2007 Wild Coho Forecasts for Puget Sound & Washington Coastal Systems

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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.

The measure of freshwater production is smolt abundance. 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. Historically, these data had been incorporated into some forecasts. However beginning in 1996, a wild coho forecast for all primary and most secondary management units in Puget Sound and the Washington Coast was developed by the WDFW Science Division (Seiler 1996). A forecast for Lower Columbia wild coho was added in 2000 (Seiler 2000). With the ESA listing of Lower Columbia coho in 2005, additional work has gone into improving the Lower Columbia wild coho forecast methodology found in this report.

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. With the listing of Lower Columbia coho, harvest impacts are expected to be limited to affect rebuilding of the ESU. Forecasts for Lower Columbia coho are expected to have a greater influence on the management of Columbia River, if not coastal fisheries in 2007. In addition to the primary wild coho management units and Lower Columbia River populations, production from 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 twelve 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 2007, based on estimates of smolt production and marine survival.

Production Unit	PRODUCTION X	MARINE SURVIVAL =		RECRUITS		
	Estimated Smolt Production: Spr '06	Adults (Age 3)	Dec. (Age 2)	Adults (Age 3)	Dec. (Age 2)	Jan. (Age 3)
Puget Sound						
Primary Units						
Skagit River	735,876	2.5%	3.3%	18,400	24,500	22,640
Stillaguamish River	288,000	3.5%	4.7%	10,100	13,400	12,380
Snohomish River	800,000	4.5%	6.0%	36,000	48,000	44,350
Hood Canal	846,000	4.1%	5.5%	34,700	46,200	42,690
Straits of Juan de Fuca	**see note below**					
Secondary Units						
Nooksack River	90,000	2.5%	3.3%	2,300	3,000	2,770
Strait of Georgia	16,000	2.5%	3.3%	400	500	460
Samish River	100,000	2.5%	3.3%	2,500	3,300	3,050
Lake Washington	90,000	3.5%	4.7%	3,200	4,200	3,880
Green River	81,000	3.5%	4.7%	2,800	3,800	3,510
Puyallup River	59,000	3.5%	4.7%	2,100	2,800	2,590
Nisqually River	20,000	3.5%	4.7%	700	900	830
Deschutes River	4,214	3.5%	4.7%	147	197	180
South Sound	172,000	3.5%	4.7%	6,000	8,000	7,390
East Kitsap	93,000	3.5%	4.7%	3,300	4,300	3,970
Puget Sound Total	3,395,090			122,647	163,097	150,690
Coast						
Queets River	245,294	2.5%	3.3%	6,132	8,174	7,550
Quillayute River	237,000	2.5%	3.3%	5,925	7,898	7,300
Hoh River	109,000	2.5%	3.3%	2,725	3,632	3,360
Quinault River	109,000	2.5%	3.3%	2,725	3,632	3,360
Independent Tributaries	127,000	2.5%	3.3%	3,175	4,232	3,910
Grays Harbor						
Chehalis River	2,117,000	2.5%	3.3%	52,925	70,549	65,190
Humptulips River	230,000	2.5%	3.3%	5,750	7,665	7,080
Willapa Bay	595,000	2.5%	3.3%	14,875	19,828	18,320
Coastal Systems Total	3,769,294			94,232	125,610	116,070
Lower Columbia Total	498,900	2.5%	3.3%	12,473	16,626	15,360
GRAND TOTAL	7,663,284			229,352	305,333	282,120

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	29	14	11,510	47,088	4.1	26,242	1,874	1,2,3,4,5
Bingham Creek	26	35	15,233	70,342	4.6	30,660	876	2,3
Deschutes River	28	160	892	133,198	149.3	51,724	323	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	25	140	27,314	99,354	3.6	64,928	464	1,4,5
Stillaguamish River	3	540	203,072	379,022	1.9	275,940	511	6
Skagit River[b]	17	1,918	617,600	1,884,700	3.1	1,064,293	555	1,2,3,8
Chehalis River	22	2,114	502,918	3,592,275	7.1	1,941,485	918	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 2006, we estimated that 735,876 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 2006.

	Number	Formula
Total mainstem trap catches	11,073	
Skagit Hatchery/Lake Shannon	-1,399	
Wild coho captured (c)	**9,674**	
LVs recaptured (r)	234	N = (m+1)(c+1)
LVs released (m)	17,873	(r+1)
Total production (N)	**735,876**	
Variance (Var)	2.21E+09	Var = (m+1)(c+1)(m-r)(c-r)
Standard Deviation (sd)	47,004	(r+1)^2(r+2)
Coefficient of Var (CV)	6.39%	CV = sd/N
Confindence Interval (CI)	92,128	CI = +/- 1.96(sd)
Estimated coho production		
Skagit River	735,876	
Upper CI (95%)	828,004	
Lower CI (95%)	643,748	

This even year brood production is 39% below the even-year brood average production of 1,201,099. Flows during Summer 2005 were much lower than average for North Sound tribs, substantially reducing summer rearing space. The Puget Sound Summer Low Flow Index (PSSLFI) registered a value of 7.1, a little over 1 point below the long-term average of 8.5, which has ranged from 4.5 to 13.5 over the previous 41 years. However, low flows for the Central and North Puget Sound components of the index (Snoqualmie to Nooksack) averaged only 55% of their long-term summer low flow averages. Peak winter flows during egg incubation may also have contributed to the low smolt production. Peak streamflow was measured at 76,600 cfs at the Mt Vernon gage on December 11, 2004. This is somewhat above the median peak flow of 59,400 cfs over the 1988 – 2004 brood years that correspond to trap operations.

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 effects of lower summer base flows and the moderately high peak flow during incubation on 2004 brood coho in the Skagit River, we reduced the mean system production by 20%, to estimate 288,000 smolts produced in 2006.

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.

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 assume 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. This approach yields an average production of 1,000,000 coho from the Snohomish Basin.

To account for the combined effects of lower than average summer flows and moderately high peak incubation flows, we decreased the average production by 20% to estimate 800,000 smolts were produced in the Snohomish Basin in 2006.

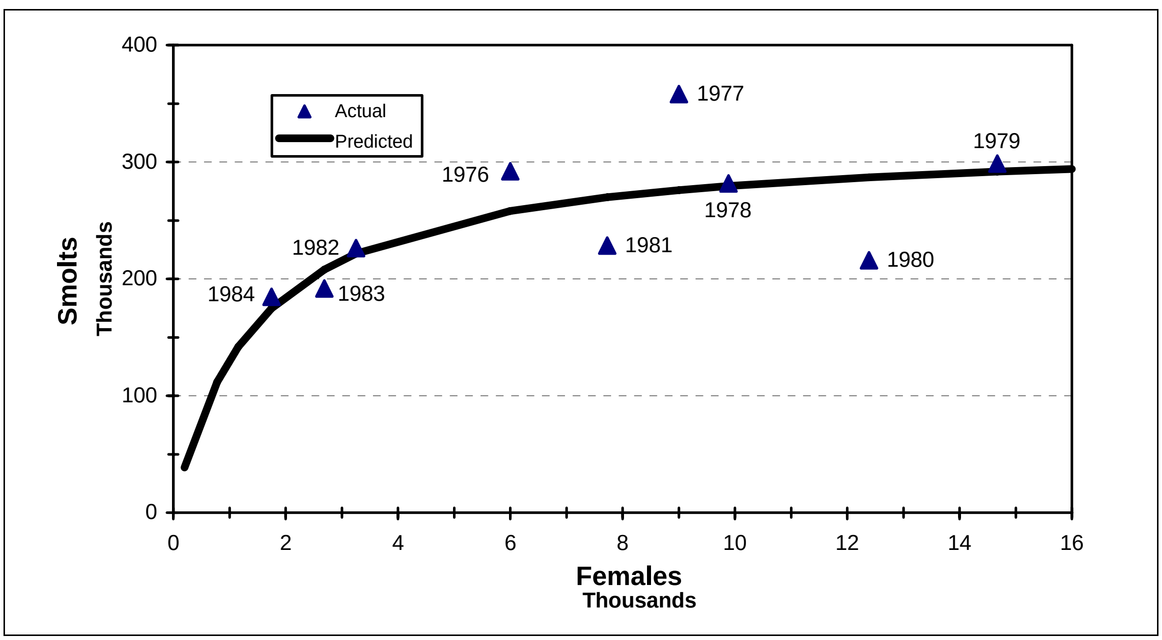

Figure 1: SF Skykomish River wild coho spawners and recruits, by brood year.

Hood Canal

In 2006 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 2006, Big Beef Creek produced 38,579 coho smolts from 2,041 females passed upstream in 2004, an average of 18 smolts per female. This production was 47% above the long-term average of 26,242 smolts. The adjacent streams (Stavis, Seabeck, and Little Anderson Creeks) yielded 8,043, 1,829 and 1,743 coho smolts, respectively, which are well above the average 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 1.44.

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 (50,194 smolts) with these rates projects production for the entire Hood Canal in 2006 at 851,000 and 660,000 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 ($1 \div 0.0456$) 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 38,579 coho produced from Big Beef Creek in 2006 by this rate estimates total Hood Canal production at 846,000 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 2006. We used a value of 20% of the production projected by T.R.28 to estimate 90,000 smolts in 2006.

Strait of Georgia

We selected a value of 30% of the projected production (T.R.28) to estimate 16,000 smolts in 2006.

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 recent years (2000 to 2004), escapements have averaged over 10,000 adult coho per year. 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 2006. 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 42,111 and 46,985 coho smolts. The other significant coho producing tributary, Issaquah Creek, was trapped once in 2000 producing 19,182 coho smolts. The 2006 production from the Cedar River and Bear Creek represents 131% and 167% 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 (117,869 smolts) up to 120,000 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 90,000 naturally-produced coho smolts entered Puget Sound from Lake Washington.

Green River

In 2006, we continued operating a floating screw trap in the mainstem of the Green River at R.M. 34, from late January through mid-July. Although this project is directed at assessing wild chinook production, we also enumerated all salmonids captured. Coho production from above the trap was estimated at 39,711 smolts in 2006.

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 64,341 coho smolts. As with many smaller Puget Sound low gradient streams that we have trapped, we believe coho production is regulated by the amount of low flow habitat available in the late summer/early fall months. Therefore, we adjusted the year 2000 smolt production of 64,341 by the ratio of PSSLFI values between these two brood years (7.1 ÷ 10.5 = 67.9%). This ratio (68%) estimates 41,000 coho smolts were produced from Big Soos Creek in 2006.

Addition of the Green River and Big Soos Creek productions estimates total coho production at 81,000 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 2006. An estimated 31,367 coho passed their trap in 2006 (Berger, A., R. Conrad, and M. Parnel. 2006. Puyallup River juvenile salmonid production assessment project 2006. Puyallup Tribal Fisheries). This represents 11% of the T.R. 28 potential for this portion of the Puyallup drainage. Applying this rate to the T.R. 28 potential for the entire Puyallup Basin (556,243) yields a 2006 coho smolt production estimate of 59,000.

Nisqually River

For the Nisqually River, we approximated coho production at 20,000 smolts through applying a rate of 10% 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).

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 2004 brood is one of the weak brood lines present in the Deschutes River. The coho return to the Deschutes River in 2004 included only 30 females. We operated the smolt trap from April 25 to May 25 in 2006. Long term data indicated approximately 82% of the coho outmigration occurs during this period. Expansion of the data estimates a total production of 4,214 smolts in 2006, which results in a system productivity of 140 smolts/female. This production represents only 1.9% of the production potential (219,000) estimated in T.R. 28.

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. For example, 2006 smolt production from Skookum, Mill, Johns, and Sherwood Creeks (monitored by the Squaxin Island Tribe) averaged only 2.5% of the potential estimated in T.R. 28. 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. For example, coho escapement into Minter Creek is controlled by the hatchery rack and only unmarked adults are released upstream. The 2006 smolt production was approximately

12,200 coho. Using the same method as was presented in T.R. 28, we estimate the 2006 production at 72% of its potential. Therefore, given the wide disparity in production within this unit, 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 2006.

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 2006, the Hood Canal streams we trap 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 2006. This project measured wild coho production at 750 and 290 smolts, respectively, 25% of the value predicted in T.R.28 (1,040 ÷ 4,140 smolts).

Escapement in 2004 was somewhat reduced from the previous two years, but not excessively so. Productivity was greatly reduced for the 2004 brood; measured at only 9 smolts/female compared to 15-20 in the previous two years. This reduction in productivity is counter to what would be expected given the reduced escapement. In past years, Steele Creek production relative to its T.R. 28 potential has been similar or only slightly less than that of the Hood Canal streams. Since such a dramatic difference was measured in 2006, it is likely a result of conditions in Steele Creek that may not be indicative of the East Kitsap Management Unit as a whole. Therefore, 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 2006.

Coastal Systems

Queets River

During Spring 2006, 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 49,059 coho smolts. They also conducted a night-seining project in the lower Queets River, which, in conjunction with a linear programming model, estimated 245,294 wild coho smolts were produced from the entire Queets/Clearwater system (Rob Rhodes, QfiD, pers comm). Relating these smolt production estimates to the drainage areas in the two systems yields production rates of 350 smolts/mi^2 and 545 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).

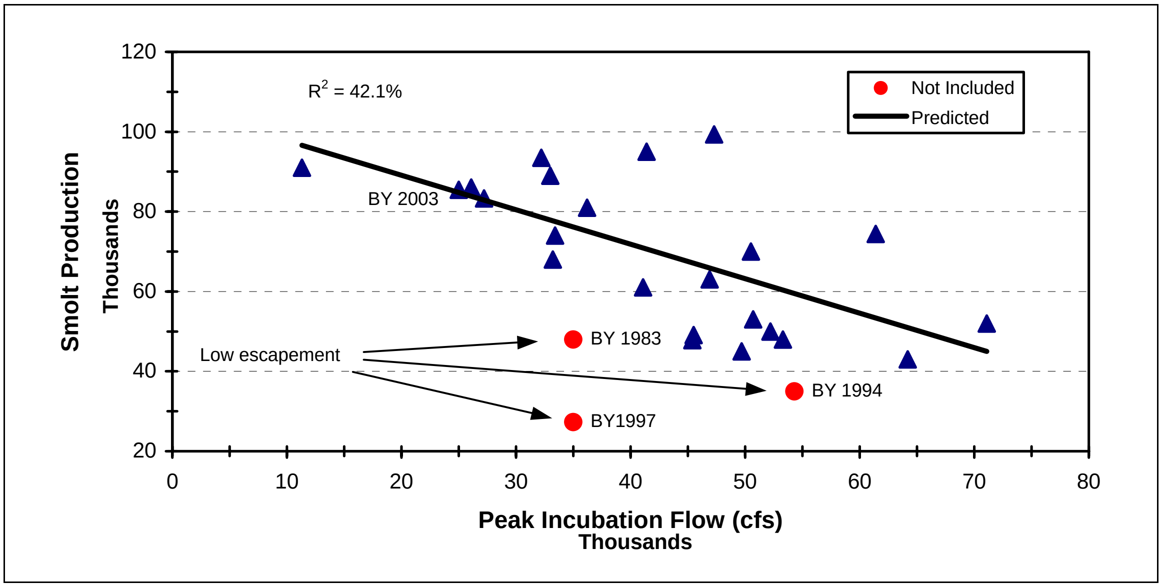

Figure 2: Clearwater River wild coho smolt production and Queets River flow, during egg incubation, brood years 1979-2003 (regression does not include low-escapement broods).

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.

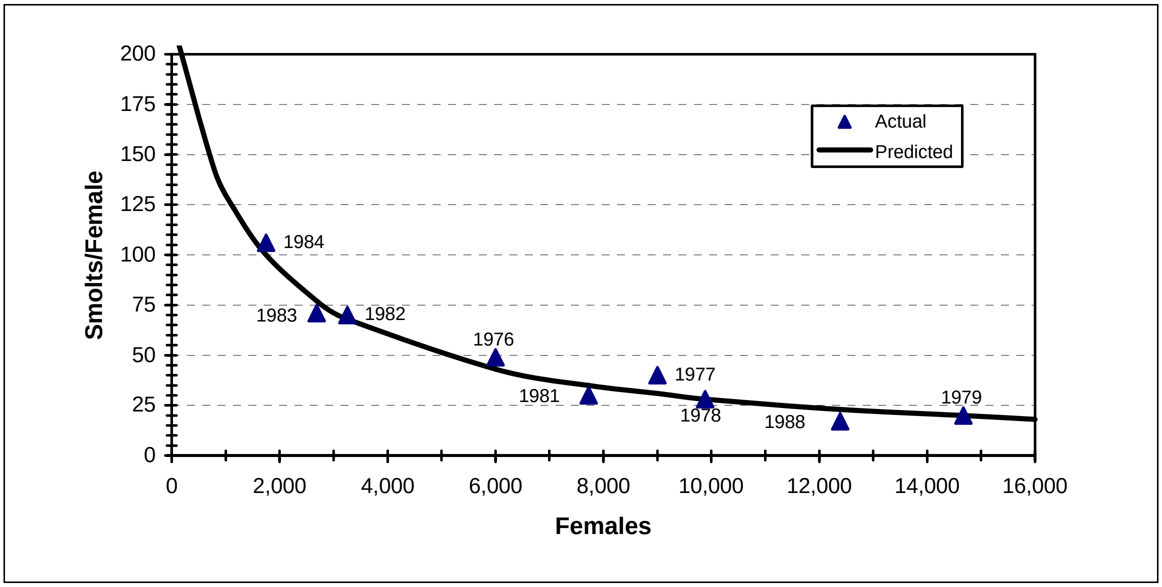

Figure 3: Productivity as a function of spawner abundance, SF Skykomish River wild coho.

For the 2004 brood, the peak flow during egg incubation (45,500 cfs) occurred on January 18, 2005. With this value, the flow relationship predicts Clearwater coho production in Spring 2006 at 67,068 smolts, substantially higher than the 49,059 estimated from the trapping data. The flow data used in the relationship is from the Queets River. Coho from the Clearwater River may have been more severely impacted by this storm event than the peak flows from the Queets River indicate.

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 2006 was estimated by adjusting average production with the ratio of Clearwater smolt production in 2006 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 2006, QFiD biologists estimated that the Clearwater River produced 49,059 smolts. This smolt yield is 0.77 times the level this system produced over the three years that we also estimated production in the Bogachiel River. Assuming the 2004 brood production in the Quillayute was reduced by the same rate, we project that the average of 417 smolts/mi^2 decreased to 323 smolts/mi^2 in 2006. This rate, applied to the 521mi^2 outside the Dickey River, estimates 168,000 smolts. We also decreased the average Dickey River production (88,344 smolts) by this same factor, to project that this system produced 68,000 smolts in 2006. Adding these estimates yields a total Quillayute system production of 237,000 smolts in 2006.

Hoh River

Due to the similarity and proximity of the Hoh watershed to that of the Clearwater River, we used the Clearwater 2006 production rate to approximate Hoh River coho smolt production. At the rate of 350 smolts/mi^2, the 299-mi^2 drainage area of the Hoh River system produced an estimated 105,000 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 250 smolts/mi^2. This results in an estimated production of 109,000 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 300 smolts/mi^2 to the total watershed area (424 mi^2; Table 4) estimates 127,000 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 five 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 (65%) of the inter-annual variation in estimated smolt productions, providing seeding levels are adequate (Figure 4).

We excluded four brood years (1990, 1994, 1997, and 2000) 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).

2000 brood: Other factors affecting coho production include the magnitude of peak winter flows during incubation (negative effect) and of summer low flows during parr rearing (positive effect). This brood experienced the lowest peak winter flow and third highest summer low flow since trapping began with the 1980 brood.

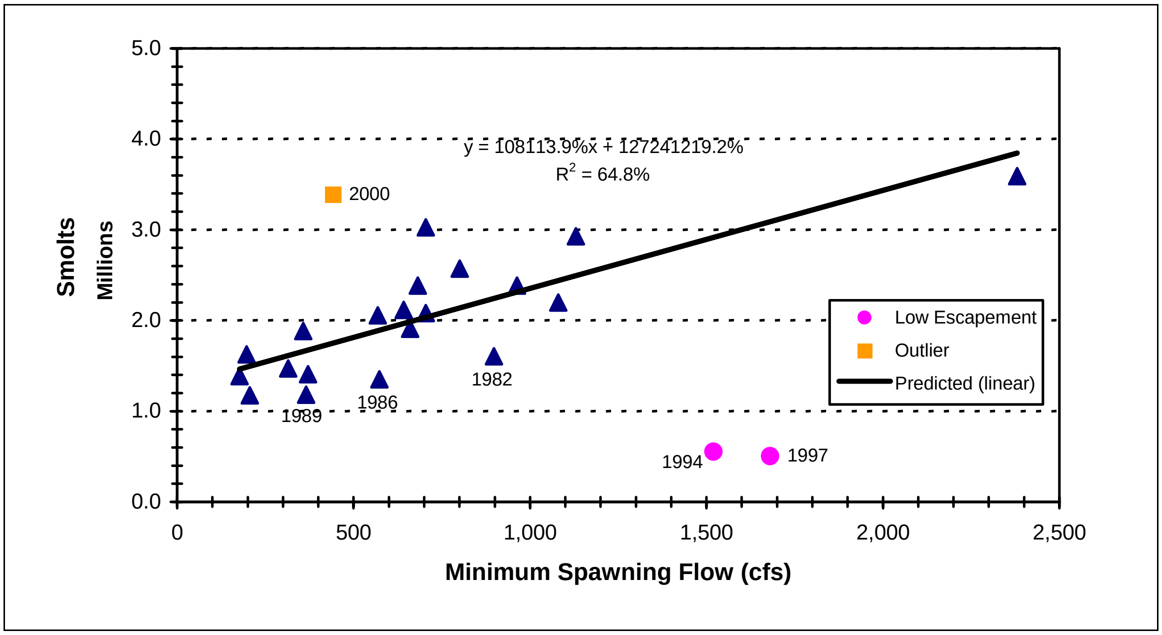

Figure 4: Chehalis River coho smolt production as a function of minimum spawning flow, November 2 through December 15, Chehalis River at Grand Mound, brood years 1980-2003.

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 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 twenty 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 2004 was low; we estimated slightly over 31,000 adults entered the Chehalis Basin (2.1M smolts x 1.5% survival-to-return).

During the coho spawning and flow correlation window (November 1 - December 15) in 2004, the minimum flow value of 1,030 cfs at Grand Mound occurred on November 15. This value has only been exceeded three times in the data set used to derive the regression shown in Figure 4. Using 1,030 cfs in the flow relationship predicts a production of 2,384,512 smolts from the 2,114-mi^2 Chehalis Basin (including the Wishkah River) during Spring 2006. At a parent escapement of 31,133, this estimates a productivity of 77 smolts/spawner or 154 smolts/female. Under much lower escapements (6700 estimated) and similarly favorable environmental conditions, the 1997 brood produced 166 smolts/female. Nevertheless, 154 smolts/female represents a very high productivity value. Rather than forecast run sizes from this extreme, we reduced productivity to a more moderate 125 smolts per female, which still reflects a high level of productivity rarely observed other than during underseeded conditions, to estimate the 2004 brood smolt production at 1,945,813. This represents an average rate of 920 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 2,117,015 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 (920 smolts/mi^2) to estimate system production at 230,000 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 2006.

Lower Columbia River

In 2006, WDFW monitored a total of eight streams for coho salmon abundance in the Lower Columbia River ESU. These locations included the mouths of independent tributaries to the Lower Columbia River including Mill, Abernathy, and Germany Creeks, sites in the Cowlitz subbasin at Mayfield Dam, Cowlitz Falls Dam, and the Coweeman River near the lower stream gauge station (RM 7.5), and Cedar Creek, tributary to the NF Lewis River, near the Grist Mill fish ladder (RM 2). Individual population estimates are not finalized but preliminary estimates were developed from capture-mark-recapture data using a pooled Petersen estimate (Schwarz and Taylor 1998) except for the estimates at Mayfield and Cowlitz Falls dams. At the Mayfield site, Paulik and Thompson (1967) estimated the collection efficiency for this site was 66.4% for coho salmon smolts. WDFW estimated the average fish collection efficiency at the upper Cowlitz Falls project was 19.9% in 2006 based on mark-recapture tests (John Serl, WDFW unpublished). Typical releases to evaluate collection efficiency are ~ 1000 per year at Cowlitz Falls, so it was assumed a recapture of 199 fish. Similar assumptions were made for Mayfield dam with a release of 1000 smolts and a recapture of 664. These assumptions were made to include a measure of uncertainty in the smolt production estimates for the Tilton and Cowlitz Rivers.

Preliminary smolt production estimates are found in Table 5. Estimates were conducted in WinBUGS (Spiegehalter et al. 2003) using a using a binomial mark-recapture model (Rivot and Prevost 2002). Vague or non-informative priors were used, which allowed posterior predictive distribution to be determined by the likelihood function without being influenced by the prior. Two chains were run and after the burn-in period, simulations were run until MC error was less than 5% of the posterior SD. Convergence was monitored using Gelman and Ruben diagnostics. It is assumed the reported results obtained through Gibbs sampling are representative of the underlying stationary distribution and the Markov Chains have converged. Results are displayed as the median and the 90% Credible Interval.

Table 5. Estimated Smolt Production and Density from monitored coho salmon streams in the Lower Columbia River ESU during 2006.

	Smolt Abundance			Smolt Density (smolts/sq. mile)		
node	**5.00%**	**median**	**95.00%**	**5.00%**	**median**	**95.00%**
Cedar Nat. Origin	37140	38450	40230	700.8	725.5	751
Cedar	44880	46040	47680	846.9	868.6	892.1
Coweeman	7522	7995	8676	63.21	67.18	71.47
Mill	6481	6665	6914	223.5	229.8	236.4
Abernathy	4148	4410	4793	143	152.1	161.8
Germany	2219	2327	2475	96.5	101.2	106.3
Tilton	32730	33650	34960	205.9	211.7	217.9
U. Cowlitz	341100	370100	414200	327.4	355.2	383.8

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 noticed coho smolt production is also correlated to drainage area. Since WDFW estimates of lower Columbia River tributaries spawning and rearing habitat were not readily available drainage area was used as a surrogate for spawning and rearing habitat quantity. Estimates of smolts per square mile of drainage area are also found in table 5.

There are two estimates for Cedar Creek due to the occurrence of a Remote Site Incubation (RSI) program. The first estimate, labeled Cedar NO, is the estimated production from natural production and the second estimate labeled Cedar Creek is for the total natural and RSI production. Since all RSI juveniles were thermally marked, the RSI production was obtained by sampling otoliths from trapped smolts and decoding the otoliths. The proportion of non-RSI smolts was a binomial based on the total catch and the number of natural origin smolts, which was multiplied by the total Cedar Creel population estimate to obtain the estimate of natural origin smolts. Unfortunately, otoliths collected from the 2006 smolt outmigration have not been decoded so the proportion of RSI fish from the 2005 was used.

The density of coho salmon smolts in Cedar Creek was estimated to be 869 smolts per square mile of drainage area but without the RSI smolts the number was reduced to 726 smolts per square mile. These density estimates are twice are high as the next best estimate and is probably 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 Tilton and U. Cowlitz watershed had densities of 211 and 355 smolts per square mile. Other watersheds with hatcheries had high levels of spawning escapement in 2004, 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 Cowlitz and Tilton Rivers was applied to all watersheds with hatcheries. The square miles of drainage area in these watersheds was 831 square miles, and the resulting smolt production was predicted to be 240,500 (90% CI 129,800 – 387,900) and is found in Table 6.

The Coweeman, Germany, Abernathy, and Mill subwatersheds have no operating coho hatcheries but hatchery coho salmon do stray and spawn in them. The densities ranged from a low of 67 to a high of 230 smolts per square mile. The median density of smolts per square mile (138) from these watersheds was multiplied by 620 square miles to predict smolt production from non-monitored streams without a hatchery. This abundance is listed in Table 6 and was predicted to be 85,770 smolts (90% CI 51,890 - 121,200).

The smolt production for the monitored systems was the sum of 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 from the Tilton River was the number trapped at Mayfield Dam (Julie Henning, WDFW pers, comm.) 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 171,300 (90% CI 169,800 – 173,000). The total abundance estimate for the Washington portion of the LCR ESU is found in Table 6 and was estimated 498,900 smolts (90% CI 382,400 – 653,400).

These coho smolt estimates are believed to be relatively unbiased because estimates are obtained from a census or M-R programs, where care is taken to meet the assumptions required for unbiased population estimates. The smolt monitoring sites were not randomly chosen but are 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 mainstem and NF Toutle Rivers included only drainage area from tributaries and it excluded the mainstem, which is still recovering from the eruption of Mt. St. Helens.

Table 6. 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	129800	240500	387900	156.2	289.4	466.8
Unmonitored W_Streams	51890	85770	121200	83.69	138.3	195.4
Monitored Streams	169800	171300	173000			
Nat. Origin Smolt Prediction	382400	498900	653400			

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.

Rivot, E., and E. Prevost. 2002. Hiearchical Bayesian analysis of capture-nark-recapture data. Can. J. Fish. Aquat. Sci. 53:2157-2165.

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.

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 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 1975-2003, from a high of 32% to a low of 2%, with last years return (2003 brood) having the lowest marine survival on record. 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 2003, 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 seventeen broods, has experienced significantly lower survival rates than those of other stocks measured (Figure 5, Table 5). However, record low marine survivals observed in the other Puget Sound coho stocks returning in 2006 were as poor as or exceeded the low marine survival measured for the Deschutes 2003 brood coho.

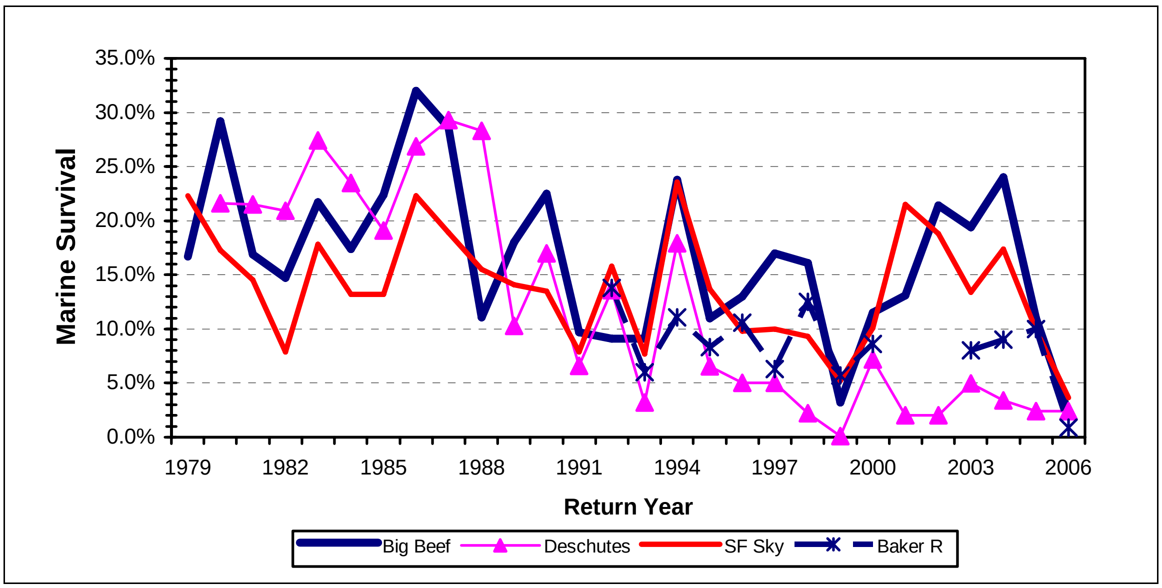

Figure 5: Marine Survival of wild coho (age-3) measured at four Puget Sound streams.

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, survival of fish returning to Sunset Falls in 2006 also hit an all-time low (3.6%).

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

Year		Big	Des	SF	Big	Des	SF	Baker	Average	
Brood	**Rtn**	**Beef**	**River**	**Sky**	**Beef**	**River**	**Sky**	**River**	**Early**	**Late**
1975	1978	13.3								
1976	1979	16.7		22.3					19.5	
1977	1980	29.2	21.6	17.3					22.7	
1978	1981	16.9	21.3	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	19.1	13.2					18.2	
1983	1986	32.0	26.9	22.3					27.1	
1984	1987	28.6	29.5	18.9					25.7	
1985	1988	11.1	28.4	15.5					18.3	
1986	1989	18.0	10.8	14.1					14.3	
1987	1990	22.5	17.2	13.5					17.7	
1988	1991				9.7	6.6	7.9			8.0
1989	1992				9.1	13.6	15.8	13.8		13.1
1990	1993				9.1	3.2	7.7	6.0		6.5
1991	1994				23.8	17.9	23.6	11.1		19.1
1992	1995				11.0	6.5	13.7	8.3		9.9
1993	1996				13.0	5.0	9.8	10.6		9.6
1994	1997				17.0	5.0	10.0	6.3		9.6
1995	1998				16.1	2.2	9.3	12.5		10.0
1996	1999				3.2	0.1	5.2	5.8		3.6
1997	2000				11.5	7.2	10.1	10.6		9.9
1998	2001				13.1	2.0	21.5	n/a		12.2
1999	2002				21.4	2.0	18.8	n/a		14.1
2000	2003				19.7	5.0	13.4	6.7		11.2
2001	2004				24.4	3.4	17.4	9.7		13.7
2002	2005				11.0	2.4	9.9	6.4		7.4
2003	2006				2.2	2.4	3.6	0.9		2.3
	Average	20.3	22.4	15.9	13.5	5.3	12.4	8.4	19.7	10.0
	Min	11.1	10.8	7.9	2.2	0.1	3.6	0.9	14.3	2.3
	Max	32.0	29.5	22.3	24.4	17.9	23.6	13.8	27.1	19.1
	Count	13	11	12	16	16	16	13	12	16

Survival of Baker River coho, over thirteen brood years (1989-1997, 2000-2003), has ranged just over fifteen-fold, from a high of 13.8% to a low of 0.9%. 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). This was not the case with the 2003 brood, as with Big Beef Creek and the SF Skykomish, Baker River coho returning in 2006 had the lowest marine survival measured thus far (0.9%).

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 and 2003 broods appeared to resume the former pattern averaging 12.9 adult recruits for each jack return. Given these disparate adult:jack ratios, we developed separate regression models for each data set (Figure 7).

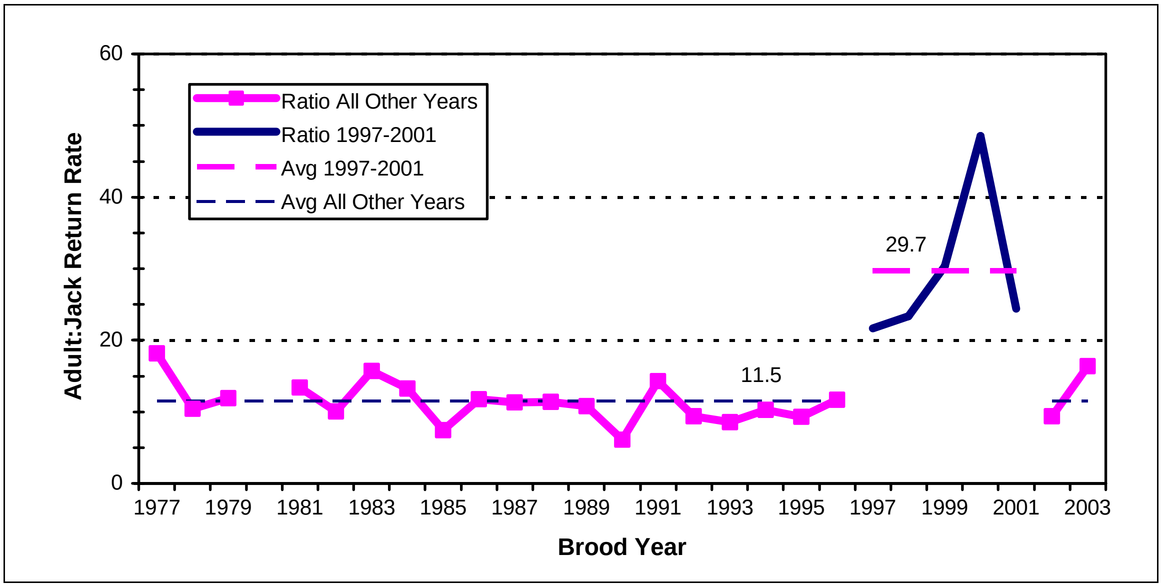

Figure 6:   Ratio of adult recruits to jack returns, by brood year, Big Beef Creek tagged wild coho.

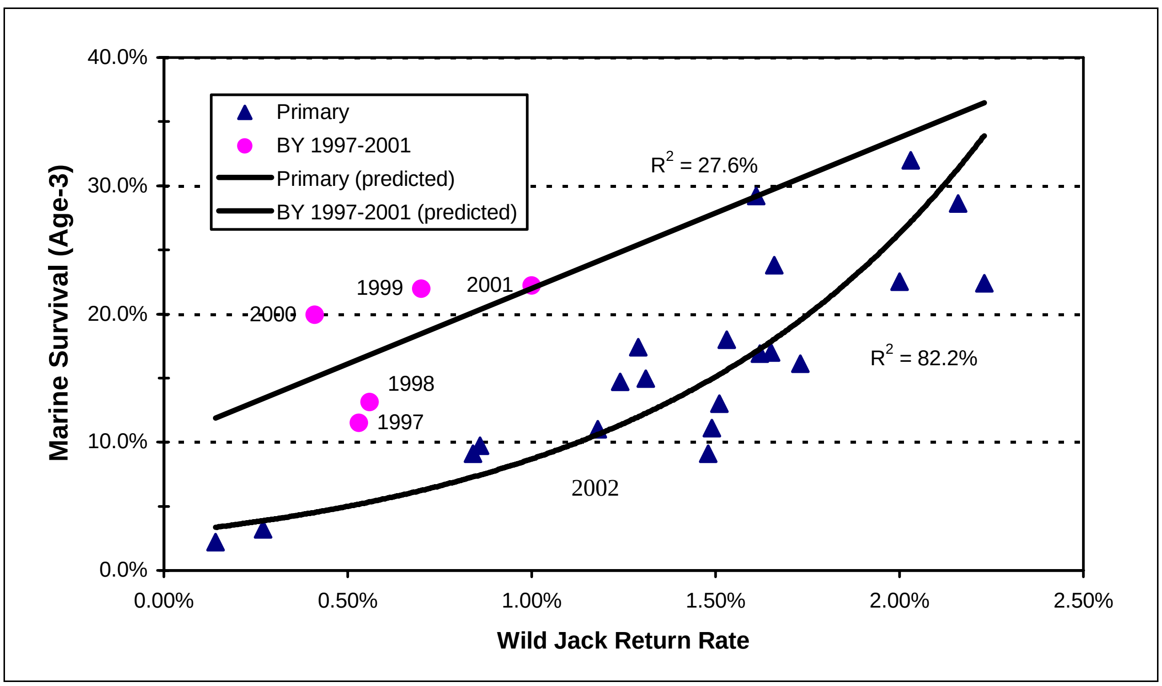

Figure 7:   Wild coho adult marine survival, relative to same-brood jack return rates, Big Beef Creek, brood years 1977-2003.

In 2006, we estimate only 82 tagged wild jacks returned from 33,329 smolts tagged in Spring 2006. Assuming the trend from the previous two brood would indicate the "Primary" model is the best predictor of marine survival, this jack return rate (0.30%) estimates the Age 3 marine survival of Hood Canal coho at 4.1%.

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 2.5%.
- For the Stillaguamish River, Lake Washington, Green River, and East Kitsap we selected a rate of 3.5%.
- For the Snohomish River, a relationship between SF Skykomish marine survival and Big Beef survival was used to estimate Snohomish River survival at 4.5%
- For the Puyallup River, we selected a rate of 3.5%.
- For the Nisqually River and South Puget Sound, we selected a rate of 3.5%.
- The Deschutes River received the lowest survival rate of 3.5%.

Countering the much lower than average marine survivals forecasted elsewhere, deep south Puget Sound marine survival was forecasted slightly higher than the recent year average (3%). There is some evidence that survival for this population may be higher for the 2004 brood. Jack returns to the Deschutes River ladder trap in 2006 were much higher than the nearly non-existent returns observed in recent years and the fish were larger than average size. Production from the 2003 brood is estimated to be too low for a better-than-average survival rates to greatly influence 2007 fishery management.

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 4.3% over 24 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 30% 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 five broods and over-predicted for five broods (Table 6). Four of the five over-predictions have occurred during the last four years. Overall, summed survivals across these ten years, predicted survival rates have exceeded actual values by a little over 1%.

Relating the 21 wild tagged jacks that returned to the Bingham Creek trap in 2006 to the 17,938 smolts tagged earlier that year, adjusted for handling mortality (16%) and tag loss (4%), predicts marine survival for the 2004 brood at 5.2% using the "late" years relationship. In the previous three broods (2001 – 2003) actual marine survivals have been ½ to 1/3rd the predicted values. Therefore, we selected a value of 2.5% to estimate marine survival for 2004 brood coho.

Lacking an indication to the contrary, we also used 2.5% for all other coastal systems.

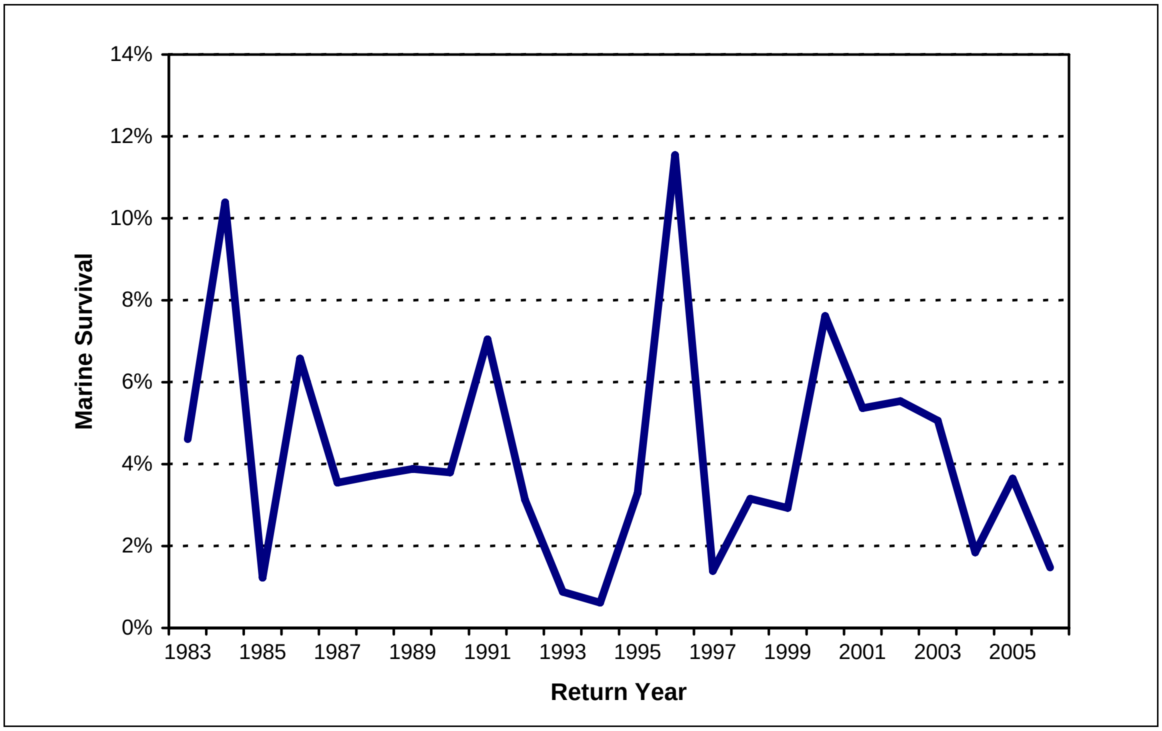

Figure 8: Marine survival of tagged wild coho from Bingham Creek.

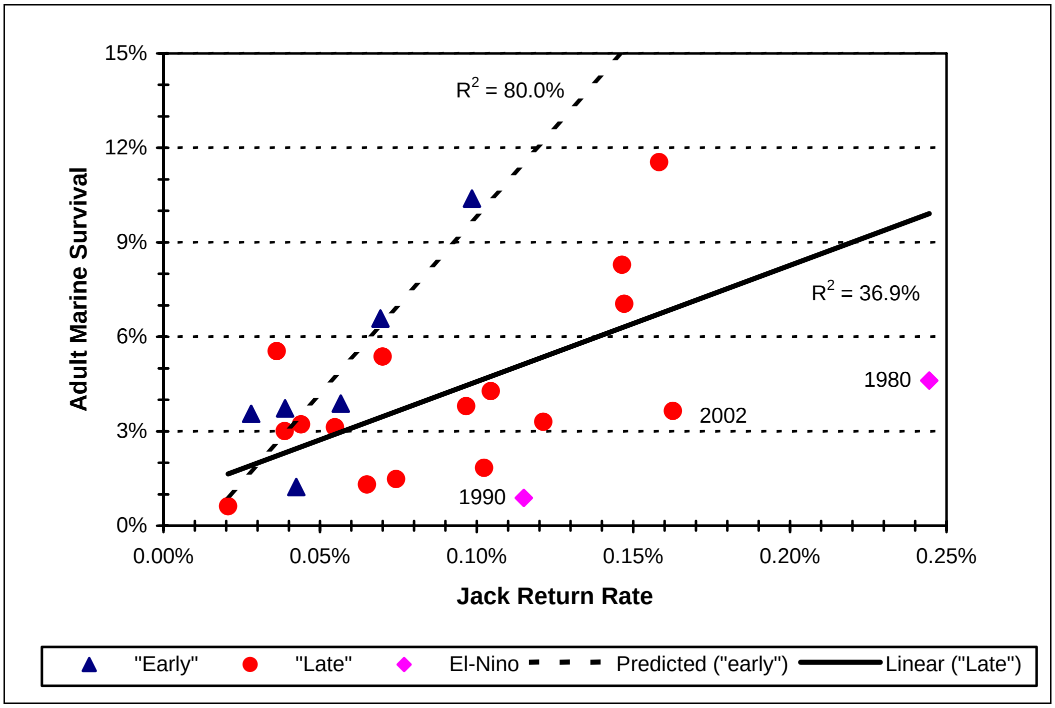

Figure 9: Jack return and adult marine survival, Bingham Creek, brood years 1980-2003.

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	
1994	1997	3.0%	1.3%	+129%
1995	1998	1.0%	3.2%	-69%
1996	1999[a]	2.0%	3.0%	-33%
1997	2000[b]	6.0%	8.3%	-28%
1998	2001	3.2%	5.4%	-40%
1999	2002[c]	3.0%	5.5%	-46%
2000	2003[d]	7.0%	4.3%	+64%
2001	2004	6.0%	1.9%	+227%
2002	2005[e]	4.0%	3.7%	+9%
2003	2006	3.8%	1.48%	+157%

[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] Selected value intermediate to late and early model predictions.
[e] Late model predicted 7.6%. Reduced to 4% due to 2001 overprediction.

Lower Columbia River

Lacking any indicators for wild coho survival in the Lower Columbia River, we also used the 2.5% rate for this system.