecasts often have no predictive value because watersheds become fully seeded 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 freshwater at the conclusion of the freshwater life stage. The Washington Department of Fish and Wildlife (WDFW) and tribal natural resource departments have made substantial investments in monitoring smolt populations in order to assess escapement goals and improve run size forecasts.

Marine survival is survival from ocean entry through the ocean rearing phase to the point that harvest begins. 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 tag groups are enumerated at upstream trapping structures. Data from these monitoring stations describe patterns in survival among years and watersheds.

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 by extrapolating information from neighboring or comparable watersheds. Long-term studies on wild coho populations have been used to identify environmental variables contributing to freshwater production and to regional patterns in marine survival.

The Wild Salmon Production Evaluation (WSPE) Unit within the WDFW Fish Program Science Division has developed forecasts of wild coho run size for the last seventeen years. Beginning in 1996, a wild coho forecast was developed for all primary and most secondary management units in Puget Sound and the Washington coast (Seiler 1996). A forecast 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 2011 run-size forecasts for 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 fisheries managers. The following sections describe the approach used to derive smolt production and marine survival estimates.

Table 1. 2011 wild coho run forecast summary for Puget Sound, Coastal Washington, and Lower Columbia.

	Production X	**Marine Survival =**	**Recruits**	
Production Unit	**Estimated Smolts Spring 2010**	**Predicted Marine Survival**	**Adults (Age 3)**	**Jan. (Age 3)**
Puget Sound				
Primary Units				
Skagit River	1,447,000	13.7%	198,200	244,200
Stillaguamish River	555,000	13.7%	76,000	93,700
Snohomish River	1,500,000	19.6%	294,000	362,200
Hood Canal	535,000	20.7%	110,700	136,400
Straits of Juan de Fuca	**see note below**			
Secondary Units				
Nooksack River	135,000	13.7%	18,500	22,800
Strait of Georgia	16,000	13.7%	2,200	2,700
Samish River	11,000	13.7%	1,500	1,900
Lake Washington	79,000	19.6%	15,500	19,100
Green River	110,000	19.6%	21,600	26,600
Puyallup River	234,000	16.1%	37,700	46,400
Nisqually River	225,000	16.1%	36,200	44,600
Deschutes River	5,000	16.1%	805	1,000
South Sound	57,000	16.1%	9,200	11,300
East Kitsap	54,000	16.1%	8,700	10,700
Puget Sound Tot	4,963,000		830,805	1,023,600
Coast				
Queets River	238,000	10.0%	23,800	29,300
Quillayute River	442,000	12.0%	53,040	65,300
Hoh River	194,000	10.0%	19,400	23,900
Quinault River	217,000	10.0%	21,700	26,700
Independent Tributaries	254,000	8.5%	21,590	26,600
Grays Harbor				
Chehalis River	2,045,000	8.5%	173,825	214,200
Humptulips River	222,000	8.5%	18,870	23,200
Willapa Bay	510,000	8.5%	43,350	53,400
Coastal Systems Total	4,122,000		375,575	462,600
Lower Columbia Total	549,800	8.5%	46,733	57,600
GRAND TOTAL	9,634,800		1,253,113	1,543,800

Following the release of this forecast, predicted marine survival for Central Puget Sound (Lake WA, Green R., East Kitsap) was lowered to 6.2% based on additional information on the observed range of marine survival of natural-origin coho in the Lake Washington management unit.

Note: Tribal biologists m ber of Straits tributaries. Forecasts for the Straits will be based on t

Puget Sound Smolt Production

Approach

Wild coho production estimates for each of the primary and secondary management units in Puget Sound were derived from results of juvenile trapping studies conducted by the WSPE Unit. Over the past 30 years, the WSPE unit has measured wild coho production in the Skagit, Stillaguamish, Snohomish, Green, Nisqually, and Deschutes rivers as well as in tributaries to Lake Washington and Hood Canal. Analysis of these long-term data sets have demonstrated that wild coho smolt production is limited by a combination of factors including seeding levels (i.e., escapement), environmental effects (flows, marine derived nutrients), and habitat degradation. In several systems, census adult coho data are available to pair with the juvenile abundance estimates. In these systems, we have demonstrated that freshwater productivity (juveniles/female) is a decreasing function of spawner abundance (Figure 1). This density-dependent response in juvenile survival may result from decreased competition for rearing habitat. As a result, overall production of juvenile coho (juveniles/female * # females) in healthy watersheds is rarely limited by spawner abundance, and the majority of variation in juvenile production is generated by environmental effects (Bradford et al. 2000). Summer rearing flows are a key environmental variable affecting the freshwater survival and production of Puget Sound coho (Smoker 1955, Mathews and Olson 1980), although extreme flow events in the overwinter rearing period (Kinsel et al. 2009) and localized habitat factors such as woody debris, pool habitat, and road densities also impact smolt production (Quinn and Peterson 1996, Sharma and Hilborn 2001). In addition, recent increases in pink salmon returns to Puget Sound have dramatically increased the marine derived nutrients available for coho parr during their summer and winter rearing periods.

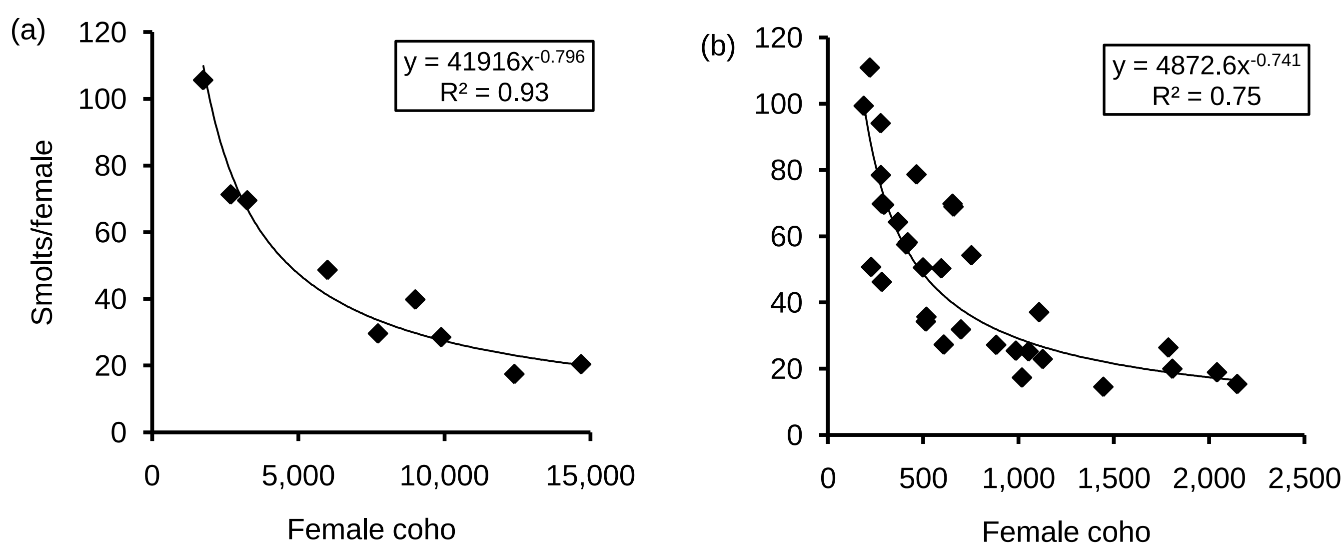

Figure 1. Freshwater productivity (juveniles/female) as a decreasing function of female coho escapement in the South Fork Skykomish (*a*, Sunset Falls, brood year 1976-1984) and Big Beef Creek (*b*, brood year 1978-2008) watersheds.

In some watersheds, habitat degradation and depressed run sizes have been a chronic issue. Smaller watersheds, which provide important spawning habitat for coho, are particularly vulnerable to both habitat degradation and low escapements. Density-dependent compensation is not observed when habitat degradation is severe or when escapements fall below critical thresholds. For example, the freshwater productivity of 1989 brood year coho in the Deschutes River was far below predicted levels following the January 1990 landslide into an important spawning area for this stock in Huckleberry Creek (Figure 2a). In addition, chronically low coho returns to the Deschutes River, beginning in the mid-1990s, have resulted in much lower freshwater survival (juveniles/female) than would be predicted from productivity curves derived from earlier years in the Deschutes (Figure 2b) or from other watersheds (Figure 1).

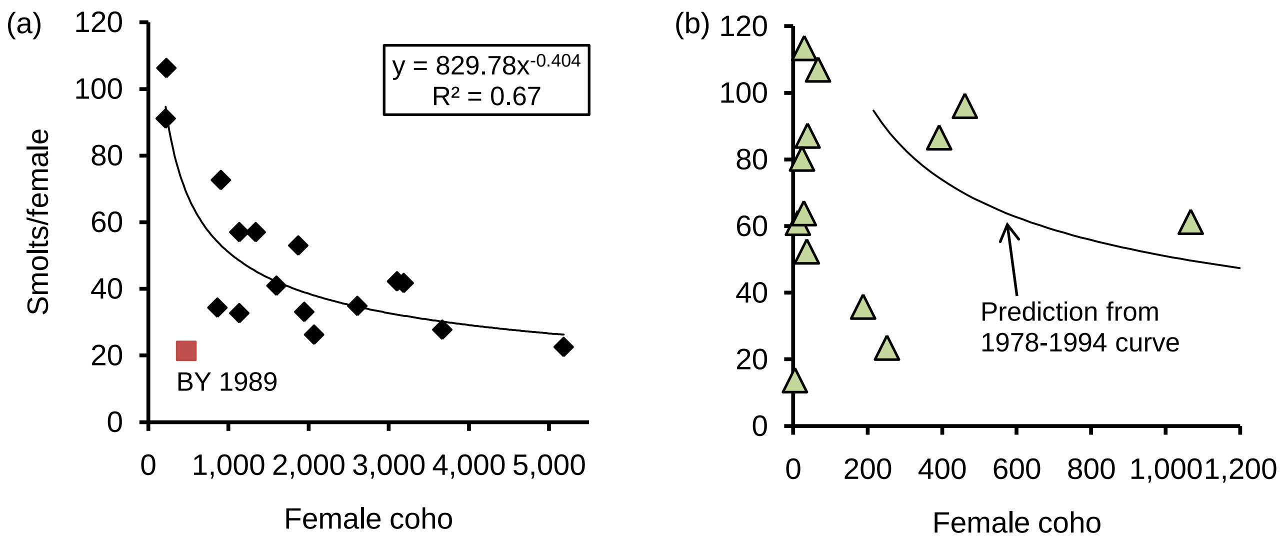

Figure 2. Freshwater productivity (juveniles/female) as a function of female coho escapement in the Deschutes River. For brood year 1978-1994 (*a*), coho productivity was a decreasing function of escapement (black square) with the exception of brood year 1989 (red square). The 1989 brood year corresponded with a landslide during egg incubation. For brood year 1995 to 2008 (*b*), spawner escapements have been chronically depressed and coho productivity has been far below the levels predicted (black line) under higher escapements (1978-1994).

In 2010, the WSPE Unit measured coho smolt production in six of the Puget Sound management units (Skagit, Hood Canal, Lake Washington, Green, Nisqually, and Deschutes). Smolt production from three additional management units (Puyallup, South Sound, East Kitsap) was available due to juvenile monitoring studies conducted by the Puyallup and Squaxin tribes and the Steele Creek Organization for Resource Enhancement. For watersheds where trapping data were not available in 2010, coho smolt production was estimated using several approaches.

One approach was based on the potential production predicted for each watershed by Zillges (1977). This approach was used to estimate production from an entire watershed when smolt production is known from at least some portion of that watershed. Zillges (1977) assumed that summer low flows were the primary limiting factor for Puget Sound coho and predicted potential smolt production based on the wetted summer habitat of Puget Sound streams. Rearing habitat was estimated for each stream number defined in the Washington stream catalog (Williams et al. 1975) and coho densities in each reach were estimated based on previous measures from both small (Chapman 1965) and large (Lister and Walker 1966) watersheds. Average production estimates for Puget Sound watersheds have ranged from 10.8% to 116.0% of the predicted potential production (Table 2). Because Zillges provides a common metric (rearing habitat) by stream segment, his predictions are useful to expanding production measured in one portion of the watershed to other areas of the watershed.

A second approach was the use of a Puget Sound Summer Low Flow Index (PSSLFI, Appendix A). This index was used to estimate production in watershed where smolt production was historically measured in that watershed but was not available for a given year. The PSSLFI index was calculated from a representative series of eight USGS stream flow gages in Puget Sound and was based on the general observation that summer low flows are correlated among Puget Sound watersheds. Use of this approach assumes that summer low flows are the key variable influencing freshwater survival of coho and that smolt production from one year can be predicted by applying the ratio of summer low flows to smolt production from another year.

A third approach to estimating coho production was based on marine derived nutrients provided by pink salmon. Over the past decade, pink salmon escapements in Puget Sound have increased to levels unprecedented in recent history. While some areas of Puget Sound (i.e., Straits of Juan de Fuca and Hood Canal) have not experienced these increased returns, other areas (e.g., Whidbey Basin and main and south sound) have experienced 4 to 10-fold increases in pink salmon escapements in a few short years. This forecast demonstrates that the increases in pink salmon have had a measurable effect on coho production in the Skagit River and uses this information to estimate coho production in the neighboring Stillaguamish and Snohomish basins where no direct measures of production are available.

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).

		Smolt production above trap			Zillges (1977) potential above trap		
Stream	No. Years	Average	Min	Max	Average	Min	Max
Hood Canal							
Big Beef	33	26,936	11,510	47,088	69.8%	29.8%	122.1%
Little Anderson	17	549	45	1,969	10.8%	0.9%	38.6%
Seabeck	17	1,401	496	2,725	13.3%	4.7%	26.0%
Stavis	17	5,832	1,663	9,667	116.0%	33.1%	192.3%
Skagit River	21	1,046,686	617,588	1,884,668	76.3%	45.0%	137.5%
SF Skykomish River	9*	249,331	212,039	353,981	82.0%	69.7%	116.4%
Stillaguamish River	3	284,142	211,671	383,756	42.9%	31.9%	57.9%
Green River	7	65,898	22,671	194,393	29.2%	10.1%	86.2%
Lake Washington							
Cedar River**	12	54,376	13,322	83,060	45.0%	11.0%	68.7%
Bear Creek	12	31,190	9,807	52,791	62.3%	19.6%	105.4%
Deschutes***	32	46,806	1,187	133,198	21.3%	0.5%	60.7%

* Data does not include the three years when smolt production was limited by experimental escapement reduction.

** Cedar River production potential does not include new habitat open to coho above Landsburg Dam beginning in 2003.

*** Deschutes smolt production in this table include yearling and sub yearling smolts. Both age classes are known to contribute to adult returns.

Puget Sound Primary Units

Skagit River

A total of 1,447,000 wild coho smolts are estimated to have emigrated from the Skagit River in 2010 (Table 1). This estimate is based on catch of wild coho in a juvenile trap operated on the lower main stem Skagit River (river mile 17.0 near Mount Vernon, Washington). The juvenile trap was calibrated using recaptures of wild yearling coho marked and released from an upstream tributary (Mannser Creek). Coho abundance was calculated using a Petersen estimator with Chapman modification (Seber 1973, Volkhardt et al. 2007).

Between 1990 and 2010, wild coho production in the Skagit River has averaged 1,047,000 smolts (Table 2). Freshwater productivity (smolts/female) during this period was a function of coho spawner abundance (Figure 3). The smolt-spawner function derived based on Skagit coho estimates is comparable to systems with census counts (Figure 1) which lends further credibility to the Skagit juvenile and adult estimates.

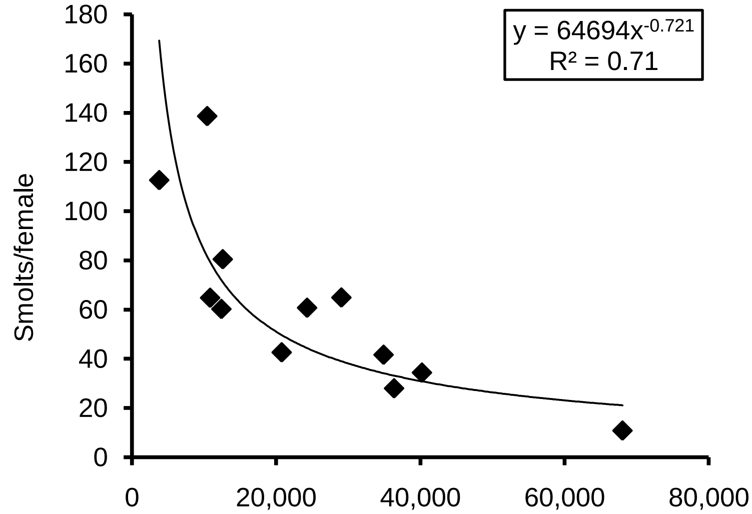

Figure 3. Juvenile productivity (smolts/female) of Skagit coho as a function of estimated coho escapement, brood year 1997-2008. Methodology for coho escapement changed in 1997.

Over the past decade, pink salmon returns to the Skagit River have ranged 19-fold with the 2009 return being the highest. Even-year broods of coho overlap with odd-year pink returns during the coho summer rearing period. In pink return years, coho smolt production is positively correlated with the abundance of pink spawners (Figure 4). In 2010, coho production in the Skagit River was 69% higher than production predicted from spawner abundance alone.

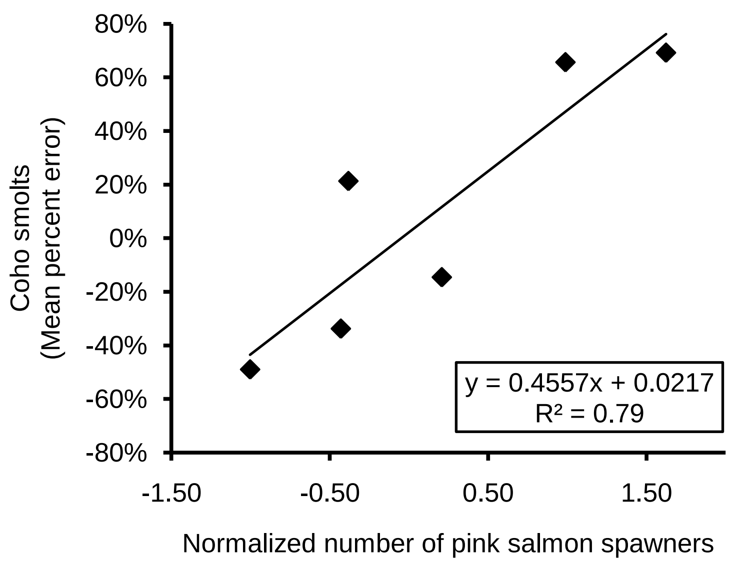

Figure 4. Coho smolts from the Skagit River as a function of pink salmon abundance, even coho brood years 1998 to 2008. Smolts are the mean percent error [(Actual-Pred)/Predicted] of production predicted from female spawners alone. Pink spawner numbers were normalized to compare with other systems [(A-Avg(A)/SD(A)].

Stillaguamish River

A total of 555,000 coho smolts are estimated to have emigrated from the Stillaguamish River in 2010 (Table 1). This estimate is based on historical data and the assumption that coho production is impacted by similar variables in the Stillaguamish and Skagit river systems.

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

The 2010 Stillaguamish coho production was estimated to be 555,000 smolts, 150% of that measured in 1981-1983. This estimate assumed that escapement was adequate to fully seed the watershed and that coho survival was positively influenced by large returns of pink salmon in 2009. Between 1997 and 2009, normalized values of pink salmon escapement were correlated between the Stillaguamish and Skagit River and the 2009 abundances were the highest in both watersheds (Figure 5). High pink escapement resulted in a 69% increase in Skagit coho production over what would have been predicted based on escapement alone. In the Stillaguamish, assuming that a coho production of 370,000 smolts represents “average” production, this value was increased by 50% to 555,000 smolts for the 2010 smolt estimate.

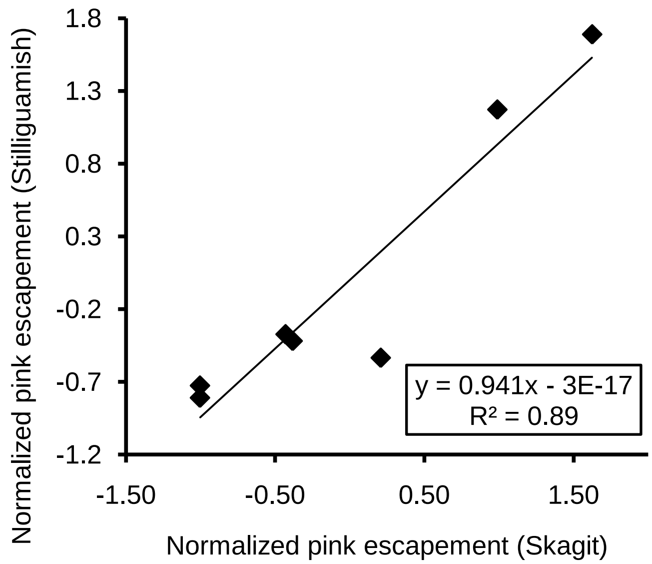

Figure 5. Correlation between pink salmon escapments in the Stillaguamish and Skagit watersheds, brood year 1997-2009. Escapement is normalized for comparison.

Snohomish River

A total of 1,500,000 coho smolts are estimated to have emigrated from the Snohomish River in 2010 (Table 1). A juvenile trap was operated on the Skykomish and Snoqualmie rivers by the Tulalip Tribe in 2010; however, analyses of these data will not be completed until later in the year. Therefore, the 2010 estimate is based on historical measures of smolt production in the South Fork Skykomish River expanded to the entire Snohomish watershed and the assumption that pink salmon escapement was the dominant environmental variable influencing freshwater survival of the 2010 coho smolts. This approach will be validated with the Tulalip trap estimates once these data become available.

Between 1978 and 1986, the WSPE unit operated a juvenile trap below Sunset Falls on the South Fork Skykomish River. Coho production estimates were generated with a 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 number of tagged coho smolts released from the juvenile trap. The back-calculation method accounts for South Fork Skykomish coho production above and below the trap. Between 1978 and 1983, average production was 276,000 smolts (range = 212,000 to 354,000 smolts) and inter annual variation in smolt production was not correlated with spawner abundance. Between 1982 and 1984 (corresponding to the 1984 to 1986 outmigration), escapement was experimentally reduced in order to determine whether smolt production could be limited by lower escapements. For these three years, limited escapement (1,000 to 3,000 females) reduced coho production to an average of 198,000 smolts. A basin-wide estimate for these years was derived by expanding average coho production in the South Fork Skykomish by 20.7%, the portion of the Snohomish system's drainage area represented by the South Fork Skykomish sub-basin. With this method, average coho production for the Snohomish basin is 1,333,000 smolts (Seiler 1996). This estimate was subsequently reduced to 1,000,000 smolts to account for the portions of the watershed that are not accessible to anadromous fish (i.e., 450 mi^2 or 26%; Seiler 1999).

Smolt production in 2010 was estimated to be 1,500,000 smolts, 50% higher than the estimated watershed average. This estimate assumed that coho survival was positively influenced by large returns of pink salmon in 2009. Between 1997 and 2009, normalized values of pink salmon escapement were correlated between the Snohomish and Skagit River systems and the 2009 abundances were the highest in both watersheds (Figure 6). Furthermore, the 2008 coho escapement to the Snohomish system was assumed to adequately seed the watershed. Returns to Sunset Falls (8,982 adults, ~4,491 females) were at a level previously demonstrated to maximize smolt production (Seiler 1996). Therefore, the smolt production associated with a fully seeded watershed (1,000,000 smolts) was increased by an expected 50% benefit from high pink salmon returns.

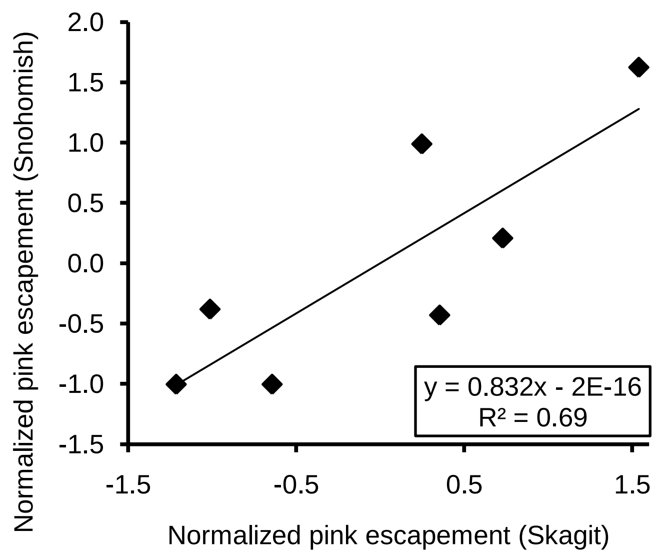

Figure 6. Correlation between pink salmon escapements in the Snohomish and Skagit watersheds, brood year 1997-2009. Escapement is normalized for comparison.

Hood Canal

A total of 535,000 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 measured production.

In 2010, wild coho production was measured in Big Beef Creek (n = 24,396), Little Anderson Creek (n = 214), Seabeck Creek (n = 496), and Stavis Creek (n = 1,663). Coho smolts in these watersheds were captured in fan traps (BBC) and fence weirs. Catch was extrapolated for early and late migrants using historical migration timing data. The extrapolation was less than 5% of each estimate.

The 2010 production of coho smolts from Big Beef Creek was limited by a combination of lower than average summer stream flows and low escapement. Stream flows in the summer of 2009 were lower than average across Puget Sound. For example, the Skokomish River gage (#12061500), one of the eight stream gages used in the Puget Sound Summer Low Flow Index, averaged 87% of its long-term average (Appendix A). The positive correlation between Big Beef coho smolt production and the summer flow index (Figure 7) suggest that low summer flows were an important variable limiting smolt production in Big Beef Creek in 2010. In addition, the number of smolts produced was nearly as high as one would expect based on the low numbers of spawners for this brood year. The 24,396 smolts produced by 220 females represents 110 smolts/female, indicative of a system where adult returns are low enough to dramatically increase juvenile survival (Figure 1). Low returns of Big Beef Creek coho in 2008 were the result of low marine survival (4.2%) and a harvest rate of 64.4%.

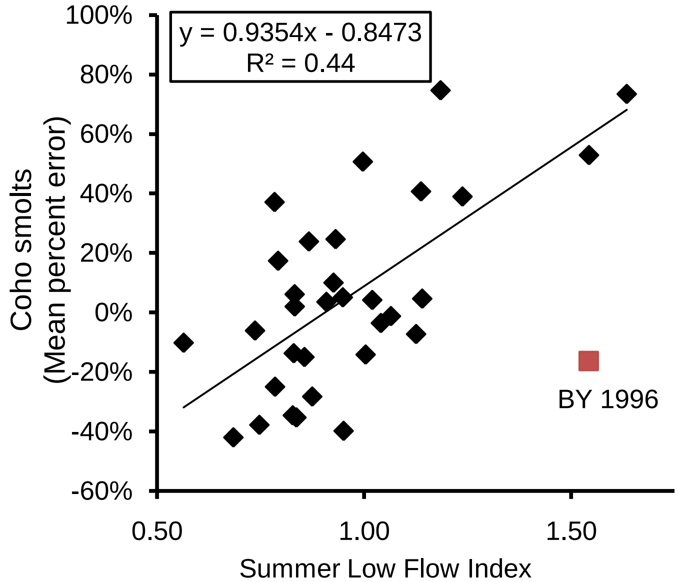

Figure 7. Coho smolt production as a function of summer low flows, Big Beef Creek brood year 1978-2008. Smolts are the mean percent error [(Actual-Pred)/Predicted] from production predicted by female spawners alone. Summer flows were the 60-day average low flow index from the Skokomish River USGS gage # 12061500. Brood year 1996 had extremely high incubation flows and is an outlier to this relationship.

Three approaches have been used to estimate the smolt production of wild coho in Hood Canal. These approaches use different rates to expand measured production at Big Beef Creek and neighboring tributaries to a Hood Canal estimate. The first approach assumes that coho production from four tributaries (Little Anderson, Big Beef, Seabeck, 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.

The three approaches described above estimated that the 2010 wild coho production in Hood Canal ranged between 353,000 and 535,000 smolts. Using the Zillges approach, the total of 26,769 smolts from the four tributaries were expanded to an estimated 455,215 Hood Canal smolts. Using the second approach (HCJTC 1994 revision), the total of 26,769 smolts from the four tributaries were expanded to 353,449 Hood Canal smolts. The third approach expanded the 24,396 smolts from Big Beef Creek to a total of 535,000 Hood Canal smolts. This forecast is based on the expansion provided by the third approach.

Puget Sound Secondary Units

Nooksack River

A total of 135,000 coho smolts are estimated to have emigrated from the Nooksack River in 2010 (Table 1). Smolt abundance estimates from the Nooksack were not available in 2010. Therefore, coho production in this watershed was estimated by applying a proportion of the Zillges (1977) production potential.

Summer rearing flows were likely to be an important factor determining the 2010 production of Nooksack coho smolts. In comparison with more southern Puget Sound watersheds, the Nooksack River did not experience the large returns of pink salmon in 2009 and was therefore unlikely to receive the benefits of additional marine derived nutrients observed in the Skagit and assumed for the Stillaguamish and Snohomish systems. Among the flow gages in Puget Sound (including Nooksack #12213100, Appendix A), the average 60-day low flow during summer of 2009 was just 75% of the long-term average.

Previous forecasts have estimated the Nooksack wild coho production to be 20% and 50% of its predicted potential production of 451,275 smolts (Zillges 1977). This reduction was due, in part, to the assumption that high harvest rates and habitat degradation were limiting coho production in the Nooksack (Seiler 1996). Based on the assumption that escapement and habitat degradation continue to limit production and that low summer flows limited freshwater survival, the 2010 production of Nooksack wild coho was estimated to be 135,000 (30% of potential production).

Strait of Georgia

A total of 16,000 coho smolts are estimated to have emigrated from the Straits of Georgia watersheds in 2010 (Table 1). Production was not directly measured in 2010, nor were historical estimates available from these watersheds. Therefore, production was estimated based on the potential predicted by Zillges (1977) and the assumption that summer low flows limited smolt production this management unit. 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). Coho rearing in these smaller habitats were assumed to be limited by low summer flows observed across Puget Sound in the summer of 2009. This assumption was supported by the lower than average production measured in small tributaries trapped in Hood Canal, East Kitsap, and South Sound management units. Previous forecasts for the Straits of Georgia have estimated that wild coho production was 20% to 50% of its potential. The 2010 coho production was estimated to be 16,000 smolts, 30% of the total production potential for these watersheds (51,821 smolts per Zillges 1977).

Samish River

A total of 11,000 coho smolts are estimated to have emigrated from the Samish River in 2010 (Table 1). Production was not directly measured in 2010; therefore this estimate is based on adult escapement and an assumed number of smolts per spawner.

In recent years, coho returns to the Samish River have declined. In the 1980s, when hatchery supplementation for coho ended, Samish River coho continued a self-sustaining run of nearly 10,000 spawners. Under conditions favorable to survival, juvenile production of at least 100,000 smolts (20 smolts/female) are needed to produce this number of spawners (i.e., 20% marine survival and 50% harvest; Seiler 1996). In recent years, however, spawner abundances have not exceeded 2,000 adults.

Samish River adult coho escapement in 2008 was estimated from the number of fish enumerated at the Samish Hatchery weir. The weir is currently operated for the collection of Chinook brood stock (late September to early November) and misses the latter portion of the coho run. Therefore, catch in the Samish weir (September 19 to October 22) was expanded based on coho run timing at Sunset Falls (South Fork Skykomish River). In 2008, the 171 coho handled at the Samish weir were assumed to be 81% of the run, resulting in a total escapement estimate of 211 coho. Assuming a 1:1 sex ratio and a high production rate of 100 smolts/female spawner (Figure 1), a total of 11,000 smolts were estimated to have emigrated from the Samish River in 2010.

Lake Washington

A total of 79,000 coho smolts are estimated to have entered Puget Sound from the Lake Washington basin in 2010 (Table 1). This estimate is based on measured production for two major tributaries to Lake Washington (Cedar River and Bear Creek), historical production data for Issaquah Creek (2000 migration year), and an estimate of survival through Lake Washington. Juvenile traps operated in each watershed were calibrated using recaptures of marked coho released above the trap. Wild coho production was estimated with a Bailey estimator (Seber 1973, Volkhardt et al. 2007).

The potential coho production for the Lake Washington basin (768,740 smolts) predicted by Zillges (1977) is unrealistically high for such an urbanized watershed. In addition, this potential includes the lake as a substantial portion of rearing habitat, an assumption that has not been supported by field surveys (Seiler 1998). Therefore, basin-wide production was estimated based on the three sub-basins – Cedar River, Bear Creek, and Issaquah Creek – that represent the majority of coho spawning and rearing habitat.

In 2010, coho production was estimated to be 83,060 smolts in the Cedar River and 13,100 smolts in Bear Creek (Kiyohara and Zimmerman In review). Coho production in the Cedar River and Bear Creek has been monitored from 1999 to present. Over this period of time, coho production has not been correlated between these two watersheds. Among the potential reasons for these differences is the use of newly colonized habitat on the Cedar River. A fish passage facility at Landsburg Dam was completed in 2003 and provides coho with access to at least 12.5 miles of spawning and rearing habitat between Landsburg and Cedar Falls. Coho returns to this portion of the watershed have steadily increased over time. For this reason, coho production estimated for Issaquah Creek (in the Sammamish sub basin) was based on monitoring data from the neighboring Bear Creek and not the Cedar River.

The 2010 coho production from Issaquah Creek was estimated by scaling the 2000 estimate for this creek (19,812 smolts; Seiler et al. 2002a) by the 2010 to 2000 production ratios in Bear Creek. Both watersheds should be influenced by returns of natural and hatchery coho and summer low flows. In 2010, coho smolt production in Bear Creek was 50.1% of that measured in 2000 (13,100/26,133 = 50.1%). Therefore, 2010 coho production from Issaquah Creek was estimated to be 9,926 smolts (19,812 * 50.1%).

The total coho production of 79,000 smolts assumed 75% survival through Lake Washington. Coho abundance entering Lake Washington was rounded to 106,000 smolts (83,060 Cedar + 13,100 Bear + 9,982 Issaquah). The 75% survival rate was estimated from historical detections of Passive Integrated

Transponder (PIT) tags applied to coho smolts caught in the traps and redetected at the Ballard Locks (WSPE unit, unpubl. data).

Green River

A total of 110,000 natural-origin coho smolts are estimated to have emigrated from the Green River in 2010 (Table 1). This estimate is based on an estimated production of 43,763 smolts upstream of the juvenile trap (river mile 34), 25,231 smolts below the juvenile trap, and 40,728 smolts from Big Soos Creek.

In 2010, coho production above river mile 34 was estimated with a partial-capture juvenile trap. The juvenile trap was calibrated based on recapture rates of marked wild coho. Production above the trap was estimated to be 43,763 smolts using a Bailey estimator (Topping and Zimmerman 2011). This represents 19.6% of the 223,106 production potential estimated for this portion of the watershed (Zillges 1977). Coho rearing in the main stem and tributaries (except Soos Creek) below the trap was estimated to be 25,231 smolts based 19.6% of the potential production (128,630) predicted for this portion of the watershed.

Big Soos Creek enters the Green River downstream of the juvenile trap. Production of coho smolts from Big Soos Creek was not measured in 2010. A juvenile trap was operated in Big Soos Creek in 2000, and natural-origin coho production was estimated to be 64,341 smolts in this year (Seiler et al. 2002b). Big Soos Creek is a low gradient stream and coho production is likely impacted by summer low flows. Therefore, 2010 production from this creek was based on the ratio of PSSLFI values between the 2010 and 2000 outmigration years (see Appendix A for explanation of PSSLFI). This ratio (63.3%) was applied to the 2000 production estimate (64,341 smolts) yielding an estimate of 40,728 coho smolts in 2010.

Puyallup River

A total of 234,000 coho smolts are estimated to have emigrated from the Puyallup River in 2010 (Table 1). This estimate is based on measured production in the Puyallup River above the juvenile trap (46,525), an estimated production from the White River (187,050), and an estimate from the Puyallup River below the Puyallup-White confluence (6,694).

In 2010, the Puyallup Tribe operated a juvenile fish trap on the Puyallup River just upstream of the confluence with the White River. A total of 46,525 coho were estimated to have migrated past the juvenile trap (A. Berger, Puyallup Tribe, personal communication). These coho smolts represent 16.9% of the production potential for the watershed between the Puyallup-White confluence and Electron dam (Zillges 1977). However, the actual rate should be lower than this percentage as a portion of the smolts in 2010 reared in habitat not accounted for in Zillges estimations. Coho in the Puyallup River have had access to the upper Puyallup River since a fish ladder was installed at Electron Dam in 2000. Therefore, coho production below the Puyallup and White confluence was estimated to be 6,694 smolts based on a rate of 10% of potential production applied to the 66,943 potential smolts for the lower Puyallup (Zillges 1977).

Coho production from the White River was estimated to be 187,050 smolts. This estimate is the number of females passed above Buckley Dam in 2008 (7,482/2 = 3,741) multiplied by 50 smolts per female. Fifty smolts per female represent a relatively high survival that might be expected in system where escapement is limiting freshwater production (Figure 1).

Nisqually River

A total of 225,000 coho smolts are estimated to have emigrated from the Nisqually River in 2010 (Table 1). Production was estimated based on measured production above a main-stem trap (river mile 12) and expanded production for non-trapped portions of the watershed. The main-stem trap was calibrated using recaptures of marked wild coho that are released upstream of the trap. Production was calculated with a Bailey estimator (Seber 1973, Volkhardt et al. 2007).

Wild coho production above the trap (river mile 12) was estimated to be 176,577 smolts, 153% of the 115,554 smolt potential predicted by Zillges (1977). Production below the trap was estimated to be 48,353, which is 153% of the potential production predicted for this portion of the watershed (Zillges 1977). Total watershed production was the sum of these two estimates (176,577 + 48,353 = 224,930). Of note, the 2009 and 2010 production level have been 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 5,000 coho smolts are estimated to have emigrated from the Deschutes River in 2010 (Table 1), representing 2.3% of the production potential estimated by Zillges (1977). This estimate is based on catch of coho smolts in a juvenile trap operated below Tumwater Falls. A catch of 1,258 smolts was expanded by a trap efficiency of 24.7%.

At present, production of coho smolts in the Deschutes River is primarily limited by escapement (Figure 8). Coho escapement in the Deschutes River has become severely depressed over the past two decades. Two of the three brood lines are virtually extinct, and the 2008 brood is one of the two severely depressed brood lines. 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. While adult coho returning between 1980 and 1990 experienced an average marine survival of 22.3%, adult coho returning between 1991 and 2010 experienced an average marine survival of just 7.2%.

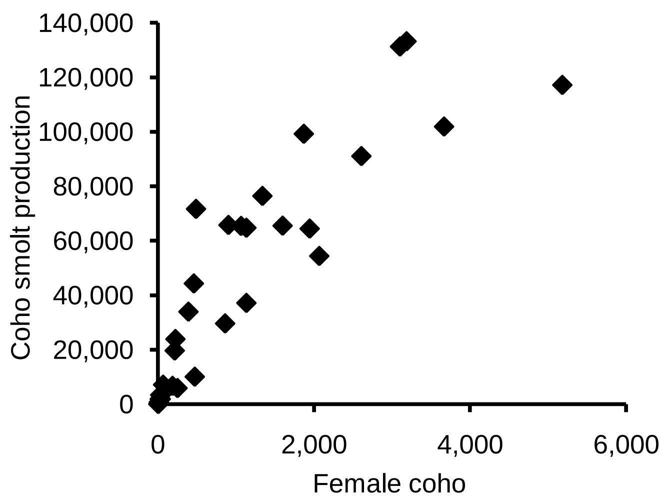

Figure 8. Spawner-juvenile recruit data for Deschutes River coho, brood year 1978-2008.

South Sound

A total of 57,000 coho smolts are estimated to have emigrated from South Sound tributaries in 2010 (Table 1). This estimate was based on results of juvenile monitoring studies in representative creeks in the southern extent of this management unit (Cranberry, Mill, Goldsborough, and Sherwood creeks). In 2010, the Squaxin Island Tribe conducted juvenile trapping studies in Cranberry Creek (*n* = 1,469), Skookum Creek (*n* = 166), Goldsborough Creek (*n* = 13,028), and Sherwood Creek (*n* = 3,717, Joseph Peters, Natural Resources Department, Squaxin Island Tribe, personal communication). This production represented just 9.7% of the 189,087 smolt potential that Zillges (1977) predicted for these watersheds. Coho production for the entire South Sound management unit was estimated to be 57,000 smolts based on 10% of the 573,770 smolt potential for all watersheds in this management unit (including production above Minter hatchery rack) predicted by Zillges (1977).

East Kitsap

A total of 54,000 coho smolts are estimated to have emigrated from East Kitsap tributaries in 2010 (Table 1). This estimate was based on an expansion of measured production in a single East Kitsap tributary. In 2010, Steele Creek coho production was measured with fence weirs operated on the North and South Forks of the creek. A total of 391 and 1,395 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) and represented 43.1% of the 4,140 smolt potential for this creek (Zillges 1977). The efforts to restore coho habitat in Steele Creek are comparable to some but certainly not all watersheds in the East Kitsap management unit. Therefore, freshwater survival of coho in Steele Creek was assumed to be above average when compared with other East Kitsap watersheds. Based on these results, a rate of 35% was applied to the 154,973 smolt potential predicted for the entire East Kitsap management unit (Zillges 1977). Total coho production for all East Kitsap tributaries was estimated to be 54,000 smolts in 2010.

Coastal Systems Smolt Production

Approach

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

In 2010, the WSPE unit measured wild coho production in the Chehalis River watershed. Smolt production from the Queets management unit was available due to juvenile monitoring conducted by the Quinault Tribe. Historical smolt abundance data was also available from the Dickey and Bogachiel rivers in the Quillayute watershed. In coastal watersheds where production was not estimated in 2010, wild coho production was estimated by applying a production rate (smolts/mi^2) to the entire drainage area of the watershed (drainage areas in Appendix B). Among the factors considered when applying a production rate to each watershed were baseline data (historical production estimates), watershed gradient, harvest impacts, and habitat condition.

Table 3. Wild coho smolt production and production per unit drainage area (smolts/mi^2) measured for coastal Washington watersheds. Clearwater and Queets data were provided by the Quinault Tribe.

		Coho smolt production			Production/mi^2		
Watershed	Number Years	Average	Low	High	Average	Low	High
Dickey (Quillayute)	3	71,189	61,717	77,554	818.3	709.4	891.4
Bogachiel (Quillayute)	3	53,751	48,962	61,580	416.7	379.6	477.4
Clearwater (Queets)	30	67,353	27,314	101,820	481.1	195.1	727.3
Queets (no Clearwater)	9	238,473	147,313	355,000	529.9	327.4	788.9
Chehalis (Grays Harbor)	27	1,927,116	502,918	3,592,275	911.6	237.9	1,699.3

Queets River

A total of 238,000 wild coho smolts are estimated to have emigrated from the entire Queets watershed in 2010 (Table 1). This estimate was based on coho production measured in the Queets River, by the Quinault Tribe (Tyler Jurasin, Quinault Tribe, personal communication) and includes production from the Clearwater River. The 2010 coho production from the Clearwater River, a sub basin of the Queets system, was 90,737 smolts or 648 smolts/mi^2 (Tyler Jurasin, Quinault Tribe, personal communication). If this production is subtracted from the total Queets coho smolt abundance, the production rate for the Queets River (excluding the Clearwater) was 327 smolts/mi^2. The 2010 production from the entire basin was the lowest estimated for the past 10 years (Table 3).

Quillayute River

A total of 442,000 coho smolts are estimated to have emigrated from the Quillayute River system in 2010 (Table 1). This estimate is based on historical measures of smolt production in two sub-basins of the Quillayute River and a comparison of production rates in these sub-basins and the Clearwater drainage, where smolt production was measured in 2010.

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

Results from the Dickey and Bogachiel monitoring were used to estimate an average production of 306,000 coho smolts for the entire Quillayute watershed (Seiler 1996). The watershed average was based on estimated production above and below the Dickey River trap summed with coho production the remainder of the basin. Average production for the entire Dickey River sub-basin was estimated by applying the production rate above the trap (818 smolts/mi^2) to the total drainage area (108 mi^2), resulting in 88,344 smolts. Average production for the Quillayute system outside the Dickey River was estimated by applying the production rate above the Bogachiel trap (417 smolts/mi^2) to the 521 mi^2 of the Quillayute watershed (excluding the Dickey River sub-basin), resulting in 217,257 smolts. The sum of these estimates is 306,000 smolts.

The 2010 Quillayute coho production was based on previously measured production of this system adjusted by the ratio of current to previous measured production from the Clearwater River (Queets basin). Because of the differences in production per unit area in the Dickey and Bogachiel rivers, the two regions of the watershed were estimated separately. The 2010 coho production in the Dickey River was estimated to be 131,633 smolts (1.49*88,344 smolts). The 1.49 expansion factor was the ratio of Clearwater production in 2010 (90,737 smolts) to average Clearwater production in 1992-1994 (90,737/61,000 = 1.49). The 2010 coho production in the Quillayute (excluding the Dickey) was estimated to be 310,678 smolts (1.43*217,257 smolts). The 1.43 expansion factor was the ratio of Clearwater coho smolt production in 2010 to average Clearwater smolt production in 1987, 1988, and 1990 (90,737/63,333 = 1.43). The total 2010 coho production of 442,000 smolts was the sum of these estimates (131,633 + 310,678).

Hoh River

A total of 194,000 wild coho smolts are estimated to have emigrated from the Hoh River in 2010 (Table 1). Smolt production was not directly measured in this watershed; therefore the estimate was based on production rate of the Clearwater system. The Hoh and Clearwater watersheds have similar watershed characteristics as well as regional proximity. The production rate of 648 smolts/mi^2 from the Clearwater was applied to the 299-mi^2 of the Hoh watershed and resulted in an estimated 194,000 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 2010 (Table 1). Smolt production was not directly measured in this watershed; therefore, the estimate was based on production rate of the Clearwater system. When compared with the Clearwater, coho production rates in the Quinault River are likely limited by additional factors such as high harvest rates (i.e., low escapement) and degraded habitat. In 2010, a production rate of 500 smolts/mi^2 was applied to the 434-mi^2 Quinault River system, resulting in an estimated 217,000 smolts.

Independent Tributaries

A total of 254,000 wild coho smolts are estimated to have emigrated from the independent tributaries of Coastal Washington (Table 1). Coho smolt production has not been directly measured in any of the coastal tributaries. In 2010, an average production rate of 600 smolts/mi^2 was applied to the total watershed area (424 mi^2; Appendix C), resulting in an estimated 254,000 smolts.

Grays Harbor

A total of 2,267,000 coho smolts are predicted to have emigrated from the Grays Harbor system in 2010 (Table 1). This estimate was derived in two steps. Wild coho production was first estimated for the Chehalis River. Production per unit drainage area of the Chehalis River system was then applied to the southern (Hoquaim, Johns, and Elk rivers) and northern (Humptulips) tributaries to Grays Harbor.

Coho smolt production in the Chehalis River is estimated using a back-calculation method. Smolts are coded-wire tagged and released from a juvenile trap on the Chehalis main stem (RM 52) and in Bingham Creek (right bank tributary to the East Fork Satsop River at RM 17.4). This tag group was expanded to a basin-wide production based on the recapture of tagged and untagged wild coho in the Grays Harbor terminal fishery. Coded-wire tag recoveries in this fishery are processed and reported by the Quinault Tribe (Jim Jorgeson, Quinault Tribe, personal communication). Smolt production was estimated after adults have passed through the fishery and returned to the river. Between 1980 brood and present, wild coho production in the Chehalis River has ranged from 503,000 to 3.6 million smolts.

An alternative approach to estimating Chehalis coho production is used for forecasting purposes because abundance from the back-calculation method is not available in the year that coho recruit into the fishery. Historically, there was a strong predictive relationship between minimum spawning flows and coho smolt production in the Chehalis watershed (Seiler 1996). However, the predictive nature of this relationship has degraded over time and led to inaccurate prediction of smolt production in some years. For example, in 2009, actual production (2,723,180 smolts) was 161% of the production predicted (1,693,985 smolts) from spawning flows. Errors in predicted smolt production were due, in part, to variation in flow-production relationship under lower and moderate spawning flows (Zimmerman 2010).

In order to predict the 2010 smolt production, four variables were examined for their predictive value. Variables were maximum and minimum spawning flows (November 1 to December 15), maximum incubation flow (December 15 to March 1), and minimum summer rearing flows (minimum of 60-day average, March 1 to November 1). The analysis was limited to a 10 year data set (smolt year 2000 to 2009) in order to minimize temporal changes in land use or watershed condition while using a data set with enough variation that patterns could be identified. Over the past decade, Chehalis smolt production was negative correlated with maximum incubation flow and positive correlated with summer low flows (high flow = more smolts, Figure 9). A multiple regression including both incubation and rearing flows did not improve the ability to predict smolt production. Furthermore, minimum or maximum spawning flows did not explain variation in smolt production over the ten year data set.

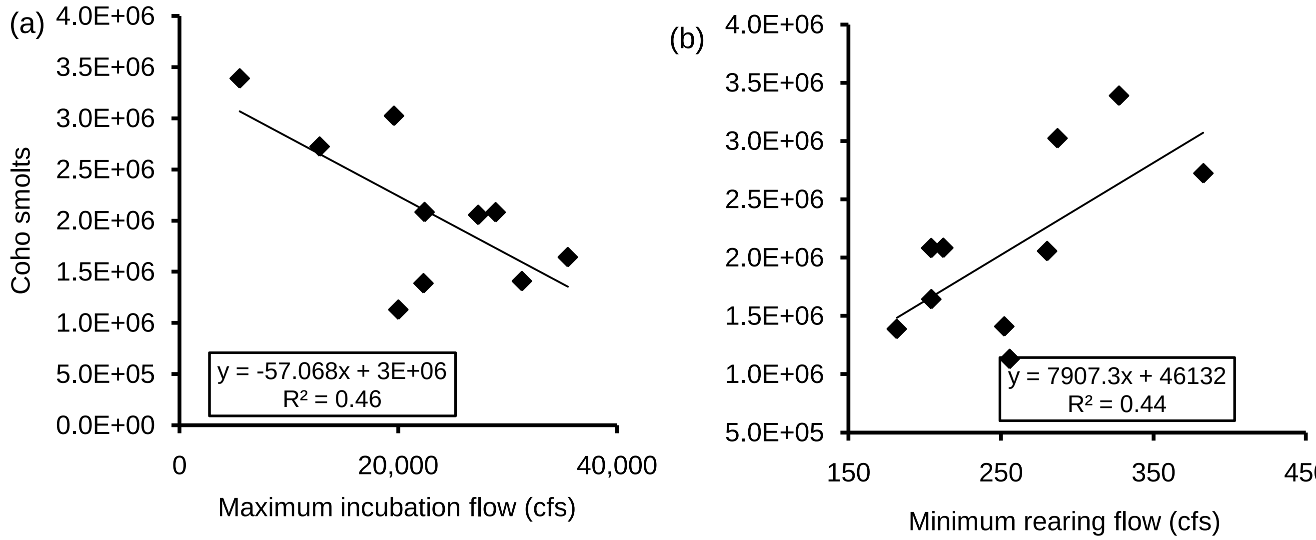

Figure 9. Chehalis River coho smolts as a function of incubation flows (*a*) and rearing flows (*b*), migration year 2000 to 2009. Incubation flows were the maximum daily mean flow at the Grand Mount USGS gage (#12027500) between December 15 and March 1. Rearing flows were the minimum 60-day average flows at the Grand Mound gage between March 1 and November 1.

Based on the minimum 60-day average summer flow of 232 cfs, coho smolt production for the Chehalis basin was predicted to be 1,880,626 (7907.3 * 232 + 46,132) and is the smolt abundance used in this forecast. Smolt production from the incubation flow relationship was predicted to be 625,971 (-57.068 * 41,600 + 3E+06) but was considered questionable and not used in this forecast. The 2010 smolts experienced the highest incubation flows (41,000 cfs at Grand Mound on January 9, 2009) in the past decade. These flows were outside the range of the derived correlation. Furthermore, peak incubation flows of 35,500 cfs at Grand Mound in January 2006 resulted in smolt production of 1.6 million in 2008. Therefore, the correlation between incubation flow and smolt production was not used to estimate the 2010 smolt production, but this relationship will continue to be evaluated in subsequent years.

Coho production for other portions of the Grays Harbor management unit was estimated from the production per unit area for the Chehalis River basin. Production per unit area for the Chehalis basin including the Wishkah River was 889 smolts/mi^2 (1,880,626 smolts per 2,114 mi^2). A total of 2,045,000 coho smolts are estimated for the entire Chehalis Basin (2,300-mi^2, including the Hoquiam, Johns, and Elk Rivers and other south side tributaries below the terminal fishery). Coho production from the Humptulips River was estimated to be 222,000 smolts (889 smolts/mi^2*250 mi^2). After summing production estimated for all watersheds in the Grays Harbor management unit, total wild coho production was estimated to be 2,267,000 smolts (2,045,000 + 222,000).

Willapa Bay

A total of 510,000 coho smolts are estimated to have emigrated from the Willapa Bay basin in 2010 (Table 1). As production was not directly measured, this estimate is based on production per unit area of the Chehalis Basin. The Willapa Basin consists of four main river systems and a number of smaller tributaries. Willapa Bay has a presumed high harvest rates (limiting escapement) and a somewhat degraded freshwater habitat. Given these impacts, wild coho production per unit area is likely to be somewhat lower than observed in the Chehalis Basin. Wild coho production in 2010 (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 549,800 natural-origin coho smolts are estimated to have emigrated from the Lower Columbia region in 2010 (Table 1). Derivation of this estimate was prepared by Dan Rawding of WDFW and is provided in Appendix C.

Marine Survival

Approach

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

Marine survival has ranged twenty-fold among the years of study. Differences in marine survival are dramatic among years and differ among regions, a result consistent with that reported from broader examinations of coho survival in the Pacific (Coronado and Hilborn 1998). Marine survival from previous years has been an inconsistent predictor for future marine survival and for marine survival in more distant regions. However, a correlation between jack return rates and adult (age-3) marine survival provides one way to predict future age-3 marine survival. The correlations between jack and adult returns observed at the WSPE long-term monitoring stations suggest that conditions in the first few months of ocean entry are an important bottleneck to overall coho survival. Multiple studies have demonstrated predictive correlations between ocean conditions (e.g., sea surface temperature, upwelling, spring transition timing) and coho marine survival (Nickelson 1986, Ryding and Skalski 1999, Logerwell et al. 2003) and have suggested that early ocean survival is an important determinant of overall survival in the marine life stage (Quinn et al. 2005).

Jack returns represent the composite of variables impacting early survival in the marine environment assuming that early marine survival remains the driver of overall return rates. While this assumption has been moderately supported by results from the WSPE monitoring stations, there are years when jack returns have had very poor predictive capacity and periods when the ratio of jack:adult returns change without a clear explanation. In the preparation for this forecast, this uncertainty was further addressed by examining the relationships between major ocean indicators (i.e., PDO, upwelling, spring transition) and marine survival. When significant correlations existed, predicted age-3 marine survival was compared between the ocean indicator and jack return approach. In Puget Sound, marine survival predicted for Big Beef Creek (Hood Canal) was applied to Puget Sound watersheds after considering relative differences among monitoring stations. In coastal Washington and Lower Columbia, marine survival predicted for Bingham Creek (Grays Harbor basin) was 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 be representative of the different Puget Sound regions. In Big Beef Creek (Hood Canal), marine survival has varied more than ten-fold (3 to 32%) between brood years 1975-2006. The 2010 returns to Big Beef may set an all time low survival rate once coded-wire tags are processed from all fisheries. 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, historical average production (276,000 smolts), and the assumption that escapement has been 85% of the total run (1995-present). In the Baker River (Skagit River, northern Whidbey Basin), marine survival of coho smolts has ranged between 1% and 14% over seventeen brood years (1989-1997, 2003-2007). In the Deschutes River (South Sound), marine survival has ranged between 2% and 29% between brood years 1977 to 2007.

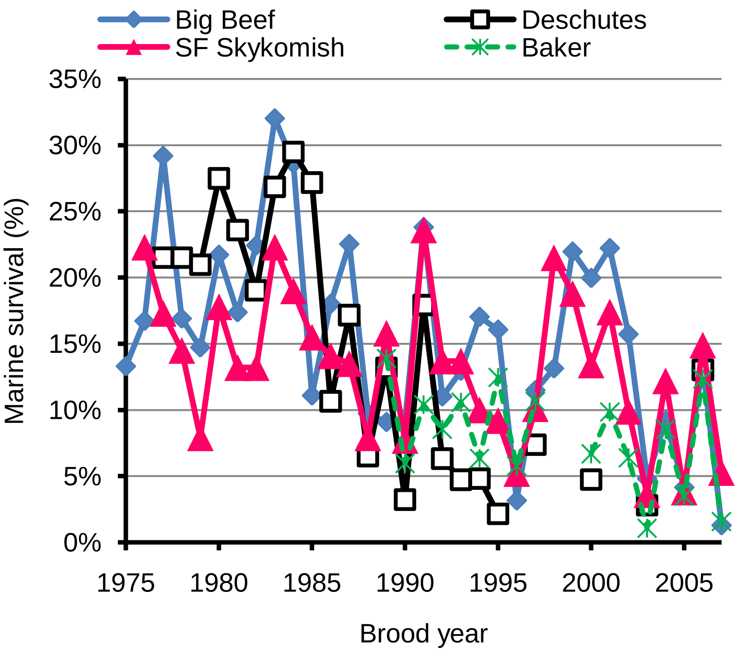

Figure 10. Marine survival of wild coho at monitoring stations in Puget Sound between 1975 and 2007 brood years

Marine survival of Puget Sound coho has declined since the long-term studies began in the late 1970s (Figure 10). This decline was most dramatic in South Sound (Deschutes River stock), but observed in all locations by the mid-1990s. Marine survival estimates for the 2003-2006 brood years tracked closely among the four populations. The 2010 forecast predicted that marine survival of Puget Sound coho would be between 2% and 5%. Preliminary marine survival estimates for the 2010 returns range between 1.3% and 5.3%. These preliminary estimates represent a lower bound to marine survival as a portion of tag recoveries from the 2010 fishery are not yet reported in RMIS. Regardless, marine survival of Puget Sound coho in the 2007 brood year is among the lowest observed over the past 30 years.

Marine survival of the Puget Sound coho populations was not correlated with metrics of ocean conditions including Pacific Decadal Oscillation (PDO) values, cumulative upwelling (Bakun index values), or spring transition dates. The absence of a relationship between these values and Puget Sound survival may be explained if environmental conditions within the sound itself are the primary factors driving levels of marine survival. For example, acoustic studies with Hood Canal steelhead smolts have demonstrated that survival from Hood Canal entry to the Strait of Juan de Fuca may be as low as 23% in this species (Moore et al. 2010). If this rate of mortality also occurs with coho, this would be a notable bottleneck to marine survival. Marine survival of Big Beef coho (Hood Canal) was correlated with jack return rates (Figure 11). Between 1977 and 1996, the ratio of adult:jack return rates averaged 11.3 (range = 6 to 18) and was remarkably consistent among years. During these years, 78% 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 increased (average = 26.8). During this period, jack return rates explain 70% of the variation in marine survival of Big Beef coho.

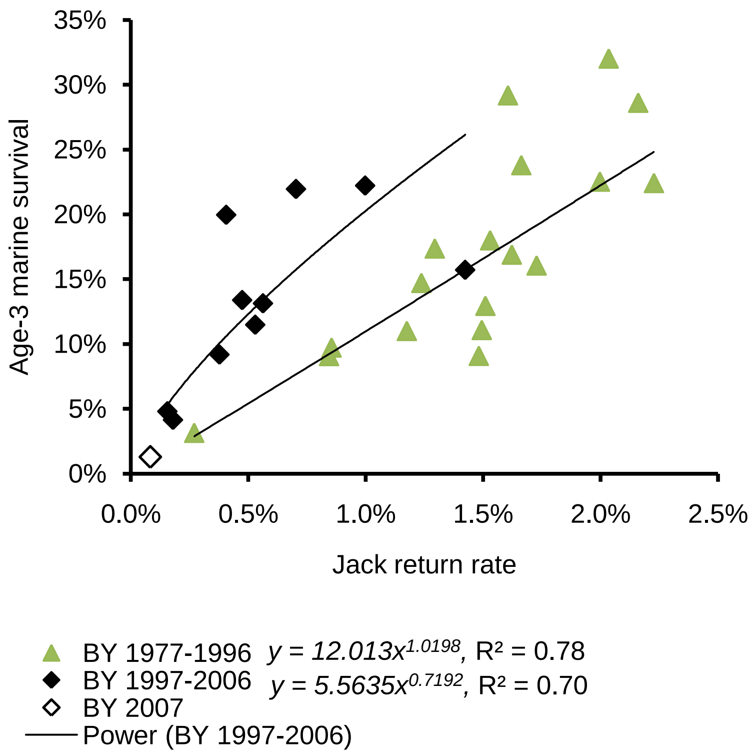

Figure 11. Marine survival of wild coho as a function of jack return rates at Big Beef Creek. Survival was estimated from coded-wire tag recoveries. Data are divided into two periods (1977-1996 and 1997-2006). Brood year 2007 results are held separately because CWT recovery data is not yet finalized.

In the fall of 2010, 177 tagged wild jacks (estimated) returned to Big Beef Creek from the adjusted tag group of 17,248 coho smolts released in spring of 2010 (tag group was adjusted for mortality and tag retention as described in approach). Marine survival of the 2011 return (2008 brood) is predicted to be 20.7% based on the jack return rate of 1.0% (Table 1). This rate was applied to the entire Hood Canal management unit.

Marine survival has differed among Puget Sound populations, and the relative differences among populations have changed over time (Figure 10). In the 1980s, marine survival was highest in the Deschutes River and lowest in the South Fork Skykomish populations. Over the past two decades, marine survival has been highest in the South Fork Skykomish and Big Beef Creek populations. These differences were numerically represented by comparing Baker, South Fork Skykomish, and Deschutes survival to that of Big Beef wild coho at 5-year intervals (Figure 12). Marine survival for the 2011 return (2008 brood) in each management unit was estimated based on the monitored population used to represent that management unit, the relative survival of that population with respect to Big Beef coho (last 5 years), and the predicted marine survival for Big Beef Creek coho returning in 2011.

Marine survival of South Sound coho (Puyallup to Deschutes) was predicted to be 16.1% [(1 - 0.222) * 0.207]. Marine survival of coho in the main basin (East Kitsap, Green, Lake Washington) and Snohomish management units was predicted to be 19.6% [(1 - 0.053) * 0.207]. Marine survival in the Straits of Georgia and management units north of the Stillaguamish was predicted to be 13.7% [(1 - 0.3360 * 0.207)].

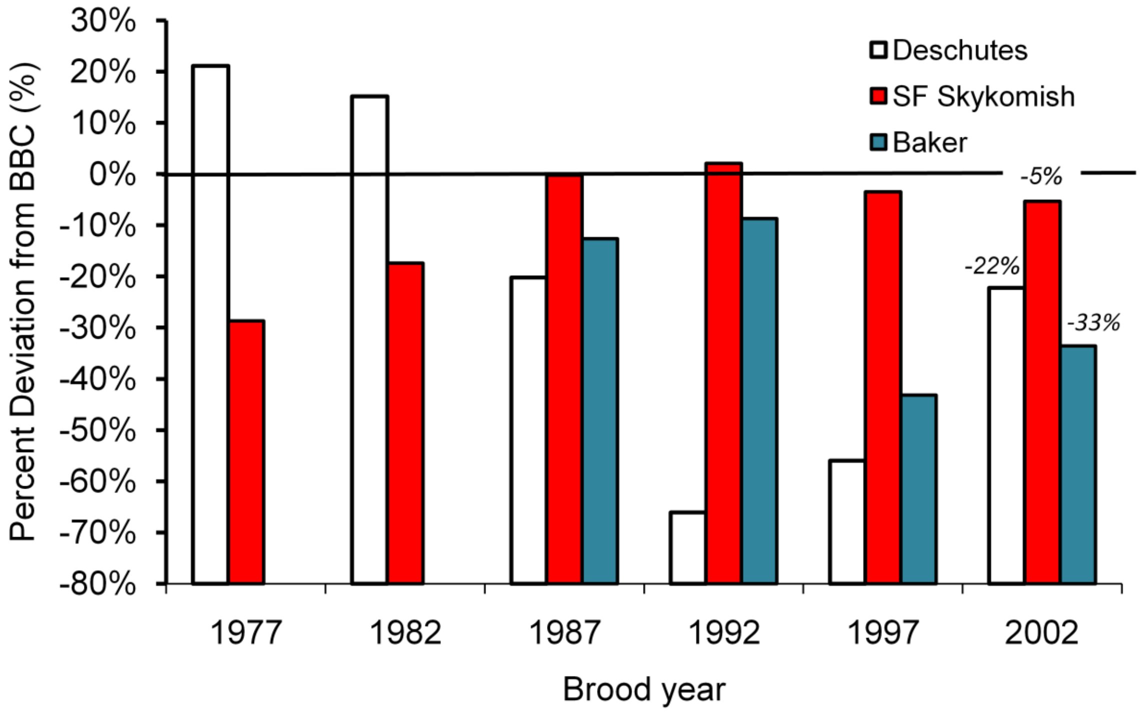

Figure 12. Marine survival of wild coho from Deschutes, South Fork Skykomish, and Baker rivers relative to Big Beef Creek. Relative difference is represented as the percent deviation of population *i* from BBC survival $(S_i - S_{BBC})/S_{BBC}$. Data are summarized by brood year in five year intervals (1977-1981, 1982-1986, 1987-1991, 1992-1996, 1997-2001, 2002-2006).

Coast

Marine survival of Bingham Creek wild coho has ranged from 0.6% to 11.6% between brood year 1980 and 2007. 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 13). Historically, different regression models were derived for each time period because marine survival predictions were biased 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.

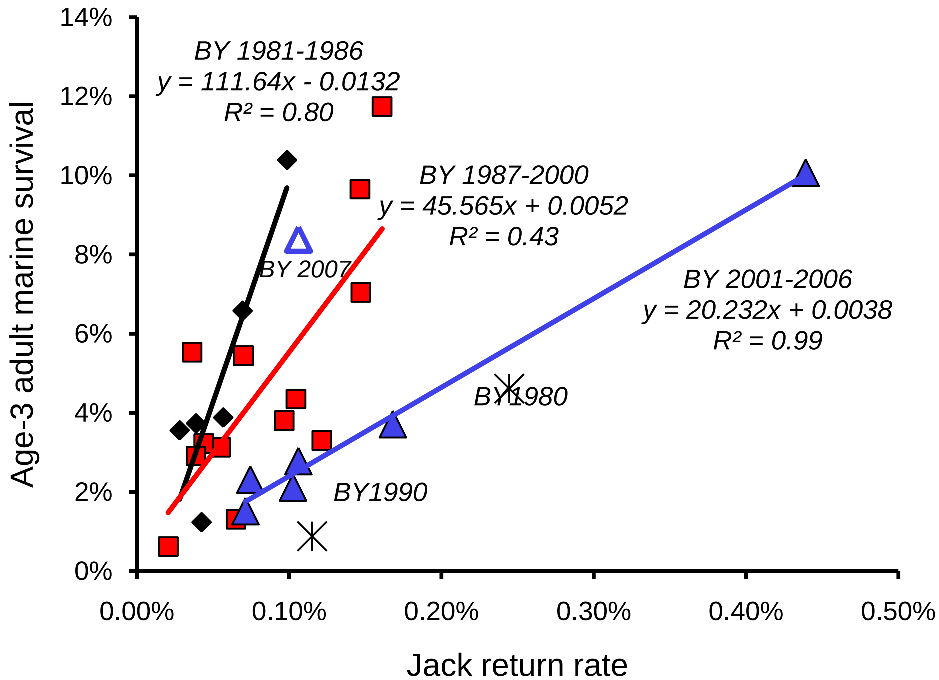

Figure 13. Adult marine survival as a function of jack return rate for Bingham Creek wild coho, brood year (BY) 1980-2007. Data are based on recoveries of coded-wire tagged wild coho. Three regression models have been fit to these data and reflect a shift in the predictive relationship over time. The 2010 return (BY 2007) did not fit the jack:adult relationship from the past five years. Brood year 1980 and 1990 were El Nino years and were treated as outliers.

The 2010 forecast predicted that marine survival of the 2007 brood year would be 2.61% (Zimmerman 2010). This prediction was based on the jack prediction model (2001-2006 brood years). However, the preliminary marine survival estimated for the 2010 return (2007 brood year) is 8.3%, much higher than predicted. This large deviation may reflect the uncertainties associated with predicting survival in an El Nino year (2009-2010) or may be the result of a shifting rati of jack to adult return rates. Therefore, the jack prediction model for Bingham Creek is once again of uncertain value for predicting future marine survival rates. A further complication to the jack-based approach is the high jack return rate in 2010. In fall of 2010, 137 tagged jacks are estimated to have returned to Bingham Creek, 0.54% of the adjusted tag group of 25,378 smolts. This return rate was greater than any other jack return to Bingham Creek since the 1980 brood year. Based on this return rate, the 2001-2006 regression model predicts that marine survival for the 2008 brood year (2011 return) will be 10.9% (20.232 * 0.54 + 0.0038). However, given the uncertainty that this model remains a good predictor and given the jack returns were outside the bounds of the current data set, an alternative approach was used as a second predictor of marine survival.

Marine survival of Bingham Creek coho was regressed on 3 different metrics representing ocean conditions. The first metric was the Pacific Decadal Oscillation Index (PDO), which is derived from sea surface temperatures in the North Pacific (Mantua et al. 1997). For analysis prupose, the PDO was averaged between May and September of the year than coho entered the ocean. The second metric was the Coastal Upwelling Index, which is based on the volume of water that upwells along the coast. For analysis purpose, cumulative upwelling was derived for the months of March to September in the year than coho entered the ocean (per Nickelson 1986). The third metric was the spring transition date, which is a measure of when the spring upwelling season begins and is based on the average upwelling indices for consecutive days and daily sea levels (Logerwell et al. 2003). All three of these metrics have been shown to influence coho marine survival, primarily with hatchery origin fish.

Of these three metrics, only PDO was significantly correlated with marine survival of Bingham Creek coho (Figure 14). A higher PDO index indicated warmer and less productive waters and was associated with lower marine survival. A negative logarithmic function (R^2 = 0.53) fit these data better than a linear function (R^2 = 0.41), indicating that the benefits to survival increase as the PDO becomes increasingly negative. Two outliers to this relationship occurred for brood years 1981 and 1993. Although these data are statistical outliers to the correlation, there is no clear biological reason why marine survival was higher than expected for these brood years. The average PDO index for the months of May to September 2010 was 0.71(data source: http://jisao.washington.edu/pdo/). Marine survival of the 2008 brood year (2011 return) is predicted to be 6.1% based on the PDO-marine survival correlation [-0.039 * ln (2.0 + 0.71) + 0.0707].

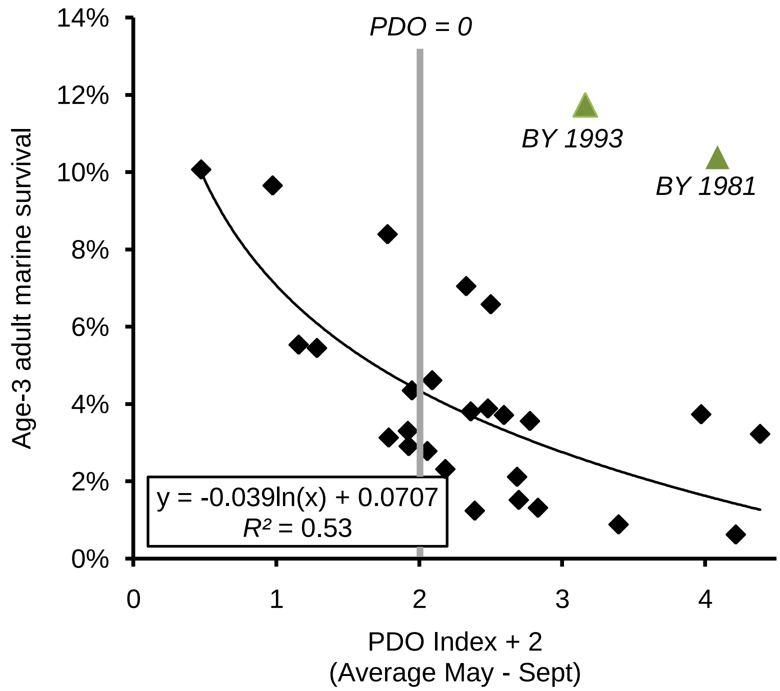

Figure 14. Marine survival as a function of the PDO index for Bingham Creek wild coho, brood years 1980-2006. The two outliers indicated (green triangles) were not included in the regression equation.

A marine survival of 8.5% was applied to the Grays Harbor, Humptulips, and Willapa Bay management units as well as independent tributaries in coastal Washington (Table 1). This rate was the average of the jack-based and the PDO models. A marine survival of 10% was applied to the Quinault, Queets, and Hoh rivers. A marine survival of 12% was applied to the Quillayute River. These upward adjustments for the northern coastal watersheds reflected the general trend of higher marine survival in the northern Washington coastal systems.

Lower Columbia River

Lacking any indicators for wild coho survival in the Lower Columbia River, an 8.5% 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, South Fork Nooksack gage (#12209000) was discontinued as of September 30, 2008. Therefore, an alternate Nooksack gage was selected (Nooksack at Ferndale, #12213100). Flows from the Ferndale gage were correlated with those on the South Fork Nooksack and the newly selected gage values were used to recalculate the PSSLFI for all previous years.

The PSSLFI is calculated each year and is the sum of flow indices from each of the eight gages. Flows corresponding to each brood year were averaged for 60 day intervals between March and November (i.e., coho summer rearing period). Low flow period typically occurs in late August or September. The watershed-specific flow index for a given year was the minimum 60-day average flow for that year divided by the long-term average of the 60-day minimums. This index was calculated based on flow data from 1963 to present. The PSSLFI was the sum of all eight watershed indices.

Based on flow data compiled between 1967 and 2009 (including alternate Nooksack gage), the PSSLFI has ranged between 4.4 and 12.7 with an average of 8.1. During this period, site-specific indices were closely correlated with each other supporting the concept that summer rearing flows are coordinated among Puget Sound basins. Summer low flows corresponding to the 2010 outmigration had an index value of 6.2 or 77% of the long-term average.

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

	Drainage area (mi^2)	
Watershed	Total	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 17, 2011

To: Mara Zimmerman

From: Dan Rawding

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

In 2010, 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, the Wind River near Little Wind River at RM 1, and Cedar Creek a tributary to the NF Lewis was monitored at RM (2). The Coweeman River, a tributary to the Cowlitz River, which was not monitored in 2009, was monitored again in 2010 near the stream gauge (RM 7.5). 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 Mill, Abernathy, and Germany trap sites in 2010 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, Coweeman River, and Cedar Creek, a pooled Petersen estimate was used to estimate seasonal trap efficiency and this was applied to the seasonal catch of smolts. At the Mayfield site, Paulik and Thompson (1967) estimated the collection efficiency for this site was 66.4% for coho salmon smolts. 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.

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.

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 95% 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 in miles 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 2010 otoliths have not been decoded, the mean natural origin proportion from 2004 to 2006 was applied to the 2010 outmigration estimate.

The natural origin coho salmon smolts in Cedar Creek were estimated to be 829 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, Tilton, and Upper Cowlitz watersheds had densities of 156, 336, and 208 smolts per square mile, respectively. Other watersheds with hatcheries had high levels of spawning escapement in 2008, 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 187,700 smolts (95% CI 169,700 – 224,100) 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 54 to a high of 387 smolts per square mile. The median density of smolts per square mile (185) 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 115,000 smolts (95% CI 107,100 - 124,100).

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 246,700 (95% CI 240,600 – 254,000). The total abundance estimate for the Washington portion of the LCR ESU is found in Table 2 and was estimated 549,800 smolts (95% CI 525,000 – 592,600).

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 to 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	10370	11230	12230	357.7	387.2	421.6
Abernathy	3074	3375	3742	106	116.4	129
Germany	1118	1240	1457	48.63	53.91	63.35
Grays	2365	4051	7539	90.95	155.8	289.9
Tilton	51030	53350	55930	320.9	335.6	351.8
Upper Cowlitz	205800	216200	227600	197.5	207.5	218.4
Coweeman	17320	21640	27490	145.6	181.9	231
Cedar	41570	43940	46470	784.3	829	876.9

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	169700	187700	224100	210.8	233.2	278.4
Unmonitored W_Streams	107100	115000	124100	172.8	185.4	200.2
Monitored Streams	240600	246700	254000			
Nat. Origin Smolt Prediction	525000	549800	592600			

References

Bradford, M.J., R.A. Meyers, J.R. Irvine. 2000. Reference points for coho salmon harvest rates and escapement goals based on freshwater production. Canadian Journal of Fisheries and Aquatic Sciences 57:677-686.

Paulik, G.J, and J.S. Thompson. 1967. An evaluation of louvers and bypass facilities for guiding seaward migrant salmonids past Mayfield Dam. Unpubl. ms., Wash. Dept. Fish. 150 p.

Schwarz, C. J., and C. G. Taylor. 1998. Use of the stratified- Petersen estimator in fisheries management: estimating the number of pink salmon (*Oncorhynchus gorbuscha*) spawners in the Fraser River. Canadian Journal of Fisheries and Aquatic Sciences 55:281-296.

Spiegelhalter, D., A Thomas, and N. Best. 2003. WinBUGS, Version 1.4. User Manual MRC and Imperial College of Science, Technology, and Medicine.

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			
Brood	Return	Creek	River[c]	SF Skykomish[b]	Baker River	Average
1975	1978	13.3%				13.3%
1976	1979	16.7%		22.3%		19.5%
1977	1980	29.2%	21.5%	17.3%		22.7%
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%	13.9%	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%		5.2%	5.8%	4.7%
1997	2000	11.5%	7.4%	10.1%	10.6%	9.9%
1998	2001	13.1%		21.5%		17.3%
1999	2002	22.0%		18.8%		20.4%
2000	2003	20.0%	4.7%	13.4%	6.7%	11.2%
2001	2004	22.2%		17.4%	9.9%	16.5%
2002	2005	15.7%		9.9%	6.4%	10.7%
2003	2006	4.8%	2.8%	3.6%	1.1%	3.1%
2004	2007	9.2%		12.2%	8.6%	10.0%
2005	2008	4.2%		3.8%	3.5%	3.8%
2006	2009	13.4%	13.0%	14.9%	12.3%	13.4%
2007[a]	2010	1.3%		5.3%	1.6%	2.7%
	Average	15.6%	14.4%	13.4%	7.9%	13.9%
	Min	1.3%	2.2%	3.6%	1.1%	2.7%
	Max	32.0%	29.5%	23.6%	13.9%	27.1%
	Count	33	23	32	17	33

[a]Brood year 2007 marine survival should be considered preliminary and a lower bound. Estimate will be finalized after expansions of all sampling data have been reported in RMIS.

[b]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.

[c]Marine survival of Dechutes coho is reported only for those years when smolt abundance was high enough to release a CWT tag group.

Citations

Blankenship, H. L. and P. R. Hanratty. 1990. Effects on survival of trapping and coded wire tagging coho salmon smolts. American Fisheries Society Symposium **7**:259-261.

Bradford, M. J., R. A. Meyers, and J. R. Irvine. 2000. Reference points for coho salmon harvest rates and escapement goals based on freshwater production. Canadian Journal of Fisheries and Aquatic Sciences **57**:677-686.

Chapman, D. W. 1965. Net production of juvenile coho salmon in three Oregon streams. Transactions of the American Fisheries Society **94**:40-52.

Coronado, C. and R. Hilborn. 1998. Spatial and temporal factors affecting survival in coho salmon (*Oncorhynchus kisutch*) in the Pacific northwest. Canadian Journal of Fisheries and Aquatic Sciences **55**:2067-2077.

HCJTC. 1994. Hood Canal natural coho MSH escapement estimate and escapement goals. Point No Point Treaty Council, Washington Department of Fish and Wildlife, U.S. Fish and Wildlife Service.

Kinsel, C., P. R. Hanratty, M. S. Zimmerman, B. Glaser, S. Gray, T. Hillson, D. Rawding, and S. Vanderploeg. 2009. Intensively Monitored Watersheds: 2008 fish population studies in the Hood Canal and Lower Columbia stream complexes. FPA 09-12, Washington Department of Fish and Wildlife, Olympia, Washington.

Kiyohara, K. and M. S. Zimmerman. In review. Evaluation of juvenile salmon production in 2010 from the Cedar River and Bear Creek. Washington Department of Fish and Wildlife, Olympia, Washington.

Lister, D. B. and C. E. Walker. 1966. The effect of flow control on freshwater survival of chum, coho, and chinook salmon in the Big Qualicum River. Canadian Fish Culturist **37**:3-25.

Logerwell, E. A., N. Mantua, P. W. Lawson, R. C. Francis, and V. N. Agostini. 2003. Tracking environmental processes in the coastal zone for understanding and predicting Oregon coho (*Oncorhynchus kisutch*) marine survival. Fisheries Oceanography **12**:554-568.

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific decadal climage oscillation with impacts on salmon. Bulletin of the American Metereological Society **78**:1069-1079.

Mathews, S. B. and F. W. Olson. 1980. Factors affecting Puget Sound coho salmon (*Oncorhynchus kisutch*) runs. Canadian Journal of Fisheries and Aquatic Sciences **37**:1373-1378.

Moore, M. E., B. A. Berejikian, and E. P. Texak. 2010. Early marine survival and behavior of steelhead smolts through Hood Canal and the Strait of Juan de Fuca. Transactions of the American Fisheries Society **139**:49-61.

Nickelson, T. E. 1986. Influences of upwelling, ocean temperature, and smolt abundance on marine survival of coho salmon (*Oncorhynus kisutch*) in the Oregon Production Area. Canadian Journal of Fisheries and Aquatic Sciences **43**:527-535.

Quinn, T. P., B. R. Dickerson, and L. A. Vollestad. 2005. Marine survival and distribution patterns of two Puget Sound hatchery populations of coho (*Oncorhynchus kisutch*) and chinook (*Oncorhynchus tshawytscha*) salmon. Fisheries Research **76**:209-220.

Quinn, T. P. and N. P. Peterson. 1996. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile coho salmon (*Oncorhynchus kisutch*) in Big Beef Creek, Washington. Canadian Journal of Fisheries and Aquatic Sciences **53**:1996.

Ryding, K. E. and J. R. Skalski. 1999. Multivariate regression relationships between ocean conditions and early marine survival of coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences **56**:2374-2384.

Seber, G. A. F. 1973. The estimation of animal abundance. Charles Griffin and Company Limited, London.

Seiler, D. E. 1984. Freshwater salmon production evaluate annual progress report. Dingell-Johnson Project F-73-R-3, Washington Department of Fisheries, Olympia, Washington.

Seiler, D. E. 1996. Statewide wild coho forecasts for 1996. Fish Science, Washington Department of Fish and Wildlife, Olympia, Washington.

Seiler, D. E. 1998. Statewide wild coho forecasts for 1998. Washington Department of Fish and Wildlife, Olympia, Washington.

Seiler, D. E. 1999. 1999 wild coho forecasts for Puget Sound and Washington coastal systems. Washington Department of Fish and Wildlife, Olympia, Washington.

Seiler, D. E. 2000. 2000 wild coho forecasts for Puget Sound and Washington coastal systems. Fish Science, Washington Department of Fish and Wildlife, Olympia, Washington.

Seiler, D. E., S. Neuhauser, and M. Ackley. 1984. Upstream/downstream salmonid trapping project, 1980-1982. Progress Report No. 200, Washington Department of Fisheries, Olympia, Washington.

Seiler, D. E., G. C. Volkhardt, and L. Kishimoto. 2002a. Evaluation of downstream migrant salmon production in 1999 and 2000 from three Lake Washington tributaries: Cedar River, Bear Creek, Issaquah Creek, FPA 02-07. Washington Department of Fish and Wildlife, Olympia, Washington.

Seiler, D. E., G. C. Volkhardt, L. Kishimoto, and P. Topping. 2002b. 2000 Green River Juvenile Salmonid Production Evaluation. Washington Department of Fish and Wildlife, Olympia, Washington.

Sharma, R. and R. Hilborn. 2001. Empirical relationships between watershed characteristics and coho salmon (*Oncorhynchus kisutch*) smolt abundance in 14 western Washington streams. Canadian Journal of Fisheries and Aquatic Sciences **58**:1453-1463.

Smoker, W. A. 1955. Effects of stream flow on silver salmon production in western Washington. Ph.D. dissertation, University of Washington, Seattle, Washington, 175 p.

Spiegehalter, D., A. Thomas, and N. Best. 2003. WinBUGS, Version 1.4 User Manual. MRC and Imperial College of Science, Technology and Medicine, London.

Topping, P. and M. S. Zimmerman. 2011. Green River juvenile salmonid production evaluation: 2009 and 2010 annual report, FPA 11-01. Washington Department of Fish and Wildlife, Olympia, Washington.

Volkhardt, G. C., S. L. Johnson, B. A. Miller, T. E. Nickelson, and D. E. Seiler. 2007. Rotary screw traps and inclined plane screen traps. Pages 235-266 *in* D. H. Johnson, B. M. Shrier, J. S. O'Neal, J. A. Knutzen, X. Augerot, T. A. O-Neil, and T. N. Pearsons, editors. Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.

Volkhardt, G. C., D. Rawding, L. Kihimoto, P. R. Hanratty, P. Topping, M. Ackley, C. Kinsel, K. Kiyohara, C. Sharpe, J. Serl, J. Henning, and J. Holowatz. 2008. 2008 wild coho forecasts for Puget Sound, the Washington Coast, and Lower Columbia. Fish Science, Washington Department of Fish and Wildlife, Olympia, Washington.

Volkhardt, G. C. and D. E. Seiler. 2001. Revised forecast analysis for the WDFW and Conrad forecast models. Memo to the Hood Canal Forecast Review Group, October 22, 2001.

Williams, R. W., R. M. Laramie, and J. J. Ames. 1975. A catalog of Washington streams and salmon utilization, Vol. 1, Puget Sound Region. Washington Department of Fisheries, Olympia, Washington.

Zillges, G. 1977. Methodology for determining Puget Sound coho escapement goals, escapement estimates, 1977 pre-season run size prediction and in-season run assessment., Technical Report No. 28, Washington Department of Fisheries, Olympia, Washington.

Zimmerman, M. S. 2010. 2010 wild coho forecasts for Puget Sound, Washington Coast, and Lower Columbia. Washington Department of Fish and Wildlife, Olympia, Washington.