2008 Wild Coho Forecasts for Puget Sound, the Washington Coast, and Lower Columbia

Washington Department of Fish & Wildlife
Science Division
by
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Introduction

Run size forecasts for wild coho stocks are an important element of the joint state-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 variation in survival rates during freshwater and marine rearing phases. 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 (Volkhardt et al. 2007).

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 in 2005, harvest impacts are limited to affect rebuilding of the ESU. As a result, forecasts for Lower Columbia natural coho populations are having a greater influence on the management of Columbia River and coastal fisheries. 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 thirteen 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 2008, based on estimates of smolt production and marine survival.

Production Unit	PRODUCTION X	MARINE SURVIVAL =		RECRUITS		
	Estimated Smolt Production: Spr '07	Adults (Age 3)	Dec. (Age 2)	Adults (Age 3)	Dec. (Age 2)	Jan. (Age 3)
Puget Sound						
Primary Units						
Skagit River	747,491	8.0%	10.7%	59,800	79,700	73,640
Stillaguamish River	288,000	7.0%	9.3%	20,200	26,900	24,860
Snohomish River	800,000	7.5%	10.0%	60,000	80,000	73,920
Hood Canal	626,875	6.0%	8.0%	37,600	50,100	46,290
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	56,250	8.0%	10.7%	4,500	6,000	5,540
Lake Washington	62,000	7.0%	9.3%	4,300	5,800	5,360
Green River	65,000	7.0%	9.3%	4,600	6,100	5,640
Puyallup River	65,183	5.0%	6.7%	3,300	4,300	3,970
Nisqually River	20,000	5.0%	6.7%	1,000	1,300	1,200
Deschutes River	1,726	5.0%	6.7%	86	115	110
South Sound	172,000	5.0%	6.7%	8,600	11,500	10,630
East Kitsap	77,487	7.0%	9.3%	5,400	7,200	6,650
Puget Sound Total	3,111,012			219,686	292,815	270,560
Coast						
Queets River	301,250	2.0%	2.7%	6,025	8,031	7,420
Quillayute River	290,725	2.0%	2.7%	5,815	7,751	7,160
Hoh River	128,570	2.0%	2.7%	2,571	3,428	3,170
Quinault River	162,750	2.0%	2.7%	3,255	4,339	4,010
Independent Tributaries	159,000	2.0%	2.7%	3,180	4,239	3,920
Grays Harbor						
Chehalis River	1,783,058	2.0%	2.7%	35,661	47,536	43,920
Humptulips River	193,811	2.0%	2.7%	3,876	5,167	4,770
Willapa Bay	510,000	2.0%	2.7%	10,200	13,597	12,560
Coastal Systems Total	3,529,164			70,583	94,088	86,930
Lower Columbia Total	476,100	2.0%	2.7%	9,522	12,693	11,730
GRAND TOTAL	7,116,276			299,791	399,596	369,220

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	30	14	11,510	47,088	4.1	26,343	1,882	1,2,3,4,5
Bingham Creek	26	35	15,233	70,342	4.6	30,877	882	2,3
Deschutes River	28	160	892	133,198	149.3	49,287	308	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	27	140	27,314	99,354	3.6	65,646	469	1,4,5
Stillaguamish River	3	540	203,072	379,022	1.9	275,940	511	6
Skagit River[b]	18	1,918	617,600	1,884,700	3.1	1,046,686	546	1,2,3,8
Chehalis River	24	2,114	502,918	3,592,275	7.1	1,913,474	905	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.

<u>Key</u>

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 2007, we estimated that 747,491 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 production appears to follow an oscillating trend pattern since trapping began in 1990. Production averaged 837,000 between 1990 and 1996. Average production increased to over 1.3 million smolts between 1997 and 2003. Smolt production over the last four years has declined to the previous level, averaging 836,000. Over these eighteen years, production has ranged from 618,000 to 1,885,000 smolts. For many years, even-numbered brood years produced substantially more smolts compared to odd-numbered years. We attributed this pattern to a positive interaction with adult pink salmon, which spawn primarily in odd years. However, this pattern has been less evident over the last four years.

Table 3. Estimation of wild coho smolt production, Skagit River 2006.

	Number	Formula
Total mainstem trap catches	14,282	
Skagit Hatchery/Lake Shannon	-1,176	
Wild coho captured (c)	**13,106**	
LVs recaptured (r)	333	N = (m+1)(c+1)
LVs released (m)	19,047	(r+1)
Total production (N)	**747,491**	
Variance (Var)	1.60E+09	Var = (m+1)(c+1)(m-r)(c-r)
Standard Deviation (sd)	39,961	(r+1)^2(r+2)
Coefficient of Var (CV)	5.35%	CV = sd/N
Confindence Interval (CI)	78,324	CI = +/- 1.96(sd)
Estimated coho production		
Skagit River	747,491	
Upper CI (95%)	825,815	
Lower CI (95%)	669,168	

The 2005 brood production is 16% below the odd-year brood average production of 892,274. Flows during Summer 2006 were much lower than average for North Sound tributaries, substantially reducing summer rearing space. The Puget Sound Summer Low Flow Index (PSSLFI) registered a value of 5.9, which is 2.5 point below the long-term average of 8.4. This index has ranged from 4.5 to 13.5 over the previous 44 years. Low flows for the Central and North Puget Sound components of the index (Snoqualmie to Nooksack) averaged only 60% of their long-term summer low flow averages. Peak winter flows during egg incubation did not greatly effect the 2005 brood. Peak streamflow was measured at 57,400 cfs at the Mt Vernon gage on January 11, 2006. This is only slightly above the median peak incubation flow (October – February) of 56,550 cfs over the 1988 – 2005 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 on the

2005 brood coho in the Skagit River, we reduced the mean system production by 20%, to estimate 288,000 smolts produced in 2007.

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, we decreased the average production by 20% to estimate 800,000 smolts were produced in the Snohomish Basin in 2007.

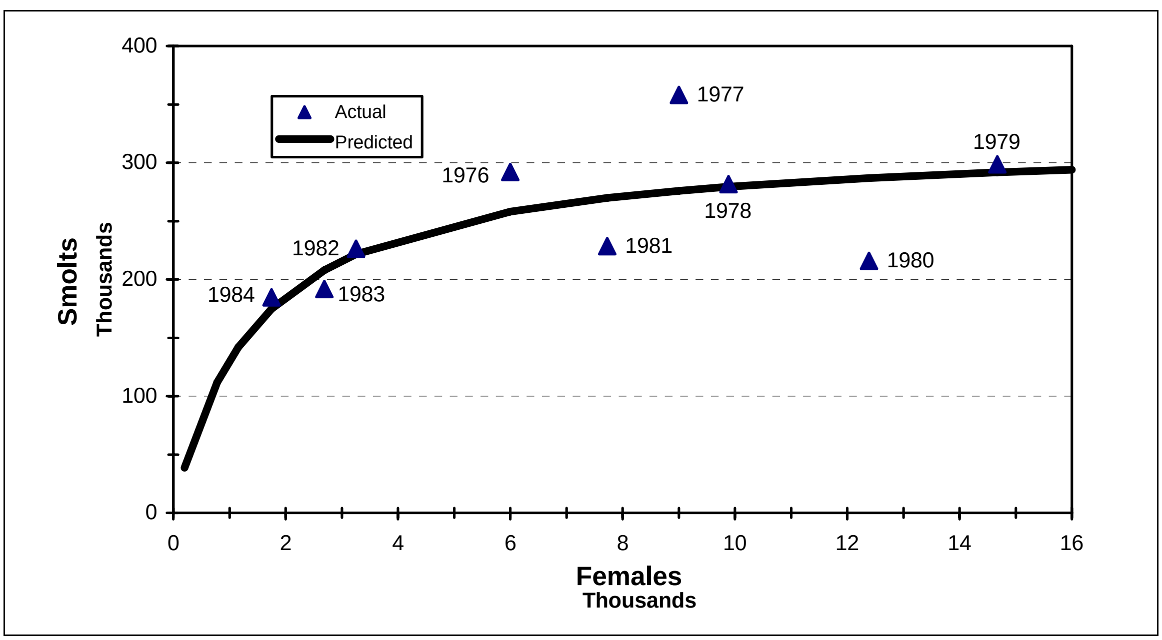

Figure 1: SF Skykomish River wild coho spawners and recruits, by brood year.

Hood Canal

In 2007 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 2007, Big Beef Creek produced 29,250 coho smolts from 625 females passed upstream in 2005, an average of 47 smolts per female. This production was 10% above the long-term average of 26,343 smolts. The adjacent streams (Stavis, Seabeck, and Little Anderson Creeks) yielded 6,749, 787 and 1,075 coho smolts, respectively. Production from Stavis Creek is slightly above average as it is for Big Beef Creek. Production from Little Anderson Creek is twice its long-term average production highlighting the improving habitat conditions observed in that stream. Production from Seabeck Creek was at an all-time low in 2007. This stream has been greatly impacted by gravel transport and bed aggradation in the lower part of the watershed causing sub-surface flows over much of the year. This condition is probably worsening over time with the very low summer low flows in 2006, producing record low production in 2007. Combined, these productions are higher than the long-term average of the previous years by a factor of 1.08.

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 (37,861 smolts) with these rates projects production for the entire Hood Canal in 2007 at 642,000 and 498,000 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. Updating this rate with more recent data (through the 2002 brood) indicates Big Beef Creek represents 4.67% of the total Hood Canal run. Inherent in this analysis are two main assumptions:

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

Expanding the 29,250 coho produced from Big Beef Creek in 2007 by the updated rate estimates total Hood Canal production at 626,875 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 2007. We used a value of 25% of the production projected by T.R.28 to estimate 113,000 smolts in 2007.

Strait of Georgia

We selected a value of 30% of the projected production (T.R.28) to estimate 16,000 smolts in 2007.

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 (2001 to 2005), 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, well above the 58,000 smolts predicted in T.R. 28. If harvest rates were higher and/or marine survival lower, then smolts production would be even higher. The 2005 escapement was well below recent trends with only 1500 coho spawners estimated. This escapement level is likely too low to provide for the 100,000 smolt production level estimated in the past. By assuming a relatively high production rate of 75 smolts/female spawner, which might be expected under low seeding conditions, and assuming a 1:1 sex ratio on the spawners, we estimate 56,250 smolts were produced in the Samish River in 2007.

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 33,994 and 25,143 coho smolts. The other significant coho-producing tributary, Issaquah Creek, was trapped once in 2000 producing 19,182 coho smolts. The 2007 production from the Cedar River and Bear Creek represents 106% and 89% of the production measured in 2000 from these streams (32,169 and 28,142, respectively). Therefore, we scaled the 2000 coho production measured in Issaquah Creek by the mean of these two (0.98) to estimate the 2007 production at 18,704 smolts. Given that these systems contain most of the best habitat in the basin, we rounded their combined production (77,841 smolts) up to 82,000 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 62,000 naturally-produced coho smolts entered Puget Sound from Lake Washington.

Green River

In 2007, 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 22,671 smolts in 2007.

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 ($5.9 \div 10.5 = 56.5\%$). This ratio estimates 36,372 coho smolts were produced from Big Soos Creek in 2007.

Addition of the Green River and Big Soos Creek productions estimates 59,043 smolts migrated downstream past the mouth of Soos Creek. A substantial number of pre-smolts migrated past the smolt trap in January and February that likely reared in the lower river. Therefore, the 2007 total system production was raised to 65,000 smolt to account for these fish.

Puyallup River

The Puyallup Tribe operated a rotary screw trap on the Puyallup River, just upstream of the mouth of the White River, in 2007. An estimated 34,906 coho passed their trap in 2007 (Andrew Berger Pers Comm. Email dated 12/19/07). This represents 11.7% 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 2007 coho smolt production estimate of 65,183.

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 2005 brood is one of the weak brood lines present in the Deschutes River. The coho return to the Deschutes River in 2005 included only 37 females. We operated the smolt trap from April 23 to June 15 in 2007. Long term data indicated approximately 88% of the coho outmigration occurs during this period. Expansion of the data estimates a total production of 1,726 smolts in 2007, which results in a system productivity of 47 smolts/female. This production represents only 0.8% 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, 2007 smolt production from Cranberry, Skookum, and

Sherwood Creeks (monitored by the Squaxin Island Tribe) averaged only 4.0% 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. Although data from 2007 was not available at the time that this document was produced, the 2006 smolt production from Minter Creek provides a way to contrast deep South Sound tribs from more northerly tribs. The 2006 production from Minter Creek 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, compared to 2.5% for Skookum, Mill, Johns, and Sherwood Creeks. 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 2007.

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 2007, the Hood Canal streams we trap produced 64% 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 2007. This project measured wild coho production at 1,392 and 460 smolts, respectively, 45% of the value predicted in T.R.28 (1,852 ÷ 4,140 smolts).

Based on the results from Steele Creek monitoring, we applied a factor of 50% to the 154,973 smolts projected by T.R. 28 for the East Kitsap region to estimate 77,487 smolts in 2007.

Coastal Systems

Queets River

During Spring 2007, 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 60,250 coho smolts. They also conducted a night-seining project in the lower Queets River, which, in conjunction with a linear programming model, estimated 301,250 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 430 smolts/mi^2 and 669 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).

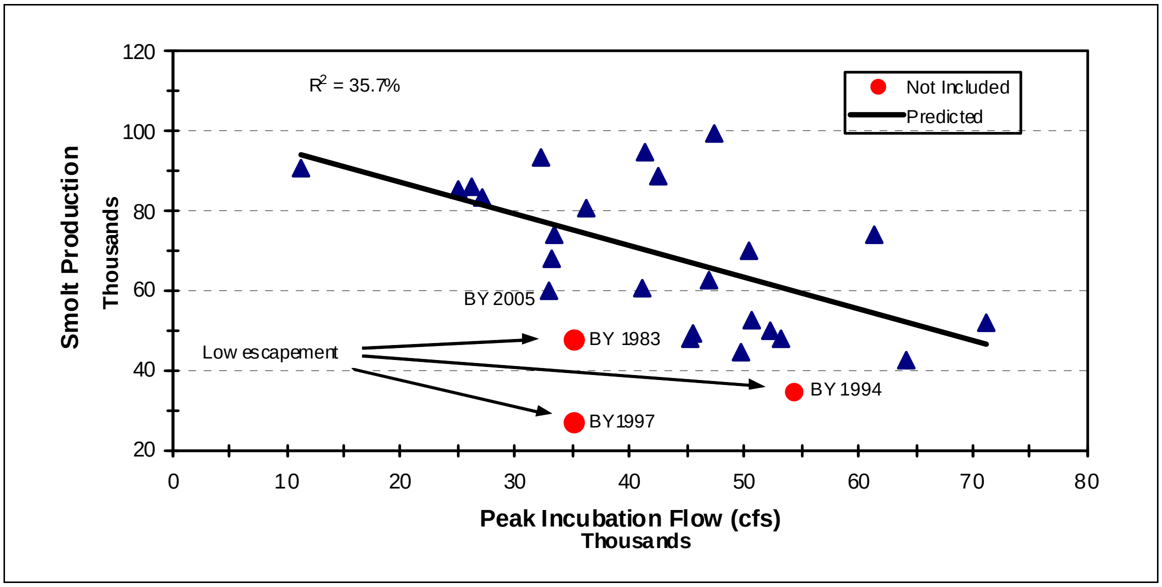

Figure 2: Clearwater River wild coho smolt production and Queets River flow, during egg incubation, brood years 1979-2003 (regression does not include low-escapement broods).

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.

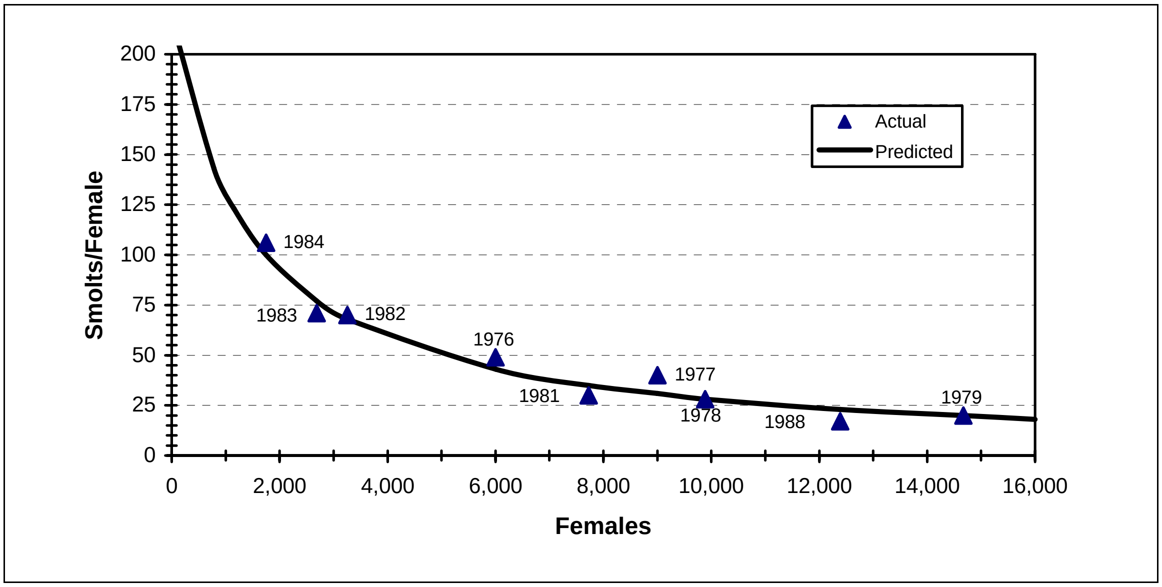

Figure 3: Productivity as a function of spawner abundance, SF Skykomish River wild coho.

For the 2005 brood, the peak flow during egg incubation (32,900 cfs) occurred on December 25, 2005. With this value, the flow relationship predicts Clearwater coho production in Spring 2007 at 77,476 smolts, substantially higher than the 60,250 estimated from the trapping data. This is the second year in a row that the flow relationship has over-estimated the actual measured abundance.

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 2007 was estimated by adjusting average production with the ratio of Clearwater smolt production in 2007 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 2007, QFiD biologists estimated that the Clearwater River produced 60,250 smolts. This smolt yield is 0.95 times the level this system produced over the three years that we also estimated production in the Bogachiel River. Assuming the 2005 brood production in the Quillayute was reduced by the same rate, we project that the average of 417 smolts/mi^2 decreased to 397 smolts/mi^2 in 2007. This rate, applied to the 521mi^2 outside the Dickey River, estimates 206,681 smolts. We also decreased the average Dickey River production (88,344 smolts) by this same factor, to project that this system produced 84,043 smolts in 2007. Adding these estimates yields a total Quillayute system production of 290,725 smolts in 2007.

Hoh River

Due to the similarity and proximity of the Hoh watershed to that of the Clearwater River, we used the Clearwater 2007 production rate to approximate Hoh River coho smolt production. At the rate of 430 smolts/mi^2, the 299-mi^2 drainage area of the Hoh River system produced an estimated 128,570 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 375 smolts/mi^2. This results in an estimated production of 162,750 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 375 smolts/mi^2 to the total watershed area (424 mi^2; Table 4) estimates 159,000 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 (51%) 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.

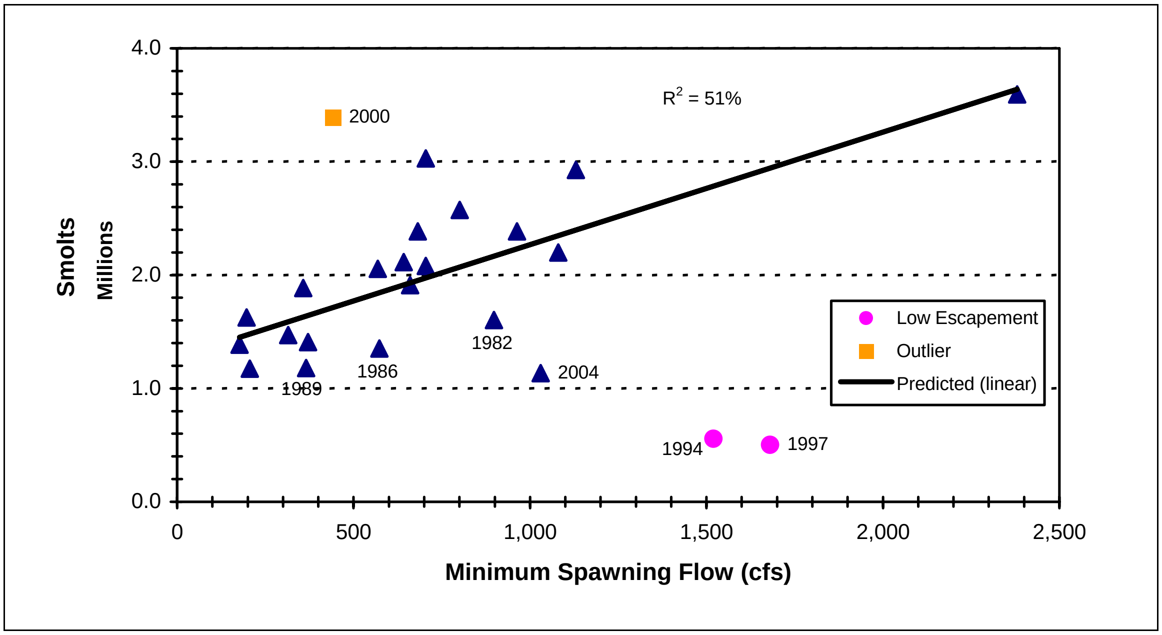

Figure 4: Chehalis River coho smolt production as a function of minimum spawning flow, November 2 through December 15, Chehalis River at Grand Mound, brood years 1980-2003.

For four 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:
- **The 2004 brood** was likely constrained by low escapement. The estimated escapement of 31,133 spawners would have needed to produce 158 smolts/female spawner to achieve the predicted smolt abundance. This level of productivity is rarely achievable. The measured production was 68 smolts/female.

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 one 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 and 2004 broods. 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 2005 was low; we estimated slightly over 43,703 adults entered the Chehalis Basin (1,387,410 smolts x 3.15% survival-to-return).

During the coho spawning and flow correlation window (November 1 - December 15) in 2005, the minimum flow value of 1,330 cfs at Grand Mound occurred on November 24. This value has only been exceeded one other time in the data set used to derive the regression shown in Figure 4. Using 1,330 cfs in the flow relationship predicts a production of 2,596,291 smolts from the 2,114-mi^2 Chehalis Basin (including the Wishkah River) during Spring 2007. At a parent escapement of 43,703, this estimates a productivity of 59 smolts/spawner or 119 smolts/female. This level of productivity is at the high end of the measured range, but is achievable in the Chehalis Basin. Under much lower escapements (6700 estimated) and similarly favorable environmental conditions, the 1997 brood produced 166 smolts/female. Yet the 2004 brood, which experienced similarly favorable conditions and a somewhat lower escapement, achieved only 68 smolts/female spawner. Therefore, we constrained the 2005 brood production assuming 75 smolts/female spawner were produced. This resulted in an estimated production of 1,638,863 smolts from the 2,114 mi^2 Chehalis River; which represents an average rate of 775 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 1,783,058 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 (775 smolts/mi^2) to estimate system production at 193,811 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 2005 brood, we selected a value of 600 smolts/mi^2. This rate, applied to the total basin area, estimates 510,000 coho smolts were produced in 2007.

Lower Columbia River

In 2007, 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 (Pat Hanratty-WDFW), sites in the Cowlitz subbasin at Mayfield Dam (Julie Henning-WDFW), Cowlitz Falls Dam (John Serl-WDFW), the Coweeman River (Cam Sharpe –WDFW) near the lower stream gauge station (RM 7.5), Cedar

Creek (Josh Holowatz-WDFW), tributary to the NF Lewis River, near the Grist Mill fish ladder (RM 2), and the Wind River above Bonneville Dam. 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 dam. At the Mayfield site, Paulik and Thompson (1967) estimated the collection efficiency for this site was 66.4% for coho salmon smolts. I assumed a release of 1000 smolts and a recapture of 664 to include a measure of uncertainty in the smolt production estimates for the Tilton River. All coho salmon juveniles captured in the Wind River were classified as parr, so no estimates were calculated for this subbasin.

Estimates were conducted in WinBUGS (Spiegehalter et al. 2003) using a using a beta-binomial mark-recapture model. 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. Preliminary smolt production estimates are found in Table 1.

Bradford et al. (2000) indicated that coho salmon smolt production was correlated to habitat. They used a distance (km) of spawning and rearing habitat as metric of habitat quantity. WDFW has observed coho smolt production is also correlated to drainage area. Since WDFW estimates of lower Columbia River tributaries spawning and rearing habitat were not readily available drainage area was used as a surrogate for spawning and rearing habitat quantity. Estimates of smolts per square mile of drainage area are also found in Table 1.

There are two estimates for Cedar Creek due to the occurrence of a Remote Site Incubation (RSI) program. The first estimate, labeled Cedar Nat. Origin, 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 2007 smolt outmigration have not been decoded so the proportion of RSI fish from the 2004 was used.

The density of coho salmon smolts in Cedar Creek was estimated to be 663 smolts per square mile of drainage area but without the RSI smolts the number was reduced to 554 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 215 and 267 smolts per square mile. Other watersheds with hatcheries had high levels of spawning escapement in 2005, 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 200,100 (90% CI 193,700 – 206,800) and is found in Table 2.

The Coweeman, Germany, Abernathy, and Mill subwatersheds have no operating coho hatcheries but hatchery coho salmon do stray and spawn in them. The densities ranged from a low of 74 to a high of 242 smolts per square mile. The median density of smolts per square mile (133) 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 2 and was predicted to be 82,520 smolts (90% CI 79,460 - 85,810).

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 form 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 193,400 (90% CI 191,200 – 195,800). The total abundance estimate for the Washington portion of the LCR ESU is found in Table 2 and was estimated 476,100 smolts (90% CI 467,900 – 484,900).

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.

It should also be noted that coho parr are observed emigrating from the Wind, Coweeman, Mill, Abernathy, and Germany (Charlie Cochran, Cam Sharpe, Pat Hanratty pers. comm.). These juveniles are likely continue rearing in freshwater below the traps and in the mainstem Columbia River and if they survive would emigrate as smolts in subsequent years. The number of coho smolts emigrating from these areas is unknown. Therefore, the coho salmon smolt abundance estimates in this report should be considered a minimum number.

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

Node	Smolt Abundance			Smolt Density (smolts/sq. mile)		
	5.00%	median	95.00%	5.00%	median	95.00%
Cedar Nat. Origin	27920	29340	30830	527	554	582
Cedar	33770	35120	36590	637	663	690
Coweeman	7568	8784	10310	64	74	87
Mill	6752	7044	7354	233	243	254
Abernathy	2994	3282	3616	103	113	125
Germany	2178	2342	2525	95	102	110
Tilton	32970	34190	35560	207	215	224
U. Cowlitz	264100	277400	292000	254	266	280

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.

Node	Smolt Abundance			Smolt Density (smolts/sq. mile)		
	5.00%	median	95.00%	5.00%	median	95.00%
Unmonitored H_Streams	193700	200100	206800	233	241	249
Unmonitored W_Streams	79460	82520	85810	128	133	138
Monitored Streams	191200	193400	195800			
Nat. Origin Smolt Prediction	467900	476100	484900			

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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 1975-2004, from a high of 32% to a low of 3%. 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 resulted from unreported and unsampled coho caught in Hood Canal net fisheries.

For brood years 1977 through 2004, 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 eighteen broods, has experienced significantly lower survival rates than those of other stocks measured (Figure 5, Table 7). However, Deschutes marine survival rates have been similar to that of other Puget Sound stocks over the last two broods.

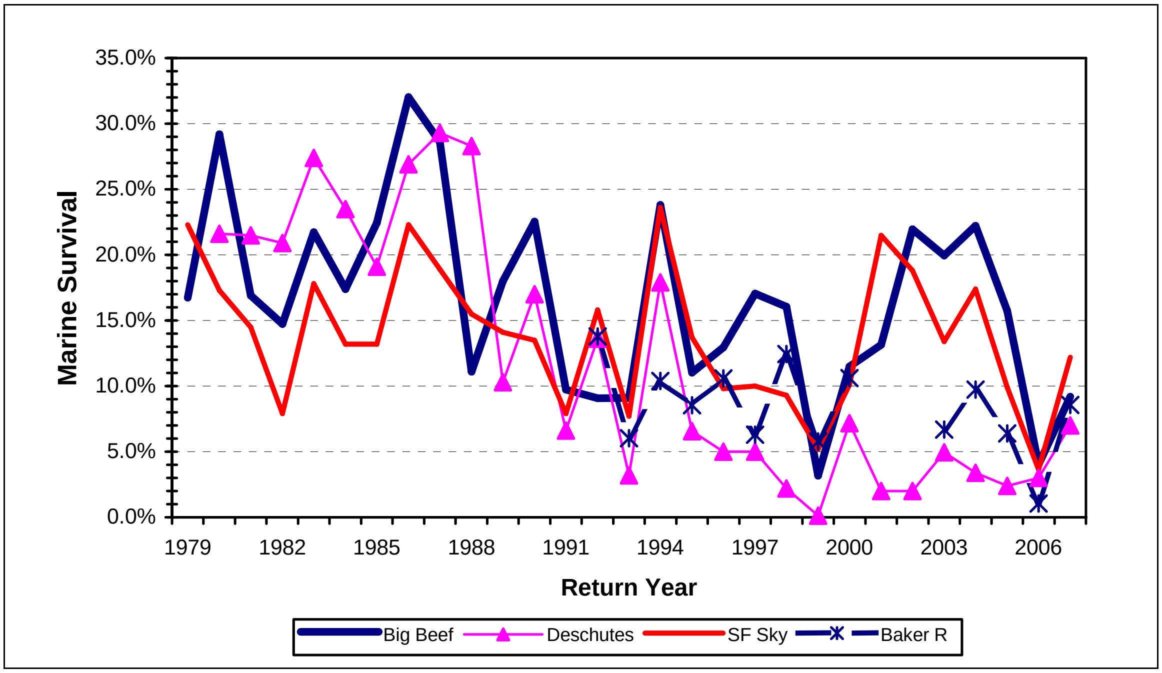

Figure 5: Marine Survival of wild coho (age-3) measured at four Puget Sound streams.

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 2004 brood, we assumed that the return of 28,581 adults to the trap represented 85% of the run, resulting in a total run of 33,625 coho. Relating this estimate to the average smolt production yields a marine survival rate of 12.2%.

Table 7. Comparison of marine survival (age 3) between Big Beef Creek, Deschutes River, SF Skykomish River, and Baker River wild tagged coho.

Year		**Big Beef**	**Des River**	**SF Sky**	**Big Beef**	**Des River**	**SF Sky**	**Baker River**	**Average**	
Brood	**Rtn**								**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				4.8	2.4	3.6	1.1		3.0
2004	2007				9.2	7.0	12.2	8.6		2.3
	Average	20.3	22.4	15.9	13.4	5.4	12.3	8.4	19.7	9.6
	Min	11.1	10.8	7.9	3.2	0.1	3.6	1.1	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	17	17	17	14	12	17

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 1.1%. While survival of Baker River coho appears to generally track the other stocks we have measured (Figure 5), over these broods it has generally exhibited a biennial pattern, with odd-numbered brood years experiencing higher survivals than even-numbered brood years (Table 7). 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 (1.1%).

Predicting 2005 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 (Primary Model). Over the subsequent broods (1997 through 2004), however, adult recruits have ranged from 11-49 times, and averaged 27.8-times respective brood year jack returns (Secondary Model)(Figure 6). The 2002 brood appeared similar to the former "primary model" pattern with 11.4 adult recruits for each jack return. Given these disparate adult:jack ratios, we developed separate regression models for each data set (Figure 7).

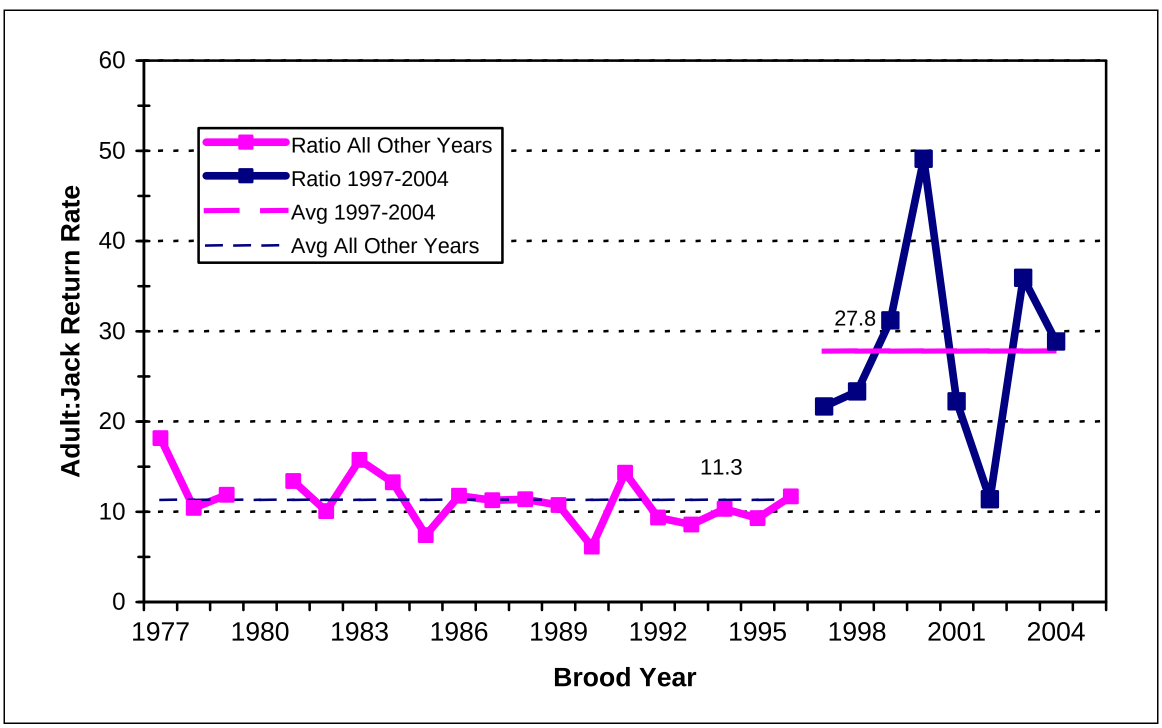

Figure 6: Ratio of adult recruits to jack returns, by brood year, Big Beef Creek tagged wild coho.

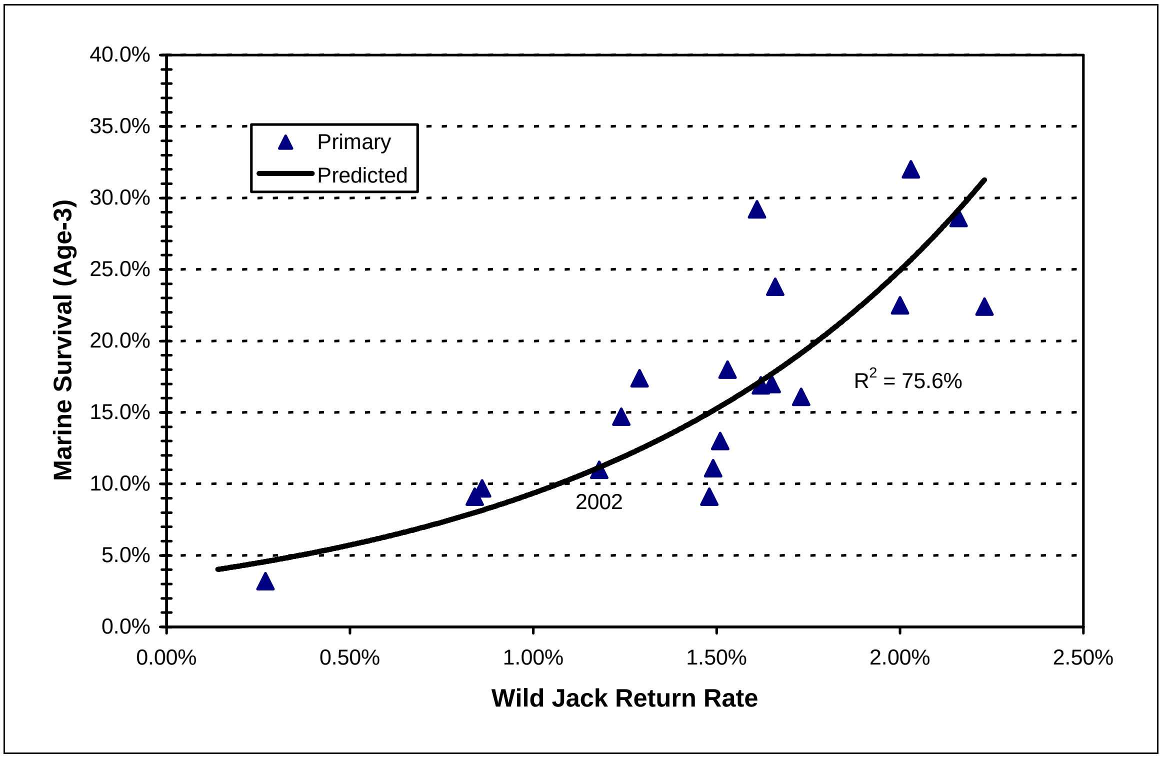

Figure 7: Wild coho adult marine survival, relative to same-brood jack return rates, Big Beef Creek, brood years 1977-2004.

In 2007, we estimate 39 tagged wild jacks returned from 21,715 smolts tagged in Spring 2007 resulting in a low jack return rate (0.18%). Using this rate, the secondary model predicted Hood Canal Age 3 marine survival at 7.9%. Since this model has not fit the 1997 to 2004 data as well as the primary model had fit the previous data set, we attempted to look at other factors that might correlate with Hood Canal marine survival. Data collected in Hood Canal by the Washington Department of Ecology was analyzed to evaluate measures of temperature, salinity, water density, and light transmission relative to marine survival. We found that maximum light transmission in the water column during June was negatively correlated with marine survival (Figure 8). This intuitively seems plausible for the following reasons:

- Most mortality during the marine rearing period likely happens soon after smolt emigration,
- Nearly all smolt outmigrants have reached Hood Canal by June,
- Low light transmission could relate to a higher density of plankton in the water column, and
- Lower light transmission would also related to higher levels of particulates in the water column, thereby decreasing the effectiveness of sight predators.

Maximum June light transmission was recorded at 98% in 2007, the highest value in the 1990 – 2007 dataset, which suggests a low marine survival for the 2005 brood. As a result, we lowered the prediction made by the "secondary" model to 6% to represent marine survival for the 2005 brood.

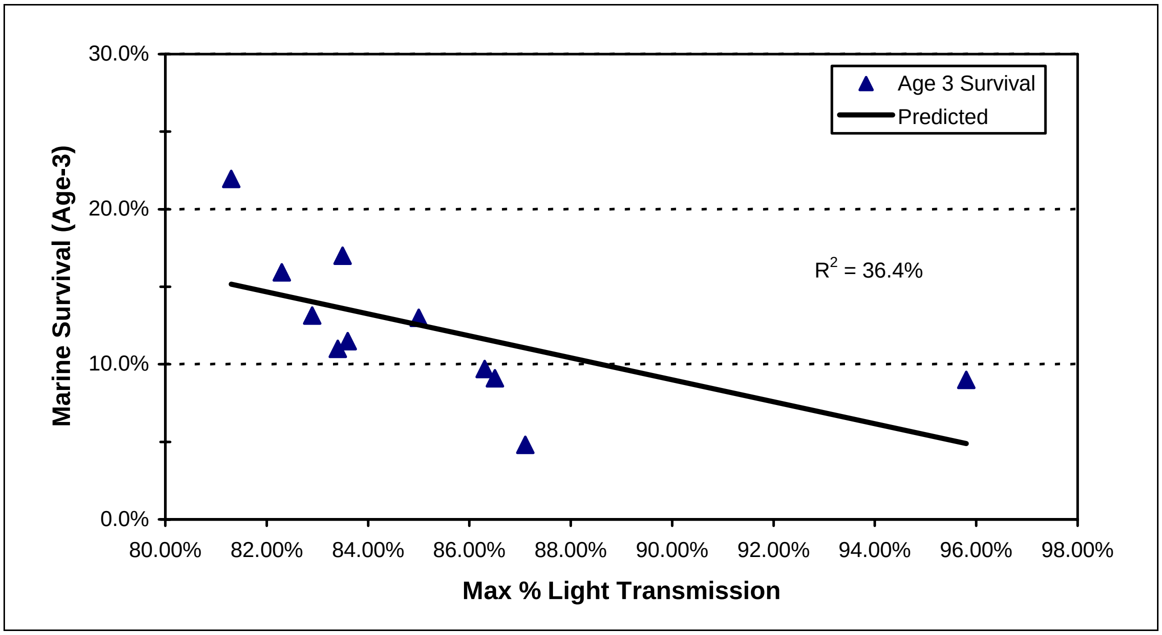

Figure 8. Big Beef Creek coho marine survival (age 3) as a function of the maximum percent light transmission recorded in the water column during June sampling off the Hamma Hamma sampling site (Dept of Ecology data).

For other Puget Sound areas, we selected the following age-3 survival rates, which incorporate recent trends and patterns in marine survival (Table 7). 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 during odd broods was used to estimate north Puget Sound survival at 8.0%.
- For the Stillaguamish River, Lake Washington, Green River, and East Kitsap we selected a rate of 7.0%.
- For the Snohomish River, a relationship between SF Skykomish marine survival and Big Beef survival was used to estimate Snohomish River survival at 7.5%
- For the Puyallup River, we selected a rate of 5.0%.
- For the Nisqually River, Deschutes River, and South Puget Sound, we selected a rate of 5.0%.

For many years, survival of deep South Sound coho was much lower than the rest of Puget Sound as is shown by the Deschutes River stock in Table 5. Over the last two broods, marine survival was only slightly below those measured at Big Beef Creek. Therefore, the 2005 brood marine survivals for deep South Sound are forecasted only slightly below that forecasted for Big Beef Creek.

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 4.2% over 25 years (Figure 9). 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. A third split was made this year since marine survival for the last four broods have consistently come in at about ½ the value predicted by the "late" model (Figure 10). 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 four broods (Table 8). Marine survival for the 2004 brood was correctly predicted based on preliminary data. The four over-predictions have occurred during the four years previous to last year, which prompted our re-evaluation of the model. Overall, summed survivals across these ten years, predicted survival rates have under-estimated actual values by a little less than 1%.

Relating the 16 wild tagged jacks that returned to the Bingham Creek trap in 2007 to the 20,172 smolts tagged earlier that year, adjusted for handling mortality (16%) and tag loss (4%), predicts marine survival for the 2005 brood at 1.6% using the new BY01-Present relationship. Unlike the previous four broods, the PDO index indicated more favorable conditions existed when juveniles were leaving the Grays Harbor estuary in 2007; therefore, the model estimate was adjusted slightly upward to 2.0%.

Lacking an indication to the contrary, we also used 2.0% for all other coastal systems.

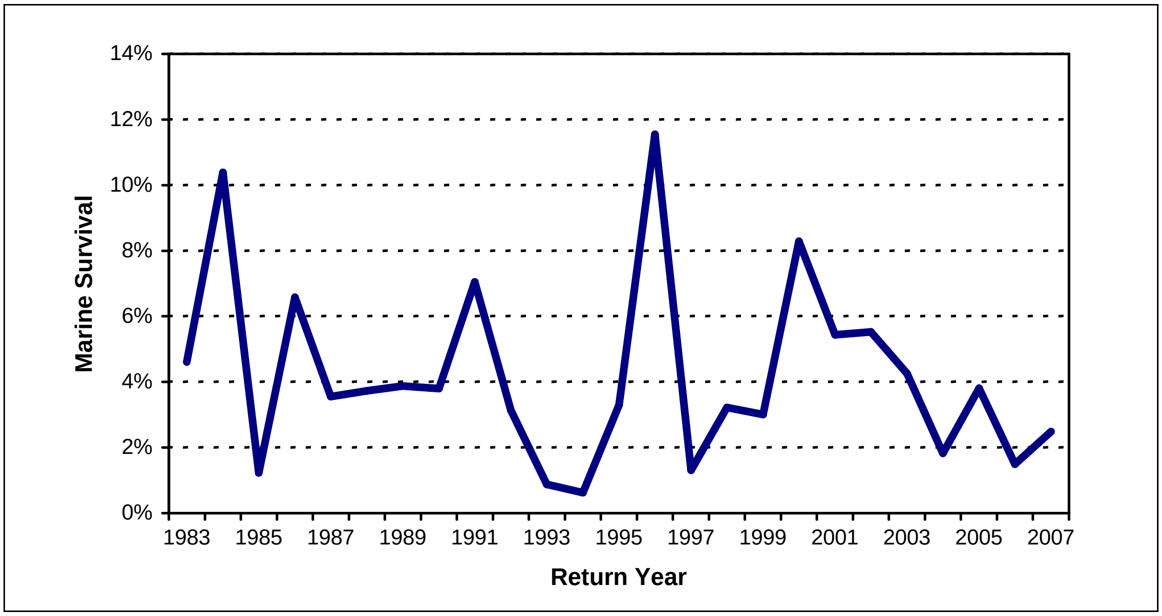

Figure 9: Marine survival of tagged wild coho from Bingham Creek.

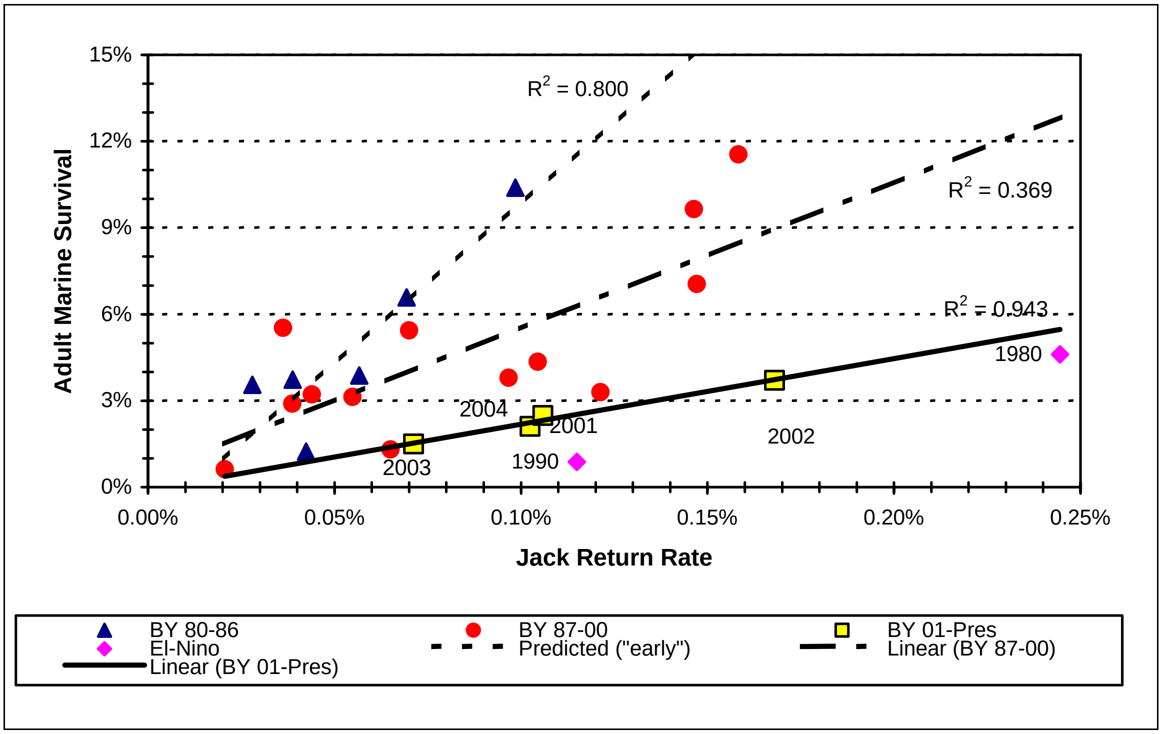

Figure 10: Jack return and adult marine survival, Bingham Creek, brood years 1980-2004.

Table 8. Forecasted and measured adult marine survival for 1995-2004 brood Bingham Creek wild coho.

Brood Year (i)	Return Year (i+3)	ADULT MARINE SURVIVAL		% Error
		Predicted	Actual	
1995	1998	1.00%	3.22%	-69%
1996	1999[a]	2.00%	2.90%	-31%
1997	2000[b]	6.00%	9.65%	-38%
1998	2001	3.20%	5.44%	-41%
1999	2002[c]	3.00%	5.53%	-46%
2000	2003[d]	7.00%	4.35%	61%
2001	2004	6.00%	2.11%	184%
2002	2005[e]	4.00%	3.71%	8%
2003	2006	3.80%	1.50%	153%
2004	2007[f]	2.50%	2.49%	0%

[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
[c] Used intermediate survival between “early” and “late” year model
[d] Selected value intermediate to late and early model predictions.
[e] Late model predicted 7.6%. Reduced to 4% due to 2001 over
[f] Selected half the value predicted by the late model due to recent trends

Lower Columbia River

Lacking any indicators for wild coho survival in the Lower Columbia River, we also used the 2.0% rate for this system.