2006 Wild Coho Forecasts for Puget Sound & Washington Coastal Systems

Washington Department of Fish & Wildlife
Science Division
by
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Introduction

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

Various approaches have been used across this state's coho producing systems to predict ocean recruits. In the past, many of these methods have relied on the relationship between adult escapement estimates and resultant run sizes. Reconstructing coho run sizes, however, is notably difficult due to the problems of accurately estimating escapements and the inability to allocate catches in intercepting fisheries by stock. Even if the run size databases were reasonably accurate, in systems that are adequately seeded, coho forecasts based solely on estimated escapement have no predictive value. Such forecasts do not account for the two primary and independent components of inter-annual variation in run size, freshwater and marine survival. Moreover, because adult-to-adult forecasts combine these two parameters, understanding the components of error in such forecasts post-season are precluded. Improving our ability to manage wild coho runs depends on learning which factors cause significant variation in abundance for each major system.

Smolts are the measure of freshwater production. In recognition of this, natural coho escapement goals throughout this state are based on the projected smolt carrying capacity of each system. To assess these goals and to improve run forecasts, WDFW and tribes have made substantial investments in monitoring smolt populations in a number of basins. These data have been incorporated into some forecasts, but, until recently, have not been used on a consistent basis or in all systems.

Marine survival rates for wild coho stocks have also been measured over many years at several stations in Puget Sound and at one station in the Grays Harbor system. These data describe the patterns of inter-annual and inter-system variation in survival within broods. Given the extreme difficulty in estimating coho escapements with survey-based approaches, only those tag groups returning to trapping structures with 100% capture capability throughout all flows estimate survival-to-return without bias.

Adult recruits are the product of smolt production and marine survival. Therefore, any estimate of adult recruits can be expressed in a simple matrix as combinations of these two components. Through a process of comparing the outcomes for each term relative to measured and or likely values, the veracity of forecasts derived from methodologies not employing smolt and marine survival estimates can be assessed. Understanding variation in hatchery runs, for example, is reduced

to analyzing the components of post-release survival because the number of smolts released, the starting population, is known.

Fisheries have been managed to achieve escapement goals for natural/wild coho stocks returning to eight production areas. These systems include: Skagit, Stillaguamish/Snohomish, Hood Canal, Straits, Quillayute, Hoh, Queets, and Grays Harbor. While the forecasts to these systems, considered the "primary" wild coho management units, have been used to determine the extent and shape of fisheries, management objectives for other areas are also under discussion. Production from these other freshwater habitat units can also be approximated by extrapolating measured smolt production and marine survival rates. Expressing natural coho production in the common terms of smolts will enable useful inter-annual comparisons within systems and annual comparisons across systems. This approach will also promote better understanding by stakeholders as it more directly connects coho production with habitat.

The Wild Salmon Production Evaluation (WSPE) Unit within the WDFW Fish Program Science Division has developed naturally produced coho run-size forecasts for the last eleven years. Presented in Table 1 are the forecasts of wild coho run size derived by combining estimates of natural smolt production and predictions of marine survival for all Puget Sound, Coastal, and Lower Columbia River stream systems. The resulting estimates of three-year old ocean recruits were adjusted to estimate the population in terms of December age-2 and January age-3 recruits to provide the appropriate coho management model inputs. The following sections detail each estimate of smolt production and marine survival.

Table 1: Wild coho run forecasts for 2006, based on estimates of smolt production and marine survival.

Production Unit	PRODUCTION X Estimated Smolt Production: Spr '05	MARINE SURVIVAL Adults (Age 3)	MARINE SURVIVAL Dec. (Age 2)	= RECRUITS Adults (Age 3)	RECRUITS Dec. (Age 2)	RECRUITS Jan. (Age 3)
Puget Sound						
Primary Units						
Skagit River	1,018,000	8.0%	10.7%	81,400	108,600	100,350
Stillaguamish River	396,000	9.0%	12.0%	35,600	47,500	43,890
Snohomish River	1,100,000	10.0%	13.3%	110,000	146,600	135,460
Hood Canal	707,000	6.5%	8.7%	46,000	61,300	56,640
Straits of Juan de Fuca	**see note below**					
Secondary Units						
Nooksack River	113,000	8.0%	10.7%	9,000	12,100	11,180
Strait of Georgia	16,000	8.0%	10.7%	1,300	1,700	1,570
Samish River	100,000	8.0%	10.7%	8,000	10,700	9,890
Lake Washington	110,000	9.0%	12.0%	9,900	13,200	12,200
Green River	153,000	9.0%	12.0%	13,800	18,400	17,000
Puyallup River	90,000	6.0%	8.0%	5,400	7,200	6,650
Nisqually River	60,000	3.0%	4.0%	1,800	2,400	2,220
Deschutes River	70,800	2.5%	3.3%	1,770	2,359	2,180
South Sound	172,000	3.0%	4.0%	5,200	6,900	6,380
East Kitsap	93,000	8.0%	10.7%	7,400	9,900	9,150
Puget Sound Total	4,198,800			336,570	448,859	414,760
Coast						
Queets River	294,000	3.8%	5.1%	11,172	14,892	13,760
Quillayute River	412,000	3.8%	5.1%	15,656	20,869	19,280
Hoh River	183,000	3.8%	5.1%	6,954	9,270	8,570
Quinault River	217,000	3.8%	5.1%	8,246	10,992	10,160
Independent Tributaries	212,000	3.8%	5.1%	8,056	10,739	9,920
Grays Harbor						
Chehalis River	2,152,000	3.8%	5.1%	81,776	109,007	100,720
Humptulips River	234,000	3.8%	5.1%	8,892	11,853	10,950
Willapa Bay	595,000	3.8%	5.1%	22,610	30,139	27,850
Coastal Systems Total	4,299,000			163,362	217,761	201,210
Lower Columbia Total	1,088,000	3.8%	5.1%	41,344	55,112	50,920
GRAND TOTAL	9,585,800			541,276	721,732	666,890

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

Smolt Production

A substantial level of coho smolt production evaluation work has been conducted in each of the eight major natural production systems, except the Hoh. In the Skagit River, total smolt production has been estimated annually since 1990. We have also estimated total system smolt production from the Chehalis Basin, the largest watershed in the state accessible to anadromous fish outside of the Columbia River, annually since 1986. Beginning in the 1970s, smolt production has also been measured from substantial portions of the Snohomish, Stillaguamish, Hood Canal, Quillayute, and Queets systems and more recently, in tributaries to the Straits of Juan de Fuca and Lower Columbia River. In aggregate, this work has produced a body of information that describes wild coho carrying capacity, largely as a function of habitat quality and quantity. Seeding levels, environmental effects (flows), and human-caused habitat degradation explain much of the inter-system and inter-annual variations in smolt production that have been measured (Table 2).

Table 2: Summary of coho smolt production evaluations in ten Western Washington streams, and sources of inter-annual variation.

Stream	Number of Years	Watershed Area (mi^2)	SMOLT PRODUCTION				Average Prod/mi^2	Identified Sources of Variation (see key)
			Range		Ratio Hi/Lo	Avg Prod		
			Low	High				
Big Beef Creek	28	14	11,510	47,089	4.1	25,802	1,843	1,2,3,4,5
Bingham Creek	23	35	15,233	70,342	4.6	30,923	884	2,3
Deschutes River	27	160	892	133,198	149.3	53,484	334	1,2,4,5
SF Skykomish River	9	362	181,877	353,981	1.9	249,442	689	7
Dickey River[a]	3	87	61,717	77,554	1.3	71,189	818	6
Bogachiel River[a]	3	129	48,962	61,580	1.3	53,751	417	6
Clearwater River	24	140	27,314	99,354	3.6	65,589	468	1,4,5
Stillaguamish River	3	540	203,072	379,022	1.9	275,940	511	6
Skagit River[b]	16	1,918	617,600	1,884,700	3.1	1,084,819	566	1,2,3,8
Chehalis River	21	2,114	502,918	3,592,275	7.1	1,889,709	894	1,2,3,4
Total		5,469						
Mean							742	
Weighted Mean[c]							695	

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

Key

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

While annual smolt monitoring within each major system would be optimal, sufficient information exists to approximate production in systems currently unmeasured. Within Puget Sound, **WDF Technical Report 28** (T.R.28) (Zillges 1977) provides one means of transferring smolt production monitoring results to other basins. This document, which is the basis for most Puget Sound wild coho escapement goals, contains estimates of the wetted habitat at summer low flow, and projections of potential coho smolt production for each stream in Puget Sound (east of Cape Flattery). For coastal systems, smolt production in unstudied watersheds can be approximated by extrapolating the smolt production per square mile of drainage basin rates measured in the study streams.

Puget Sound Primary Units

Skagit River

In 2005, we estimated that 1,018,000 coho smolts emigrated from the Skagit River (Table 3). This estimate is based on trapping and marking wild coho in a tributary, and sampling emigrants captured in the lower mainstem river with floating scoop and screw traps. Skagit River coho smolt production has generally increased over the sixteen years that we have measured it, ranging from 618,000 to 1,885,000 smolts. Over these years, production has averaged 1,085,000 smolts, with even-numbered brood years producing 1.38 times as many smolts as odd-numbered years (1,259,000 vs. 910,000). We believe this pattern results from a positive interaction with adult pink salmon, which spawn primarily in odd years.

Table 3: Estimation of wild coho smolt production, Skagit River 2005.

	Number	Formula
Total mainstem trap catches	8,748	
Skagit Hatchery/Lake Shannon	-365	
Wild coho captured (c)	**8,383**	
LVs recaptured (r)	128	$N = \frac{(m+1)(c+1)}{(r+1)}$
LVs released (m)	15,655	
Total production (N)	**1,017,519**	
Variance (Var)	7.84E+09	$Var = \frac{(m+1)(c+1)(m-r)(c-r)}{(r+1)^2(r+1)}$
Standard Deviation (sd)	88,529	
Coefficient of Var (CV)	8.70%	CV = sd/N
Confindence Interval (CI)	173,516	CI = +/- 1.96(sd)
Estimated coho production		
Skagit River	1,017,519	
Upper CI (95%)	1,191,035	
Lower CI (95%)	844,003	

This odd year brood production is 12% above the odd-year brood average production of 910,388. A number of conditions lined up to benefit smolt production in 2005:

- Flows during Summer 2004 were higher than average, creating more summer rearing space. The Puget Sound Summer Low Flow Index (PSSLFI) registered a value of 10.3, nearly two points above the long-term average of 8.5, which has ranged from 4.5 to 13.5 over the previous 40 years.
- The two severe and sudden flood events in October 2003 that impacted the 2002 brood may have benefited the 2003 brood by providing sufficient flows for spawners to access and utilize spawning (and hence rearing) habitats further upstream than in most other years.
- Peak winter flows in 2003 (following the October events) and in 2004 were lower than the average peak flow event.

Stillaguamish River

We estimated smolt production from the Stillaguamish River upstream of R.M. 16 in three years (1981-1983). Production from these broods, which received sufficient spawners to attain carrying capacity, ranged from 203,000 to 379,000, and averaged 276,000 coho smolts. Expanding for the portion of projected smolt production (T.R.28) downstream of this point (23%), we estimated mean system production at 360,000 smolts. Considering the beneficial conditions (higher summer base

flows, good spawner distribution flows, and low peak flows during incubation) that occurred for the 2003 brood coho, we increased the mean system production by 10%, to estimate 396,000 smolts produced in 2005.

Snohomish River

We measured smolt production from known numbers of spawners in the South Fork Skykomish River over nine brood years (1976-1984) (Figure 1). This sub-basin comprises 20.7% of the Snohomish River system's drainage area. Excluding the three years in which we reduced escapement, production averaged 276,000 smolts. These estimates were generated using "back-calculation" — determining coded-wire tag ratios upon adult return. Consequently, they include production which reared downstream of Sunset Falls. Trapping-based estimates for these six broods indicate that around 75% of these estimated productions emigrated as smolts from above Sunset Falls. Adjusting the estimates by this rate yields an average production of 207,000 smolts that remained above Sunset Falls until spring. Expansion of this estimate to the entire system calculates an average total production of 1,000,000 coho smolts.

Although a significant portion (450 mi^2, 26%) of the 1,714 mi^2 Snohomish Basin is inaccessible to anadromous fish, which includes the Snoqualmie Basin above Snoqualmie Falls (375 mi^2) and the Sultan Basin above the dam (75 mi^2), the habitat above Sunset Falls is also fairly steep. Therefore, we assumed that applying the production rate derived above Sunset Falls to the entire basin is appropriate, considering that the more productive, lower-gradient habitat in the middle and lower reaches offset the inaccessible areas in the upper reaches.

To account for the combined effects of higher than average summer flows, good spawner distribution flows, and low peak incubation flows, we increased the average production by 10% to estimate 1,100,000 smolts were produced in the Snohomish Basin in 2005.

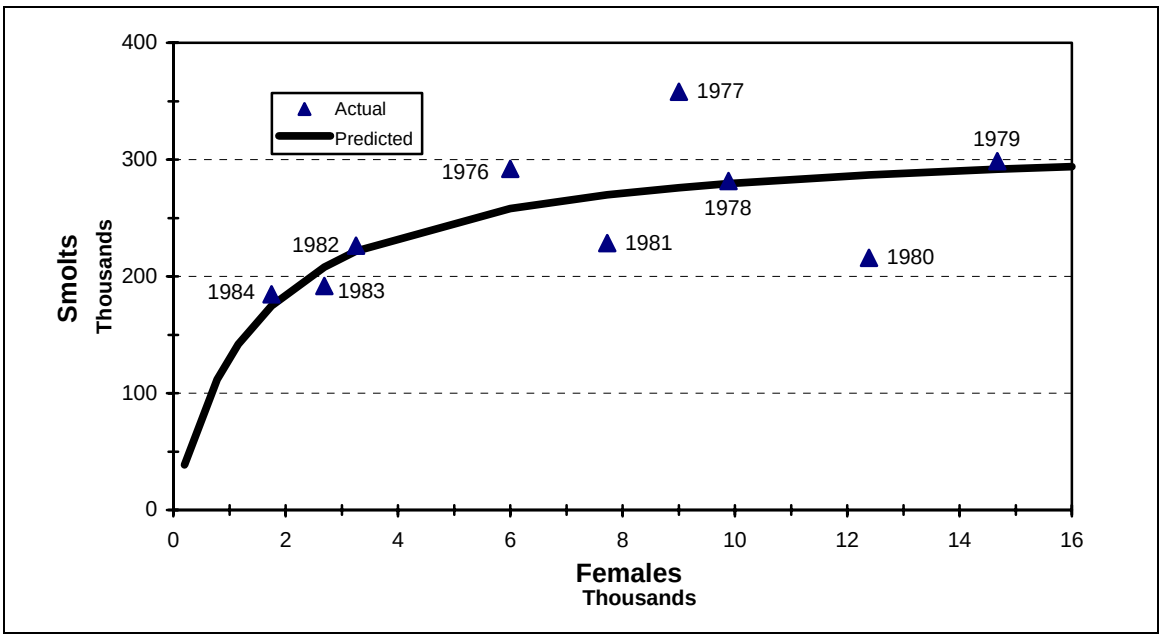

Figure 1: SF Skykomish River wild coho spawners and recruits, by brood year.

Hood Canal

In 2005 we continued trapping four streams on the east side of Hood Canal: Big Beef, Stavis, Seabeck, and Little Anderson Creeks. We have measured smolt production in Big Beef Creek each year since 1978 from known numbers of adult spawners. In 2005, Big Beef Creek produced 32,222 coho smolts from 2,147 females passed upstream in 2003, an average of 15 smolts per female. This production was 26% above the long-term average of 25,564 smolts. The adjacent streams (Stavis, Seabeck, and Little Anderson Creeks), which we have trapped since 1992, yielded 9,666, 2,620 and 1,969 coho smolts, respectively, which are record high productions measured for these three streams since trapping began in 1992 (Little Anderson Creek) and 1993 (Seabeck and Stavis Creeks). Combined, these productions are higher than the long-term average of the previous years by a factor of 181%.

The coho production potential of tributaries to Hood Canal was originally estimated at 1,006,577 smolts (T.R.28). A more recent review by the Hood Canal Joint Technical Committee (HCJTC) revised this estimate downward to 561,631 smolts. Both of these capacity estimates were predicated upon adequate seeding and average environmental conditions. These habitat-based projections estimate that the combined capacity of the four streams we trap account for 5.9% and 7.6% of Hood Canal's coho smolt production potential. Expanding the combined smolt populations from these four streams (46,477 smolts) with these rates projects production for the entire Hood Canal in 2005 at 788,000 and 612,000 coho smolts, based on the stream habitat estimated by T.R.28 and the HCJTC.

In previous years, we have selected one of these ratios to estimate total smolt production in Hood Canal. Beginning with the 1999 brood, however, we developed a new rate (4.56%) based on the HCJTC forecast review (Summer 2001), which compared predicted cohorts with those computed post-season via run reconstruction. This analysis estimated that expanding Big Beef Creek smolt production by a factor of 21.93 (1 ÷ 0.0456) best predicts Hood Canal production. Inherent in this analysis are two main assumptions:

(1) Marine survival as estimated with tagging Big Beef Creek wild coho represents survival for the entire Canal's production; and
(2) Run reconstruction accurately represents total Hood Canal recruits.

Expanding the 32,222 coho produced from Big Beef Creek in 2005 by this rate estimates total Hood Canal production at 707,000 smolts.

Puget Sound Secondary Units

Nooksack River

Considering the extent of habitat degradation and potential underseeding due to high harvest rates, we expect natural smolt production from the Nooksack River system was far below projected potential in 2005. We used a value of 25% of the production projected by T.R.28 to estimate 113,000 smolts in 2005.

Strait of Georgia

We selected a value of 30% of the projected production (T.R.28) to estimate 16,000 smolts in 2005.

Samish River

Scale sampling/analysis has indicated that virtually all of the adult coho returning to the weir at the Samish Hatchery are wild. In some recent years, 10,000 adult coho have returned. Even at a relatively low harvest rate and a high marine survival, production would need to exceed 100,000 smolts to produce this escapement. If harvest rates were higher and/or marine survival lower, then smolts production would be even higher. Lacking a direct estimate, we selected a value of 100,000 smolts to approximate production in 2005. This production represents 60% of the potential projected in T.R.28.

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

Coho production in each of these systems is impacted to various degrees by habitat degradation through development, diking and water withdrawals. Each of these systems also contains a dam on the mainstem that blocks access to the upper watershed. Hatchery fry are outplanted in portions of some of these systems in an attempt to mitigate for the presumed underseeding by natural spawners. These outplants probably contribute little, if any, to production, as the healthy habitat components are already seeded.

Lake Washington

In the Lake Washington system, we estimated coho smolt production through downstream migrant trapping in the two major tributaries: Cedar River and Bear Creek. We estimate that the Cedar River and Bear Creek produced 72,643 and 43,725 coho smolts. The other significant coho producing tributary, Issaquah Creek, was trapped once in 2000 producing 19,182 coho smolts. The 2005 production from the Cedar River and Bear Creek represents 226% and 154% of the production measured in 2000 from these streams. Therefore, we scaled the 2000 coho production measured in Issaquah Creek by a factor of 1.5 to estimate the 2005 production at 28,773 smolts. Given that these systems contain most of the best habitat in the basin, we rounded their combined production (145,141 smolts) up to 147,000 smolts to estimate the natural coho yield in the Lake Washington Basin.

On-going research associated with evaluating smolt passage at the Ballard Locks provides insight into smolt survival from the tributaries to the Locks. We assessed relative survival to the Ballard Locks through PIT-tagging (Passive Integrated Transponder) smolts caught in our traps in Bear Creek and the Cedar River. Results indicate that survival through the lake system is not 100%. To project the number of migrants entering saltwater, we applied a survival rate of 75% to estimate that 110,000 naturally-produced coho smolts entered Puget Sound from Lake Washington.

Green River

In 2005, we continued operating a floating screw trap in the mainstem of the Green River at R.M. 34, from February through mid-July. Although this project is directed at assessing wild chinook production, we also enumerated all salmonids captured. Estimating natural coho production in 2005, however, was confounded by the presence of large numbers of steelhead and chinook smolts, and unmarked hatchery coho smolts. Consequently, for two weeks during early-May, the peak of the wild coho migration, we could not operate the trap. Further complicating the analysis was that we did not have a direct measure of trap efficiency for coho salmon. We believe the Green was well seeded in 2003 since escapement levels were above average and the below average peak winter flows

likely contributed to higher than average survival during incubation. We expect rearing conditions remained better than average through the remainder of the freshwater rearing phase given the relatively high Puget Sound Low Flow Index value for 2004. Coho production above our smolt trap on the Green River averaged 99,000 smolts between 2000 and 2004. The 2005 coho production from the Cedar River (adjacent watershed and also flow regulated) was 13% higher than its average coho production over the same five years. Applying this rate to the average production from the Green River estimates production above the smolt trap at 112,000 smolts.

The other major production area in this system is Big Soos Creek, which enters the Green River downstream of our screw trap. In 2000, we trapped this stream and estimated its production at 60,000 coho smolts. In this same year, Big Beef Creek produced a record high of 47,089 smolts. We estimated production from Big Soos Creek in 2005 using the ratio of Big Beef Creek production in 2005 (32,222 smolts) to its production in 2000. This ratio (68%) estimates 41,000 coho smolts were produced from Big Soos Creek in 2005.

Addition of the Green River and Big Soos Creek productions estimates total coho production at 153,000 smolts.

Puyallup River

The Puyallup Tribe operated a rotary screw trap on the Puyallup River, just upstream of the mouth of the White River, in 2005. An estimated 55,972 coho passed their trap in 2005 (Andrew Berger pers. comm.). This represents 16% of the T.R. 28 potential for this portion of the Puyallup drainage. Applying this rate to the T.R. 29 potential for the entire Puyallup Basin (556,243) yields a 2005 coho smolt production estimate of 90,000.

Nisqually River

For the Nisqually River, we approximated coho production at 60,000 smolts through applying a rate of 30% to the estimated potential of 200,000 smolts (T.R.28). We believe Nisqually River coho production is affected by the same influences affecting other deep South Sound streams (see Deschutes River below). For this forecast, we assumed the 2005 smolt production for the Nisqually River relative to its T.R. 28 potential was equal to that measured in the Deschutes, approximately 30%.

Deschutes River

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

The 2003 brood represents the remaining strong brood line present in the Deschutes River. The coho return to the Deschutes River in 2003 included 1,067 females. For the strong broods, we usually assess smolt production by applying the proportion of coded wire-tagged returning adults to the number of smolts tagged. This is the approach that will be used to assess smolt production for the

2003 brood. However, from preliminary data we estimate 70,837 coho emigrated into South Puget Sound in 2005, which results in a system productivity of 66 smolts/female.

South Sound

This production area includes all of the independent tributaries to Puget Sound south of Area 10 (Seattle), excluding Lake Washington, and the Green, Puyallup, Nisqually, and Deschutes Rivers. Production from tributaries entering deep South Sound have suffered from the same factors described for the Deschutes River. However, the more northerly tributaries, while impacted by increasing urbanization, have probably realized somewhat higher seeding levels as a result of higher marine survival rates. We applied a factor of 30% to the potential production of 573,770 smolts projected in T.R.28. This rate estimates 172,000 coho smolts were produced from these South Sound streams in Spring 2005.

East Kitsap

The streams in this region are small and similar in character to those we trap in Hood Canal. However, habitat degradation, largely from development, has probably had a greater impact in the East Kitsap region than in our Hood Canal study streams. In 2005, Big Beef Creek produced 84% of the smolts projected by T.R.28. The SCORE volunteer group (Steele Creek Organization for Resource Enhancement) operated smolts traps in both the north and south forks of Steele Creek, the only East Kitsap tributary monitored in 2005. This project measured wild coho production at 980 and 1,447 smolts, respectively, 59% of the value predicted in T.R.28 (2,427 ÷ 4,140 smolts).

Based on results from Steele Creek monitoring, we applied a factor of 60% to the 154,973 smolts projected by T.R.28 for the East Kitsap region to estimate 93,000 smolts in 2005.

Coastal Systems

Queets River

During Spring 2005, Quinault Tribal biologists (QFiD) operated tributary traps and a scoop trap in the mainstem Clearwater River. From these data they estimated that the Clearwater River produced 85,457 coho smolts. They also conducted a night-seining project in the lower Queets River, which, in conjunction with a linear programming model, estimated 293,950 wild coho smolts were produced from the entire Queets system (Joel Schumacker, QfiD, pers comm). Relating these smolt production estimates to the drainage areas in the two systems yields production rates of 610 smolts/mi^2 and 653 smolts/mi^2 in the 140mi^2 and 450mi^2 Clearwater and Queets Basins, respectively.

Smolt production has been measured from the Clearwater River each spring since 1981 (brood year 1979). Over the first 15 broods, coho production ranged two-fold between extremes, from around 43,000 to 95,000 smolts. Estimates of parent spawners ranged six-fold, from around 300 to over 1,900 females, but, with the exception of the 1983 brood, explained none of the variation in smolt production prior to brood year 1994. Instead, we found, through an analysis of flows during the entire freshwater life, that the highest one-day flow during egg incubation explained a significant portion of the inter-annual variation in smolt production (Figure 2).

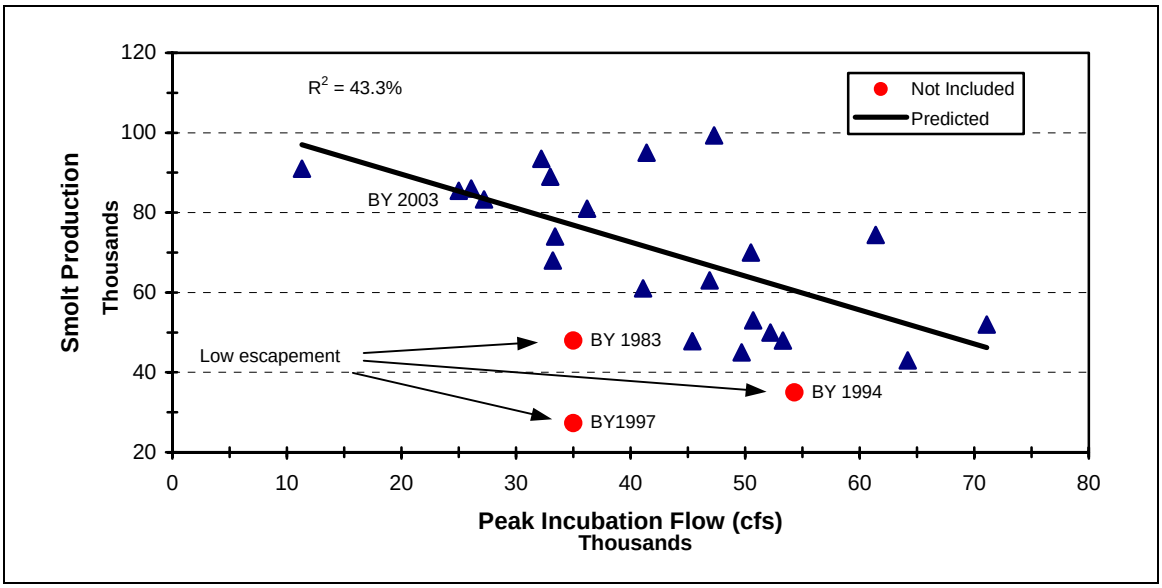

Figure 2: Clearwater River wild coho smolt production and Queets River flow, during egg incubation, brood years 1979-2003 (regression does not include low-escapement broods).

In brood year 1994, however, it appears that low escapement limited smolt production. In 1996, QFiD biologists estimated only 35,000 coho smolts were produced from the Clearwater River. Not only was this estimate the lowest on record, but it also fell well below the value predicted by the flow relationship. Relating this estimate to the 260 females estimated in the 1994 escapement yields an average of 135 smolts/female, which is a high value that also indicates underseeding (Figure 3). These outcomes confirm that the low escapement in 1994 was inadequate to seed the system, and as a result, smolt production was limited in 1996. Low marine survival continued to limit the spawning population for this brood line – only around 600 coho were estimated to have spawned in the Clearwater in 1997. As a result, in 1999, the Clearwater River produced only 27,000 coho smolts, just a fraction of the 72,500 smolts predicted by the flow relationship.

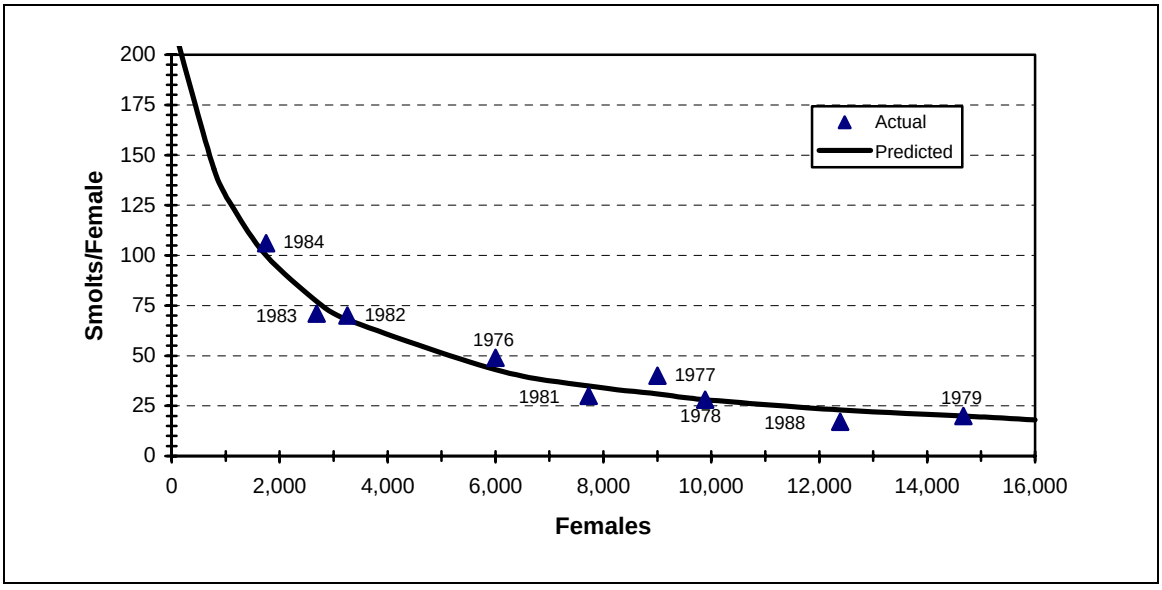

Figure 3: Productivity as a function of spawner abundance, SF Skykomish River wild coho.

For the 2003 brood, the peak flow during egg incubation (25,000 cfs) occurred on January 30, 2004. With this value, the flow relationship predicts coho production in Spring 2005 at 85,363 smolts, virtually identical to the 85,457 smolts estimated by QFiD.

Quillayute River

In the late 1980s, the WSPE Unit measured smolt production in two sub-basins of the Quillayute River — the Bogachiel and Dickey Rivers. Over three years (1987, 1988 and 1990), production from the Bogachiel River averaged 53,751 smolts. Relating this production to the 129 mi^2 upstream of the trap, estimates an average of 417 smolts/mi^2. This work also included evaluating smolt production resulting from large numbers of hatchery fry outplanted throughout the system. Results of these assessments indicated that the system was already seeded to capacity by natural spawners.

Over three years (1992-1994), production from the Dickey River averaged 71,189 smolts from the 87 mi^2 upstream of the trap. Production/area in this system averaged 818 smolts/mi^2. We attributed the production rate, higher than that measured in the Bogachiel, to this system's low gradient and resultant abundant summer and winter rearing habitat. Results indicate this system was also producing at or near capacity.

To estimate average system smolt production, we applied these average production/area values to the Quillayute system (629 mi^2). Based on stream character, we assumed the Bogachiel average production/area value (417 smolts/mi^2) best represents production in the majority (521 mi^2) of the Quillayute watershed (excluding the Dickey River Basin), which is relatively high gradient. Including the average estimated production from the Dickey River's 108 mi^2 drainage area (88,344 smolts) calculates an average system production of 306,000 smolts.

Smolt production in 2005 was estimated by adjusting average production with the ratio of Clearwater smolt production in 2005 to the average of Clearwater production in the three years that we assessed production in the Bogachiel. Over these three years, Clearwater production ranged from 48,000 to 74,000 smolts, and averaged 63,333. In 2005, QFiD biologists estimated that the Clearwater River produced 85,457 smolts. This smolt yield is 1.35 times the level this system produced over the three years that we also estimated production in the Bogachiel River. Assuming production in the Quillayute increased at this same rate, we project that the average of 417 smolts/mi^2 increased to 563 smolts/mi^2 in 2005. This rate, applied to the 521mi^2 outside the Dickey River, estimates 293,000 smolts. We also increased the average Dickey River production (88,344 smolts) by this same factor, to project that this system produced 119,000 smolts in 2005. Adding these estimates yields a total Quillayute system production of 412,000 smolts in 2005.

Hoh River

Due to the similarity and proximity of the Hoh watershed to that of the Clearwater River, we used the Clearwater 2005 production rate to approximate Hoh River coho smolt production. At the rate of 610 smolts/mi^2, the 299-mi^2 drainage area of the Hoh River system produced an estimated 183,000 smolts.

Quinault River

Low escapement due to high harvest rates and degraded habitat have likely combined to limit natural smolt production from this system lower than estimated in the Clearwater River. To approximate smolt production from this 434-mi^2 system, we selected the slightly lower production rate of 500 smolts/mi^2. This results in an estimated production of 217,000 coho smolts.

Independent Tributaries

Smolt production has not been directly measured from any of the independent coastal tributaries. Application of an average production rate of 500 smolts/mi^2 to the total watershed area (424 mi^2; Table 4) estimates 212,000 coho smolts were produced from these systems.

Table 4: Watershed areas of independent tributaries to the Washington coast.

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

Grays Harbor

We have estimated coho smolt production from the Chehalis River system for over twenty years, beginning with the 1980 brood. This estimate relies upon annually trapping/tagging wild smolts, and sampling adults caught in the Quinault Tribe's terminal net fishery in the lower Chehalis River for coded-wire tags. Resultant estimates have ranged seven-fold, from around 0.5 million to 3.6 million. Analysis to understand the components of variation has determined that flow during spawning explains most (73%) of the inter-annual variation in estimated smolt productions, providing seeding levels are adequate (Figure 4).

We excluded three brood years (1990, 1994 and 1997) from this analysis for the following reasons:

1990 brood: Tagging on this brood was limited. As a result, only six wild, tagged adult coho were recovered in an estimated 2,104 wild fish sampled, a very low incidence of 0.29%. This value estimated an unreasonably high wild production of almost six million smolts. The minimum spawning flow in 1990, however, was quite high (1,130 cfs). As a result, we believe production for this brood was high, but the low tag rate precluded making a valid estimate.

1994 brood: Escapement in 1994 was extremely low – less than 10,000 spawners.

1997 brood: Escapement in 1997 was even lower than its parent brood (1994). We estimated only 7,000 adults spawned in 1997. Fortunately, these spawners experienced a very high minimum flow, in excess of 1,500 cfs. As a result, this brood achieved a very high average production per spawner of 159 smolts/female (Figure 3).

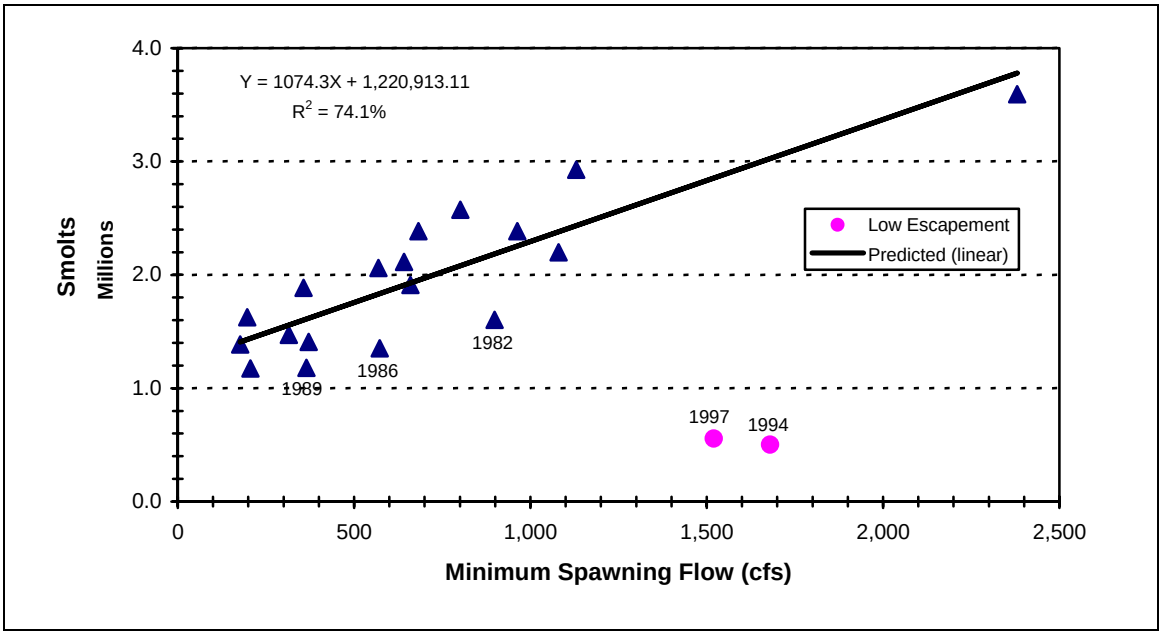

Figure 4: Chehalis River coho smolt production as a function of minimum spawning flow, November 2 through December 15, Chehalis River at Grand Mound, brood years 1980-2002.

For three broods, other important factors explain the negative deviations observed:

- **The 1982 brood** may have been constrained by low escapement;
- **The 1986 brood** was reduced by the effects of the devastating drought of summer 1987 which resulted in the lowest production on record from Bingham Creek;
- **The 1989 brood** was impacted by a severe storm that produced extremely high flows on January 10, 1990. On this date, the Chehalis River flooded, closing Interstate-5. This storm scoured spawning gravels in higher-gradient stream reaches, and triggered mass wasting events that reduced egg survival.

Apparently, in the low gradient, rain-fed, over-appropriated-for-water-withdrawals Chehalis River system, the level and timing of significant flow increases during spawning is an important determinant of natural coho production. The most plausible hypothesis we have to explain this finding is that access to the upper portions of streams throughout this watershed is a function of flow. During such very dry fall seasons as the 1987 drought, adult spawners simply cannot ascend as high in tributaries as they can in wetter years. Because fry emerge from redds and distribute generally downstream, despite favorable flow conditions following spawning, the proportion of the watershed available for rearing juveniles is largely determined by the upstream extent of the spawning population.

For the eighteen broods of Chehalis River smolt production analyzed, the flow correlation indicates that natural seeding rates have been adequate, perhaps with the exception of the 1982 brood. It also appears that the fry-planting program, in effect through the mid-1990s, did not produce enough smolts to obscure the positive effect of flow during spawning on natural production.

This flow relationship provides a means to predict system freshwater production for broods with adequate spawning escapements. The adult coho return in 2003 was relatively high; we estimated nearly 136,000 adults entered the Chehalis Basin (3,389,000 smolts x 4.0% survival-to-return).

During the coho spawning and flow correlation window (November 1 - December 15) in 2003, the minimum flow value of 705 cfs at Grand Mound occurred on November 11. This value is in the upper third of those used to derive the regression shown in Figure 4. Using 705 cfs in the flow relationship predicts a production of 1,978,000 smolts from the 2,114-mi^2 Chehalis Basin (including the Wishkah River) during Spring 2005. This represents an average rate of 936 smolts/mi^2. Application of this rate to the entire Chehalis Basin (2,300-mi^2, including the Hoquiam, Johns, and Elk Rivers, and other south-side tributaries) estimates 2,152,000 coho smolts.

In addition to the Chehalis River watershed, the 2,550-mi^2 Grays Harbor Basin includes the 250-mi^2 Humptulips River. Since we have no direct estimates for the Humptulips Basin, we used the production rate estimated in the Chehalis River (936 smolts/mi^2) to estimate system production at 234,000 coho smolts.

Willapa Bay

The Willapa Basin, with a total watershed area of 850 mi^2, is drained by four main river systems and a number of smaller tributaries. Little empirical smolt production evaluation work has been conducted in this system. Given the presumed high harvest rates in Willapa Bay, and the somewhat degraded condition of its freshwater habitat, it is likely that coho production/area was somewhat lower than that estimated in the Chehalis Basin. To approximate production of the 2003 brood, we selected a value of 700 smolts/mi^2. This rate, applied to the total basin area, estimates 595,000 coho smolts were produced in 2005.

Lower Columbia River

In Spring 2005, we continued monitoring smolt production from three tributaries to the lower Columbia River: Germany, Mill and Abernathy Creeks. In total, these systems, which drain an area of 80-mi^2, produced 25,300 coho smolts, a production rate of 316 smolts/mi^2. Production from Cedar Creek, a tributary to the Lewis River, was estimated through downstream-migrant trapping at 60,0000 coho smolts (pers comm. Shane Hawkins). Production/area from this 55-mi^2, lower-gradient system averaged 1,091 smolts/mi^2.

As most of the 2,000 mi^2 of accessible watersheds draining into the Columbia River downstream of Bonneville Dam (excluding the Cowlitz and Lewis River above their dams) is relatively high-gradient habitat, we applied the lower production rate (316 smolts/mi^2) to 90% of the total area, and the higher rate (1,091 smolts/mi^2) to the remaining 10%. With this split, we estimate 787,000 coho smolts were produced. WDFW biologists assessing out-migrant production at Cowlitz Falls Dam estimated 710,000 coho smolts (pers comm. Charles Morrill), an average production rate of 681 smolts/mi^2 for this 1,042 mi^2 basin. Of this production, an estimated 447,000 coho entered Riffe Lake. It is assumed that none of these smolts survived passage through Riffe and Mayfield Lakes to reach the lower river. In addition to the remaining 263,000 coho captured at the dam and transported to the lower river, 38,000 coho were also captured at Mayfield Dam and released downstream. Summing the production from above Mayfield Dam to the estimate from the Lower Columbia River yields a natural coho production estimate of 1,088,000 smolts from the Washington side.

Marine Survival

Puget Sound

Background

Marine survival rates for Puget Sound wild coho stocks have been measured for many years at Big Beef Creek, Deschutes River, South Fork Skykomish River, and (as of the 1989 brood) Baker River. Survival rates are based on estimated coast-wide recoveries of tagged, age-3 wild coho and numbers returning to upstream migrant trapping facilities where the entire escapement is enumerated.

Marine survival at Big Beef Creek, in terms of age-3 recruits, has varied more than ten-fold over brood years 1975-2002, from a high of 32%, to a low of 3% (1996 brood). In brood years 1988 through 1998, the marine survival rates we have measured at Big Beef Creek have represented an unknown portion of total adult recruits. This bias results from unreported and unsampled coho caught in Hood Canal net fisheries.

For brood years 1977 through 2001, marine survival of Deschutes River coho has ranged from a high of 29%, to a low of only 0.1% (1996 brood). For the first eleven broods (1977-1985), survival of this southern-most Puget Sound stock averaged 22%, just slightly higher than Big Beef Creek (21%) over these same years. Beginning with the 1988 brood, however, marine survival of Puget Sound coho declined. This trend was most evident with the Deschutes River population, which, over the last fourteen broods, has experienced significantly lower survival rates than those of other stocks measured (Figure 5, Table 5).

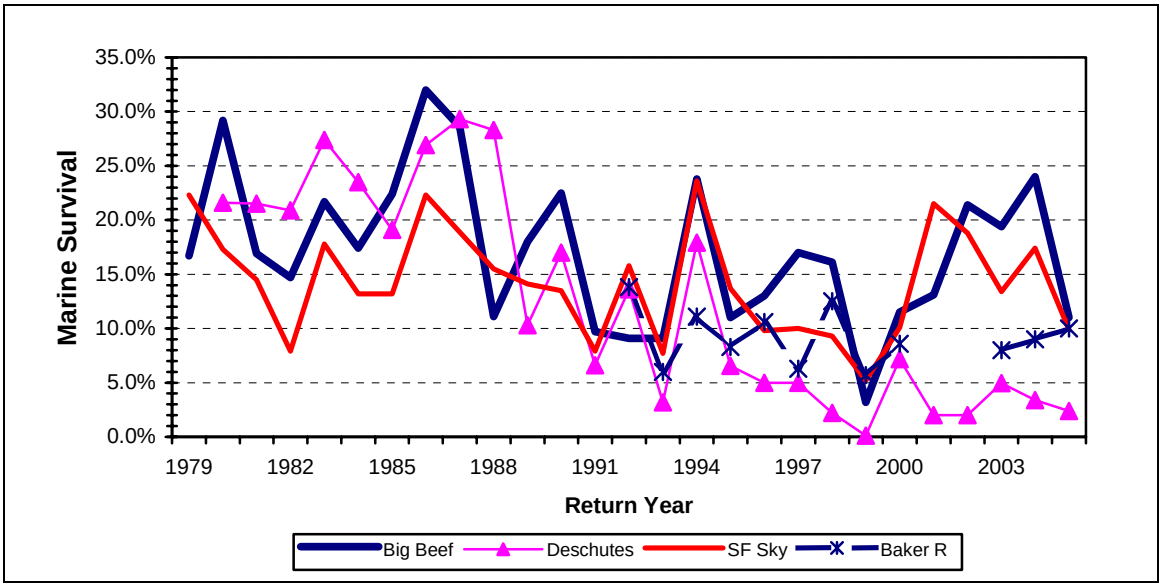

Figure 5: Marine Survival of wild coho (age-3) measured at four Puget Sound streams.

Over the nine broods (1976-1984) that we tagged wild smolts at Sunset Falls (South Fork Skykomish River), marine survival of this stock ranged nearly three fold (8% to 22%) and averaged 16%; this is somewhat lower than the rates estimated for Big Beef Creek and Deschutes River coho over the same period. We attribute this lower survival to the smaller size of smolts produced from this colder, higher-elevation system. Although we no longer trap and coded-wire tag wild coho smolts in this

system, from the 1985 brood on we have annually approximated marine survival through relating run size estimates to the average production we measured with full seeding (276,000 smolts; Figure 1). Run sizes are estimated by applying projected escapement rates to the adult returns enumerated at the Sunset Falls trap. For example, to estimate survival of the 1997 brood, we assumed that the return of 23,726 adults to the trap represented 85% of the run, resulting in a total run of 27,913 coho. Relating this estimate to the average smolt production yields a marine survival rate of 10%. As observed at the other monitoring stations and at hatcheries, survival of fish returning to Sunset Falls in 1999 also hit an all-time low (5.2%).

Table 5: Comparison of marine survival (age 3) between Big Beef Creek, Deschutes River, SF Skykomish River, and Baker River wild tagged coho.

Year Rtn	Big Beef	Des River	SF Sky	Big Beef	Des River	SF Sky	Baker River	Average Early	Average Late	Count
1978	13.3									
1979	16.7		22.3					19.5		2
1980	29.2	21.6	17.3					22.7		3
1981	16.9	21.3	14.5					17.6		3
1982	14.7	21.0	7.9					14.5		3
1983	21.7	27.5	17.8					22.3		3
1984	17.4	23.6	13.2					18.1		3
1985	22.4	19.1	13.2					18.2		3
1986	32.0	26.9	22.3					27.1		3
1987	28.6	29.5	18.9					25.7		3
1988	11.1	28.4	15.5					18.3		3
1989	18.0	10.8	14.1					14.3		3
1990	22.5	17.2	13.5					17.7		3
1991				9.7	6.6	7.9			8.0	3
1992				9.1	13.6	15.8	13.8		13.1	4
1993				9.1	3.2	7.7	6.0		6.5	4
1994				23.8	17.9	23.6	11.1		19.1	4
1995				11.0	6.5	13.7	8.3		9.9	4
1996				13.0	5.0	9.8	10.6		9.6	4
1997				17.0	5.0	10.0	6.3		9.6	4
1998				16.1	2.2	9.3	12.5		10.0	4
1999				3.2	0.1	5.2	5.7		3.6	4
2000				11.5	7.2	10.1	8.6		9.3	4
2001				13.1	2.0	21.5	n/a		12.2	3
2002				21.4	2.0	18.8	n/a		14.1	3
2003				19.7	5.0	13.4	6.3		11.1	4
2004				24.4	3.4	17.4	9.7		13.7	4
2005				11.0	2.4	9.9	6.4		7.4	4
Average	20.3	22.4	15.9	14.2	5.5	12.9	8.8	19.7	10.5	
Min	11.1	10.8	7.9	3.2	0.1	5.2	5.7	14.3	3.6	
Max	32.0	29.5	22.3	24.4	17.9	23.6	13.8	27.1	19.1	
Count	13	11	12	15	15	15	12	12	15	

Survival of Baker River coho, over eight brood years (1989-1996), has ranged just over two-fold, from a high of 13.8% to a low of 5.7%. While survival of Baker River coho appears to generally track the other stocks we have measured (Figure 5), over these broods it has exhibited a biennial pattern, with odd-numbered brood years experiencing higher survivals than even-numbered brood years (Table 5). As with the other stations, Baker River coho returning in 1999 had the lowest marine survival measured thus far (5.7%). Due to a loss of key staff, coded-wire tagging at Baker Dam was suspended in Spring 2000 and 2001; as a result, marine survival was not estimated for this

stock returning in Fall 2001 and 2002. We resumed tagging at Baker Dam in 2002, which enables estimating marine survival of subsequent broods.

Predicting 2003 Brood Marine Survival

Correlating jack returns to Big Beef Creek with same-brood survival-to-adults (ocean age-3) indicates a significant relationship since tagging began with the 1977 brood. Through brood year 1996, age-3 adult recruits averaged 11.3 times the previous year's jack return, with relatively little variation, ranging from 6-18 times. Over the subsequent five broods (1997 through 2001), however, adult recruits have ranged from 22-49 times, and averaged nearly 30-times respective brood year jack returns (Figure 6). The 2002 brood appeared to resume the former pattern with only 9.4 adult recruits for each jack return. Given these disparate adult:jack ratios, we developed separate regression models for each data set (Figure 7).

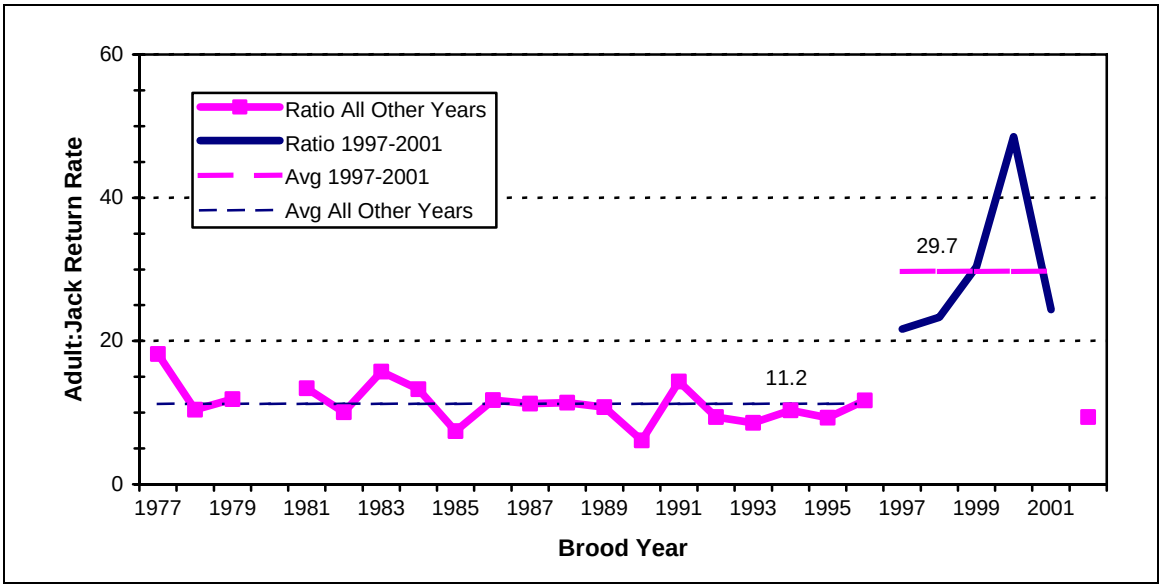

Figure 6: Ratio of adult recruits to jack returns, by brood year, Big Beef Creek tagged wild coho.

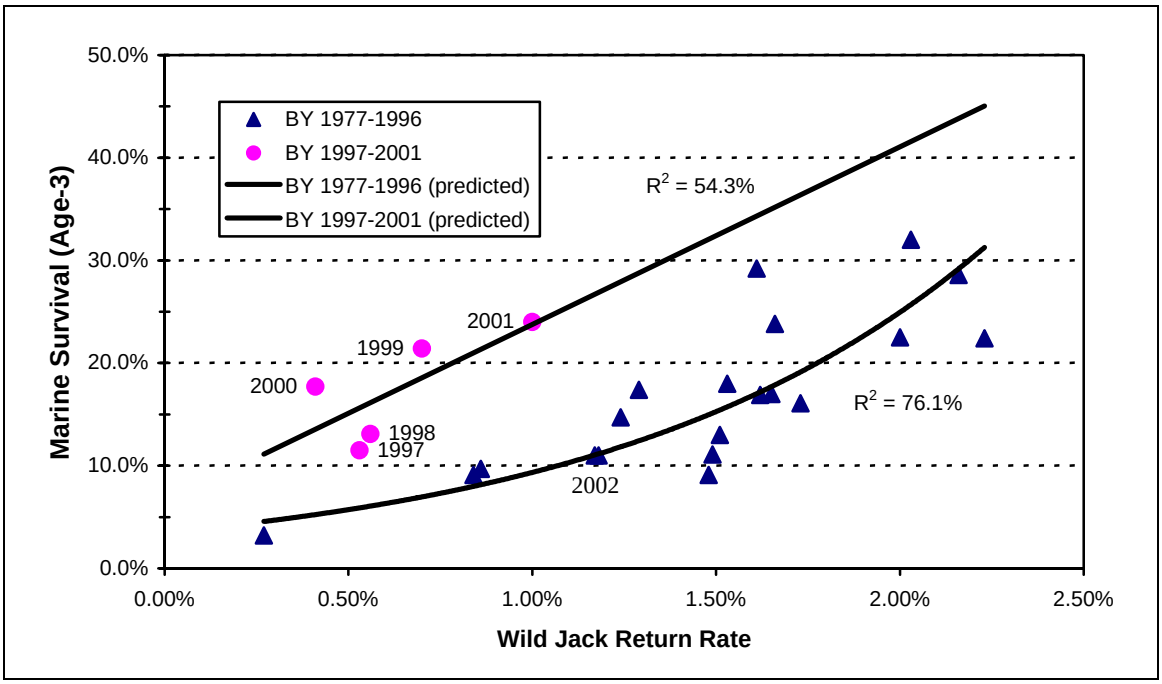

Figure 7: Wild coho adult marine survival, relative to same-brood jack return rates, Big Beef Creek, brood years 1977-2002.

In 2005, we estimate only 43 tagged wild jacks returned from 29,343 smolts tagged in Spring 2005. This return rate (0.15%) is the lowest measured at Big Beef Creek. The two regression models depicted in Figure 7 estimate marine survivals of 4% and 9% from this low jack return rate. We are uncertain which approach best predicts marine survival for the 2003 brood, therefore, we selected the mean of the two estimates, 6.5%, to estimate survival for Hood Canal coho.

For other Puget Sound areas, we selected the following age-3 survival rates, which incorporate recent trends and patterns in marine survival (Table 5). Since marine survival for SF Skykomish River and Baker coho generally trends that of Big Beef coho (Figure 5), we scaled the marine survival rates for the Snohomish and Skagit River systems using the predicted rate for Big Beef Creek. In recent years, coho produced from Central Puget Sound systems have experienced higher survival rates than those from systems to the north and, particularly, to the south. Rates for other stocks were selected based on this trend.

- For the Skagit River and other north Puget Sound systems (Nooksack, Strait of Georgia and Samish Rivers), a relationship between Baker coho marine survival and Big Beef marine survival was used to estimate north Puget Sound survival at 8%.
- For the Stillaguamish River, Lake Washington, Green River, and East Kitsap we selected a rate of 9%.
- For the Snohomish River, a relationship between SF Skykomish marine survival and Big Beef survival was used to estimate Snohomish River survival at 10%
- For the Puyallup River, we selected a rate of 6%.
- For the Nisqually River and South Puget Sound, we selected a rate of 3%.
- The Deschutes River received the lowest survival rate of 2.5%.

Coast

The wild coho trapping and tagging conducted annually at Bingham Creek (Grays Harbor) since the 1980 brood represents the only direct measurement of marine survival for jacks and adults on the Washington Coast. Marine survival (age-3) of wild Bingham Creek coho has ranged nineteen-fold, from 0.6% to 11.6%, and averaged 4.4% over 23 years (Figure 8). Over all broods measured, the relationship between jack returns and same-brood adult marine survival is poor. However, when the two El Niño broods are excluded the correlation improves, with jack returns explaining 33% of the inter-annual variation in smolt-to-adult survival. When the data set is split into "early" and "late" years, the correlations improve even more (Figure 9). In the two El Niño broods (1980 and 1990), adult survival was low relative to the high jack returns. This phenomenon was also observed elsewhere on the coast, notably in the Oregon Production Index.

Over the ten recent brood years, the WSPE Unit has under-predicted marine survival for six broods and over-predicted for four broods (Table 6). Overall, actual survival rates have exceeded predicted values by 14%.

Relating the sixteen wild tagged jacks that returned to the Bingham Creek trap in 2005 to the 26,700 smolts tagged earlier that year, adjusted for handling mortality (16%) and tag loss (4%), predicts marine survival for the 2003 brood at 3.8% using the "late" years relationship.

Lacking an indication to the contrary, we also used 3.8% for all other coastal systems.

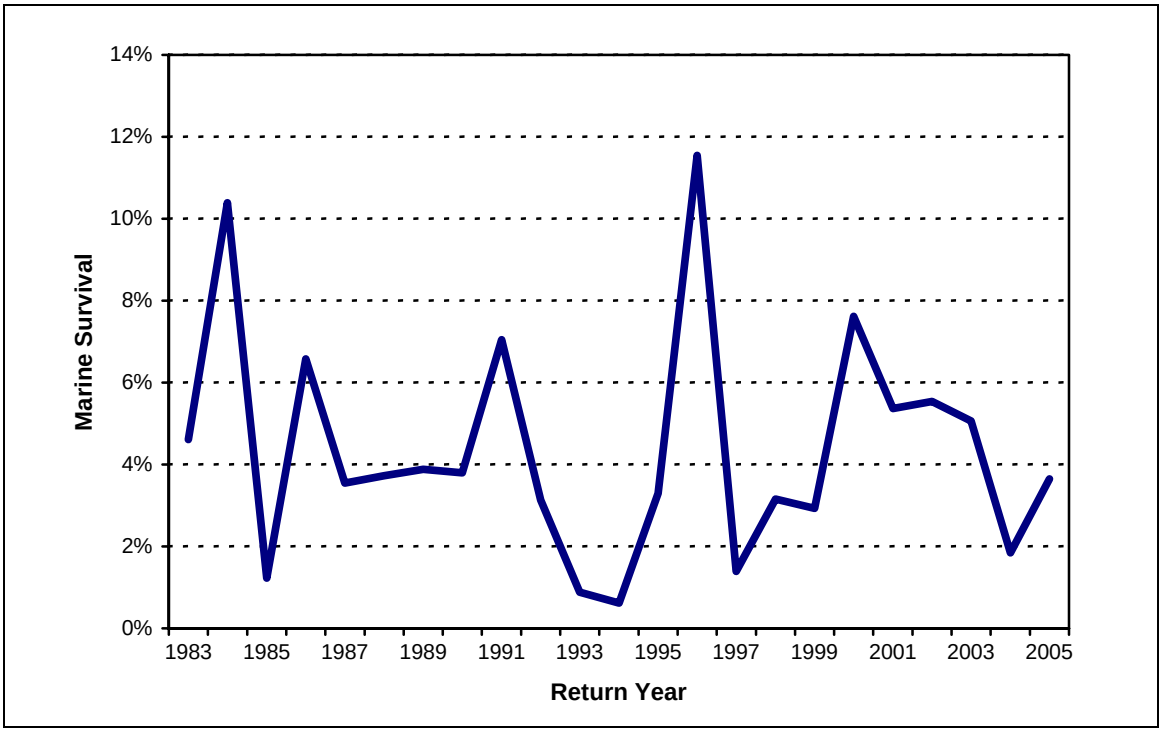

Figure 8: Marine survival of tagged wild coho from Bingham Creek.

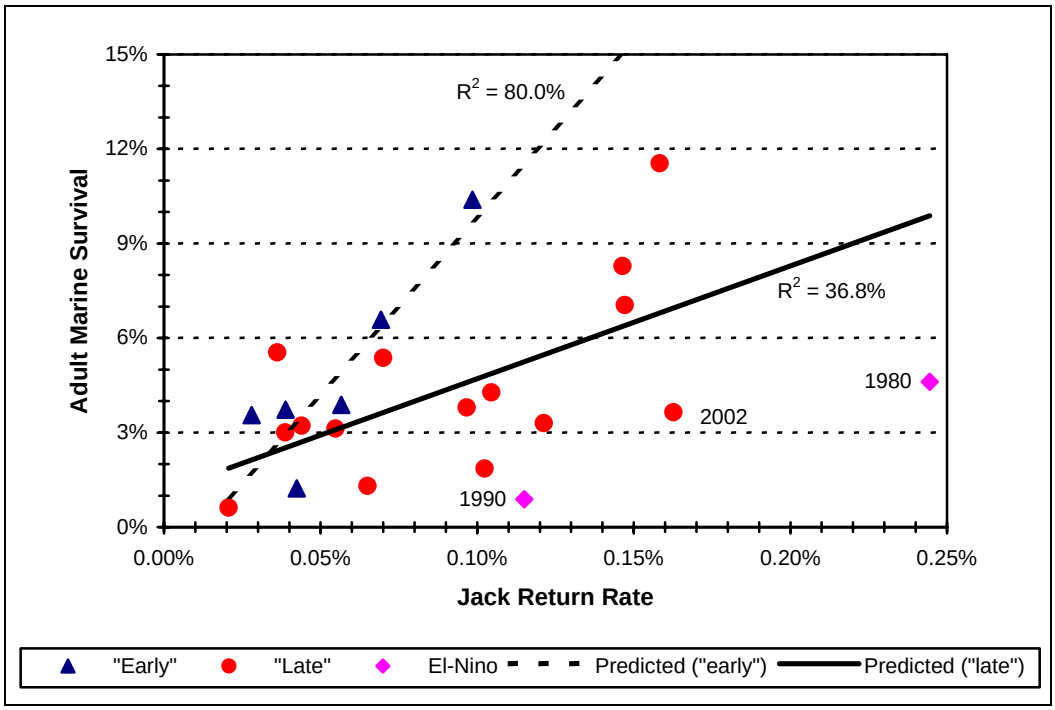

Figure 9: Jack return and adult marine survival, Bingham Creek, brood years 1980-2002.

Table 6. Forecasted and measured adult marine survival for 1993-2003 brood Bingham Creek wild coho.

Brood Year i	Return Year i+3	ADULT MARINE SURVIVAL		% Error
		Predicted	Actual	
1993	1996	5.4%	11.6%	-53%
1994	1997	3.0%	1.4%	+114%
1995	1998	1.0%	3.2%	-69%
1996	1999[a]	2.0%	2.9%	-31%
1997	2000[b]	6.0%	7.6%	-21%
1998	2001	3.2%	5.4%	-41%
1999	2002[c]	3.0%	4.5%	-33%
2000	2003	7.0%	5.1%	+37%
2001	2004[d]	6.2%	1.9%	+226%
2002	2005	4.0%	3.7%	+8%
2003	2006	3.8%		

[a] The model predicted 1.4%, which Seiler et al. elected to increase.
[b] The model predicted 7.6%, which, given the very low smolt production, Seiler et al. discounted to be conservative.
[c] Used intermediate survival between "early" and "late" year model relationships. "Early" model predicted 4.1%.
[d] The "late" year model predicted 4.8%, but 7% was selected.

Lower Columbia River

Lacking any indicators for wild coho survival in the Lower Columbia River, we also used the 3.8% rate for this system.