2004 Wild Coho Forecasts for Puget Sound & Washington Coastal Systems

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Science Division
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Introduction

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

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

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

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

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

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

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 2004, based on estimates of smolt production and marine survival.

Production Unit	PRODUCTION X MARINE SURVIVAL = Estimated Smolt Production: Spr '03	Adults (Age 3)	Dec. (Age 2)	RECRUITS Adults (Age 3)	Dec. (Age 2)	Jan. (Age 3)
Puget Sound						
Primary Units						
Skagit River	1,382,000	11.3%	15.1%	156,200	208,200	192,380
Stillaguamish River	360,000	12.0%	16.0%	43,200	57,600	53,220
Snohomish River	1,000,000	14.0%	18.7%	140,000	186,600	172,420
Hood Canal	791,000	20.0%	26.7%	158,200	210,900	194,870
Straits of Juan de Fuca	**see note below**					
Secondary Units						
Nooksack River	113,000	11.3%	15.1%	12,800	17,000	15,710
Strait of Georgia	30,000	11.3%	15.1%	3,400	4,500	4,160
Samish River	100,000	11.3%	15.1%	11,300	15,100	13,950
Lake Washington	122,000	12.0%	16.0%	14,600	19,500	18,020
Green River	96,000	12.0%	16.0%	11,500	15,400	14,230
Puyallup River	139,000	10.0%	13.3%	13,900	18,500	17,090
Nisqually River	20,000	5.0%	6.7%	1,000	1,300	1,200
Deschutes River	2,500	3.0%	4.0%	100	100	90
South Sound	143,000	5.0%	6.7%	7,200	9,500	8,780
East Kitsap	108,000	12.0%	16.0%	13,000	17,300	15,990
Puget Sound Total	4,406,500			586,400	781,500	722,110
Coast						
Quillayute River	339,000	6.0%	8.0%	20,340	27,113	25,050
Hoh River	159,000	6.0%	8.0%	9,540	12,717	11,750
Queets River	372,000	6.0%	8.0%	22,320	29,753	27,490
Quinault River	217,000	6.0%	8.0%	13,020	17,356	16,040
Independent Tributaries	212,000	6.0%	8.0%	12,720	16,956	15,670
Grays Harbor						
Chehalis River	2,152,000	6.0%	8.0%	129,120	172,117	159,040
Humptulips River	234,000	6.0%	8.0%	14,040	18,715	17,290
Willapa Bay	595,000	6.0%	8.0%	35,700	47,588	43,970
Coastal Systems Total	4,280,000			256,800	342,315	316,300
Lower Columbia Total	892,000	5.0%	6.7%	44,600	59,452	54,930
GRAND TOTAL	9,578,500			887,800	1,183,267	1,093,340

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 1970's, 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. 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	26	14	11,510	47,089	4.1	25,586	1,828	1,2,3,4,5
Bingham Creek	22	35	15,280	71,708	4.7	32,040	915	2,3
Deschutes River[a]	25	130	892	133,198	149.3	56,253	433	1,2,4,5
SF Skykomish River	9	362	181,877	353,981	1.9	249,442	689	7
Dickey River[b]	3	87	61,717	77,554	1.3	71,189	818	6
Bogachiel River[b]	3	129	48,962	61,580	1.3	53,751	417	6
Clearwater River	22	140	27,314	99,354	3.6	64,284	459	1,4,5
Stillaguamish River	3	540	203,072	379,022	1.9	275,940	511	6
Skagit River[c]	14	1,918	617,600	1,884,700	3.1	1,082,462	564	1,2,3,8
Chehalis River	19	2,114	502,918	3,592,275	7.1	1,837,273	869	1,2,3,4
Total		5,469						
Mean							743	
Weighted Mean[d]							683	

[a] Deschutes River total drainage area – 160 mi^2, of which 30 mi^2 are inaccessible above Deschutes Falls.
[b] Dickey and Bogachiel River watersheds are estimated areas above trap locations.
[c] Skagit River total drainage area – 3,093 mi^2, of which 1,175 mi^2 are inaccessible above dams.
[d] Weighted by catch.

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** Zillges 1977 (T.R.28) 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 2003, we estimated nearly 1.4 million 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 fourteen years that we have measured it, ranging from 618,000 to 1,885,000 smolts. On average, even-numbered brood years have produced 1.5 times as many smolts as odd-numbered years. 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 2003.

	Number	Formula
Total mainstem trap catches	15,449	
Skagit Hatchery/Lake Shannon	-1,676	
Wild coho captured (c)	**13,773**	
RVs recaptured (r)	178	$N = \frac{(m+1)(c+1)}{(r+1)}$
RVs released (m)	17,965	
Total production (N)	**1,382,479**	
Variance (Var)	1.04E+10	$Var = \frac{(m+1)(c+1)(m-r)(c-r)}{(r+1)^2(r+1)}$
Standard Deviation (sd)	102,145	
Coefficient of Var (CV)	7.39%	CV = sd/N
Confindence Interval (CI)	200,204	CI = +/- 1.96(sd)
Estimated coho production		
Skagit River	1,382,479	
Upper CI (95%)	1,582,683	
Lower CI (95%)	1,182,274	

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. Flows during the critical summer rearing period, as measured with the Puget Sound Summer Low Flow Index (PSSLFI), were above the 39-year average of 8.6, and varied little (from 9.5 to 10.5, average of 10.0) over these three broods.

Although the PSSLFI for water year 2002 had a value of 6.4, below the long-term average, the trend of increasing production measured in the Skagit River, which continued with the 2001 brood, provided a contrary indicator. Therefore, for Spring 2003 we elected to represent the Stillaguamish system with its average production estimate of 360,000 smolts.

Snohomish River

We measured smolt production from known numbers of spawners in the South Fork Skykomish River over nine brood years (1976-1984) (Figure 1). This sub-basin comprises 20.7% of the Snohomish River system's drainage area. Excluding the three years in which we reduced escapement, production averaged 276,000 smolts. These estimates were generated using "back-calculation" — determining coded-wire tag ratios upon adult return. Consequently, they include

production which reared downstream of Sunset Falls. Trapping-based estimates for these six broods indicate that around 75% of these estimated productions emigrated as smolts from above Sunset Falls. Adjusting the estimates by this rate yields an average production of 207,000 smolts that remained above Sunset Falls until spring. Expansion of this estimate to the entire system calculates an average total production of 1,000,000 coho smolts.

Although a significant portion (450 mi^2, 26%) of the 1,714 mi^2 Snohomish Basin is inaccessible to anadromous fish, which includes the Snoqualmie Basin above Snoqualmie Falls (375 mi^2) and the Sultan Basin above the dam (75 mi^2), the habitat above Sunset Falls is also fairly steep. Therefore, we 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.

As with the Stillaguamish River, although low summer flows may have constrained production, the above-average odd-year production measured in the Skagit River may indicate at least average production was attained. Therefore, we recommend selecting the average smolt production level for the Snohomish Basin in 2003 of one million smolts.

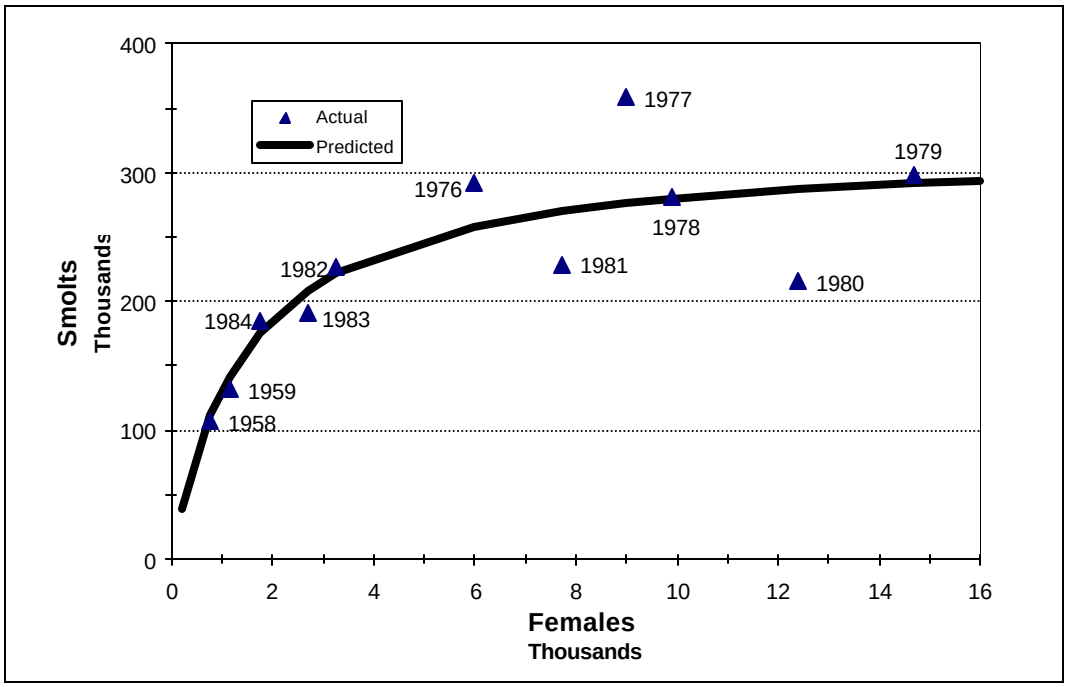

Figure 1: SF Skykomish River wild coho spawners and recruits, by brood year.

Hood Canal

In 2003 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 2003, Big Beef Creek produced 36,060 coho smolts, from 1,807 females passed upstream in 2001, an average of 20 smolts per female. This production was 143% of the long-term average of 25,166 smolts. The adjacent streams, which we also have trapped, since 1992, yielded 7,752, 1,579 and 239 coho smolts, respectively. These productions are also above the previous long-term average, by a factor of 130%. Habitat in both

Seabeck and Little Anderson Creeks are degraded by development, stormwater runoff and consequent high sediment loads.

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 (45,630 smolts) with these rates projects production for the entire Hood Canal in 2003 at 773,000 and 600,000 coho smolts based on the habitat estimated by T.R.28 and the HCJTC.

In previous years, we have selected one of these ratios to estimate smolt production. Beginning with the 1999 brood, however, we have developed a new rate (4.56%) based on the HCJTC forecast review (Summer 2001), which compared predicted cohorts with those computed post season via run reconstruction. This analysis estimated that expanding Big Beef Creek smolt production by a factor of 21.93 (1 ÷ 0.0456) best predicts Hood Canal run size. 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 36,060 coho from Big Beef Creek in 2003 with this rate estimates total production at 791,000 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 2003. We used a value of 25% of the production projected by T.R.28 to estimate 113,000 smolts in 2003.

Strait of Georgia

We selected a value of 30% of the projected production (T.R.28) to estimate 30,000 smolts in 2003.

Samish River

Scale sampling/analysis has indicated that virtually all of the adult coho returning to the weir at the Samish Hatchery are wild. In some recent years, 10,000 adult coho have returned. Even at a relatively low harvest rate and a high marine survival, production would exceed 100,000 smolts. If harvest rates were higher and/or marine survival lower, then even more smolts were produced. Lacking a direct estimate, we selected a value of 100,000 smolts as our best approximation of production in 2003. 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 75,000 and 49,000 coho smolts, respectively. Given that these systems contain most of the best habitat in the basin, their combined production accounts for the majority of the natural coho yield in the Lake Washington Basin.

One measure of the production levels in the smaller urbanized streams is provided by a smolt-monitoring project conducted by Seattle Public Utilities in Thornton Creek. Spring 2003 was the fourth year of sampling this creek, one of the most developed watersheds in the basin. Using a weir that trapped 100% of the migrants, 71 coho smolts were caught over 12 days in early May. Over this interval, the migration-timing model derived at Big Beef Creek estimates that 43% of the season's coho smolt migration occurred. During this same period, we estimate 48% of the coho migration passed our trap at Big Bear Creek. We used the average of both sites (46%) to estimate that Thornton Creek produced 150 coho smolts in 2003.

In 2000, the year that we trapped Issaquah Creek, we estimated production at 18,000 smolts, 30% of the combined coho production from Cedar River and Bear Creek in that year. Assuming production for Issaquah in 2003 comprised that same ratio, we estimate production at 37,000 smolts.

Given the extremely low production from the small urban streams, we estimated only 2,000 coho smolts were produced from all other habitat (including the lakes) outside of the Cedar River, Big Bear and Issaquah Creeks. The sum of the four production components yields an estimated 163,000 naturally-produced coho smolts entering Lake Washington.

On-going research conducted in 2003, associated with evaluating smolt passage at the Ballard Locks, provided additional insight into smolt survival from the tributaries to the Locks. We assessed relative survival to the 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 122,000 naturally-produced coho smolts entered Puget Sound from the Lake Washington system at the Ballard Locks.

Green River

In 2003, we continued operating a floating screw trap in the mainstem of the Green River at R.M. 34, from February through mid-July. Although this project is directed at assessing wild chinook production, we also enumerated all salmonids captured. Estimating natural coho production in 2003, however, was confounded by the presence of unmarked hatchery coho smolts. Many of these smolts (242,000 unmarked coho released at Keta Creek) were indistinguishable from wild fish, and therefore our actual catch of wild coho is unknown.

In the previous three years, we have estimated production at 43,000, 46,000 and 191,000 coho smolts. Based on this production record, we selected a value of 50,000 coho smolts for the habitat above the screw trap in 2003.

The other major production area in this system is Big Soos Creek, which enters the Green River downstream of our screw trap. In 2000, we trapped this stream and estimated its production at 60,000 coho smolts. In this same year, Big Beef Creek produced a record high of 47,089 smolts. We estimated production from Soos Creek in 2003 using this same proportion to Big Beef Creek production. This ratio estimates 46,000 coho smolts were produced from Big Soos Creek in 2003.

Addition of the Green River and Big Soos Creek productions estimates total coho production at 96,000 smolts.

Puyallup River

We have no direct estimates of coho smolt production from this system for 2003. In the adjacent Green River, however, in three of the last four years, production has averaged around 100,000 smolts, or 25% of the potential production estimate of 416,000 smolts in T.R.28. Application of this rate to the 556,000-smolt production potential estimated in T.R.28 yields 139,000 smolts produced from the Puyallup/White River System in 2003.

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 (TR 28). We selected this rate, half of last year's estimate, based on very low production measured at the Deschutes River.

Deschutes River

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 production, extremely poor marine survival is the primary reason that this stock's status is so low. In the 1990s, marine survival for Deschutes coho 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 nearly extinct.

The coho return to the Deschutes River in 2001 included only 24 females. Through trapping in Spring 2003, we estimated 2,500 coho smolts, a production rate of 104 smolts/female. While this production rate indicates some level of compensatory survival, it is still considerably lower than we would expect given the extremely low spawning population (Figure 2). The production of 2,500 smolts represents just 1% of the production potential (219,000 smolts) estimated in T.R.28.

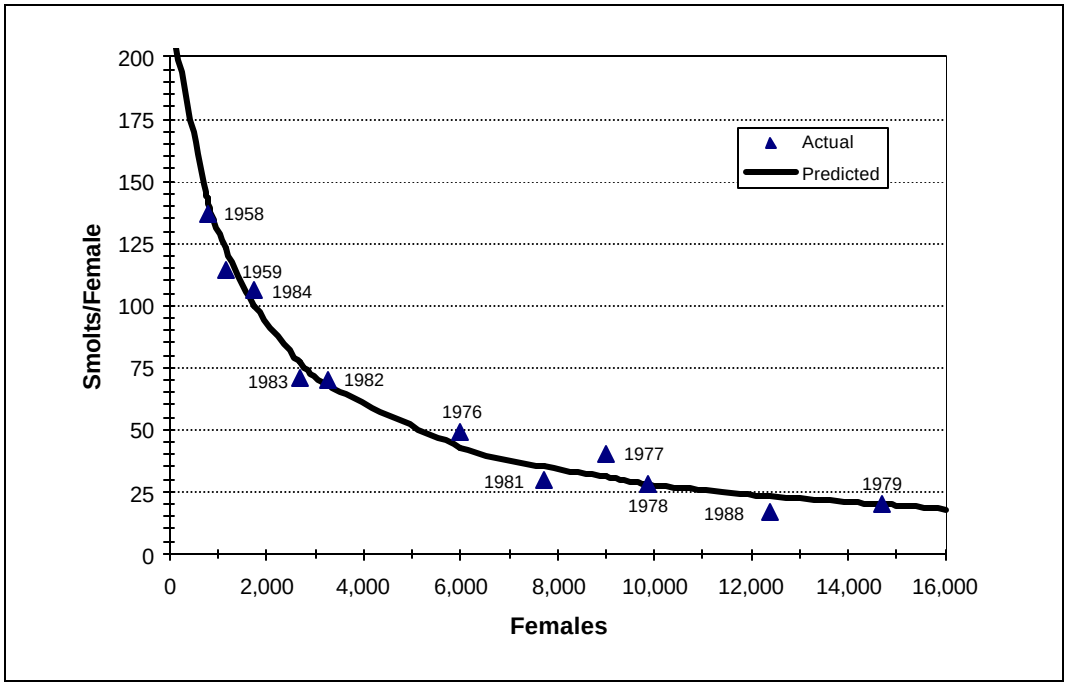

Figure 2: Productivity as a function of spawner abundance, SF Skykomish River wild coho.

South Sound

This production area includes all of the independent tributaries to Puget Sound, south of Area 10 (Seattle), excluding Lake Washington, and the Green, Puyallup, Nisqually, and Deschutes Rivers.

Production from tributaries entering deep South Sound have suffered from the same factors described for the Deschutes River. However, the more northerly tributaries, while impacted by increasing urbanization, have probably realized somewhat higher seeding levels as a result of higher marine survival rates. We applied a factor of 25% to the potential production of 573,770 smolts projected in T.R.28. This rate estimates 143,000 coho smolts were produced from these South Sound streams in Spring 2003.

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 2003, Big Beef Creek produced 93% of the smolts projected by T.R.28. Production from the only East Kitsap tributary trapped in 2003, Steele Creek, was estimated at 70% of the value predicted in T.R.28 (2,897 ÷ 4,140 smolts). The SCORE volunteer group (Steele Creek Organization for Resource Enhancement) trapped both the north and south forks, which yielded 2,458 and 439 smolts, respectively.

Based on results from Steele Creek monitoring, we applied a factor of 70% to the 154,973 smolts projected by T.R.28 for the East Kitsap region to estimate 108,000 smolts in 2003.

Coastal Systems

Queets River

During Spring 2003, Quinault Tribal biologists estimated that the Clearwater River produced 74,415 coho smolts. They also employed a linear programming model that estimated 372,075 wild coho smolts were produced from the entire Queets system (memo: John Cornell to Rob Rhoads). Relating these smolt production estimates to the drainage areas in the two systems yields production rates of 532 smolts/mi^2 and 827 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 3).

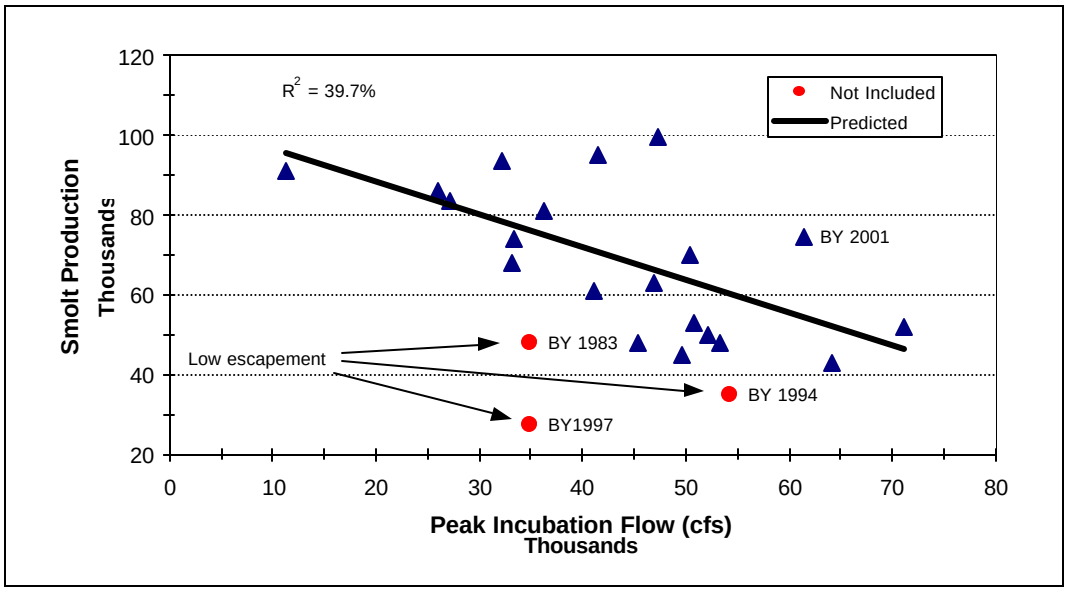

Figure 3: Clearwater River wild coho smolt production and Queets River flow, during egg incubation, brood years 1979-2001 (regression does not include low-escapement broods and brood years 1981 and 1998).

In brood year 1994, however, it appears that low escapement did limit 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 falls 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 2). 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.

Quillayute River

We 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 2003 was estimated by adjusting average production with the ratio of Clearwater smolt production in 2003 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 2003, QFiD biologists estimated that the Clearwater River produced 74,415 smolts. This smolt yield is 1.17 times the level this system produced over the three-years that we also estimated production in the Bogachiel River. Assuming production in the Quillayute increased at this same rate, we project that the average of 417 smolts/mi^2 increased to 490 smolts/mi^2 in 2003. This rate, applied to the 521mi^2 outside the Dickey River, estimates 255,000 smolts. We also increased the average Dickey River production (71,189 smolts) by this same factor, to project that this system produced 83,291 smolts in 2003. Addition of these estimates yields a total Quillayute system production of 339,000 smolts in 2003.

Hoh River

Due to the similarity and proximity of the Hoh watershed to that of the Clearwater River, we used the Clearwater 2003 production rate to approximate Hoh River coho smolt production. At the rate of 532 smolts/mi^2, the 299-mi^2 drainage area of the Hoh River system produced an estimated 159,000 smolts.

Quinault River

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

Independent Tributaries

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

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

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

Grays Harbor

We have estimated coho smolt production from the Chehalis River system for over twenty years, 1980 brood through the 1999 brood. This estimate relies upon annually trapping/tagging wild smolts, and sampling adults caught in the Quinault Tribe's terminal net fishery in the lower Chehalis River for coded-wire tags. Resultant estimates have ranged seven-fold, from around 0.5 million to 3.6 million. Analysis to understand the components of variation has determined that flow during spawning, explains most (73%) of the inter-annual variation in estimated smolt production, providing seeding levels are adequate (Figure 4).

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

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

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

1997 brood: Escapement in 1997 was even lower than its parent brood (1994). We estimated only 7,000 adults spawned in 1997. Fortunately, these spawners experienced a very high minimum flow, in excess of 1,500 cfs. As a result, this brood achieved the very high average production per spawner of 159 smolts/female (Figure 2).

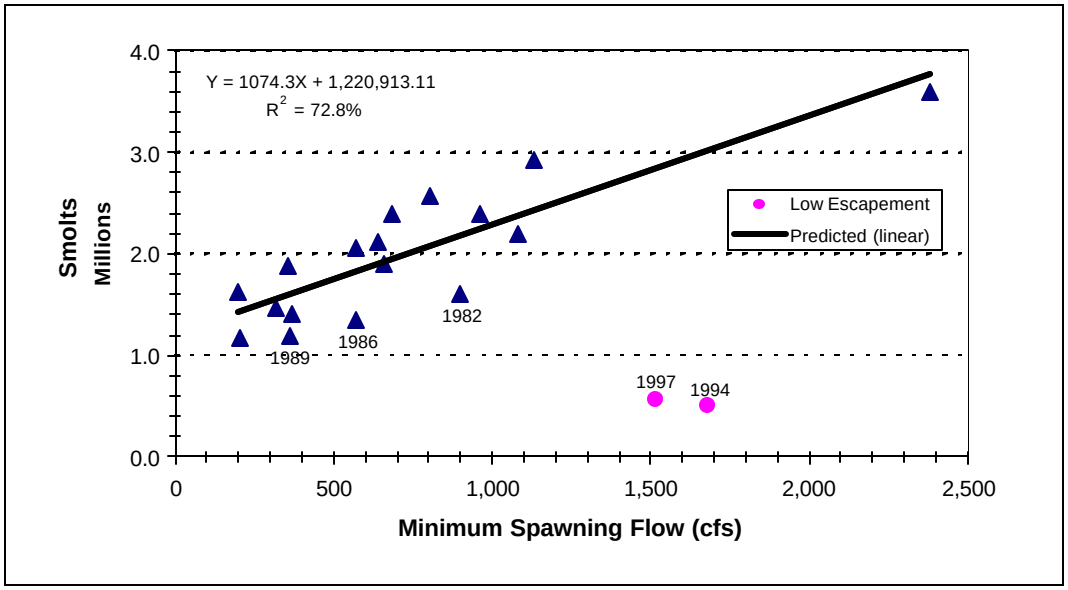

Figure 4: Coho smolt production as a function of minimum spawning flow, November 2 through December 15, Chehalis River at Grand Mound, brood years 1980-1999.

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 the severe storm that produced extremely high flows on January 10, 1990. On this date, the Chehalis River flooded, closing Interstate-5. This storm scoured spawning gravels in higher-gradient stream reaches, and triggered mass wasting events that reduced egg survival.

Apparently, in the low gradient, rain-fed, over-appropriated-for-water-withdrawals Chehalis River system, the level and timing of significant flow increases during spawning (November and December) 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.

The importance of this factor is also evident in the coho smolt production data record we have generated since the 1980 brood at Bingham Creek, a tributary to the East Fork Satsop River. Seeding rates have not constrained smolt production on any of these broods due to the contribution of Bingham Creek Hatchery-produced coho spawners. Consequently, for this low gradient stream, the relationship between smolt production and flow the previous summer is clear: production is a positive and proportional function of flow – more water equals more fish (Figure 5).

In five of the last seven broods (1995 through 2001), however, since a barrier screen at the outlet of Lake Nahwatzel was removed (1992), we have measured significant positive deviations relative to

values predicted with the summer low flow model. Productions from the five high broods are positively correlated with one-day peak November flow during spawning (Figure 6). This outcome indicates that for broods with summer rearing flows above some threshold, flows during spawning affect spawner distribution, which in turn determines total rearing habitat available for each brood.

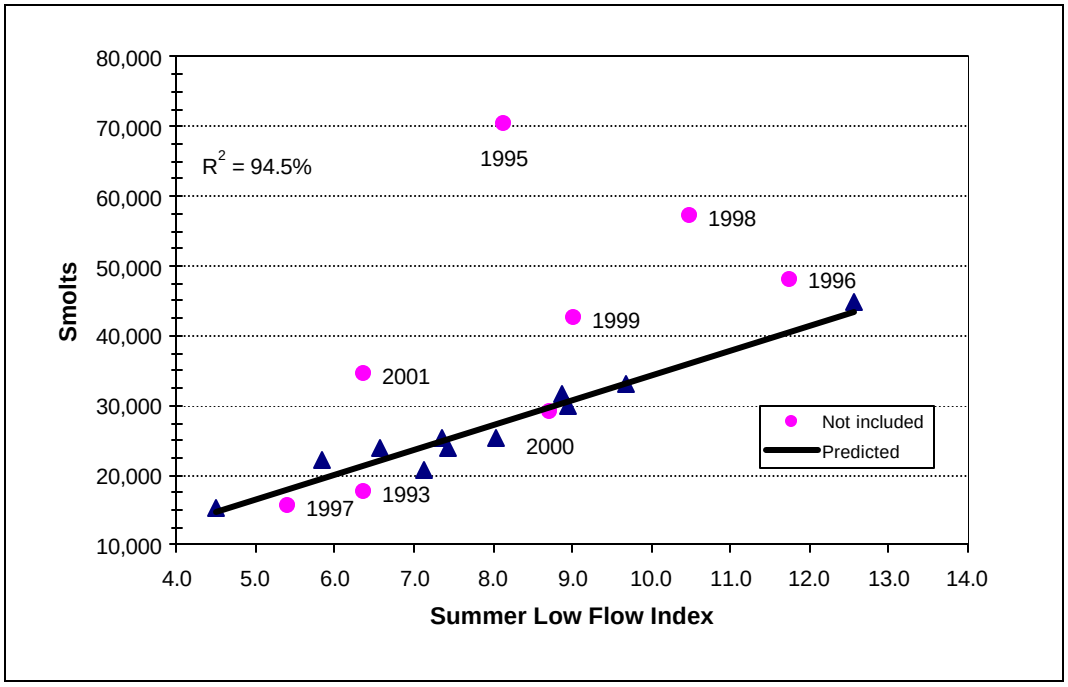

Figure 5: Wild coho smolt production vs. Puget Sound summer low flow, Bingham Creek, brood years 1980-1998 (broods 1990 and 1992 & 1994 omitted).

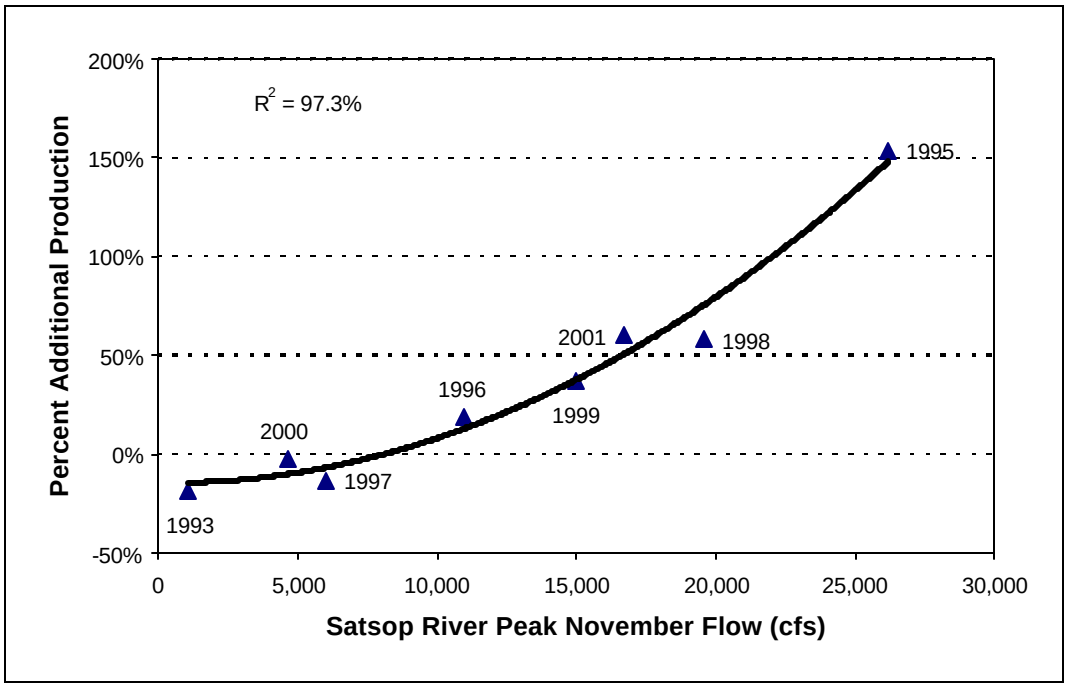

Figure 6: Additional Bingham Creek coho smolts produced following the removal of the screen at the outlet of Lake Nahwatzel, as a function of peak flow during November, during parent spawning, by brood year.

In Bingham Creek, high production results only when all of the following elements occur:

- Sufficient numbers of spawners return.
- High flows during November provide spawners access to the upper watershed.
- Access to Lake Nahwatzel permits adults to spawn in the tributaries to the lake. A drum screen, placed on the lake outlet to retain trout, blocked anadromous fish access prior to its removal in 1992. (In 1995, residents around Lake Nahwatzel reported observing large numbers of adult coho in the lake.)
- Sufficient flows throughout incubation and emergence permits large numbers of fry to seed the lake and Outlet Creek. Abundant coho fry and fingerling presence in the lake has also recently been observed and reported (pers. comm., Frank Haw, former WDF director and Lake Nahwatzel resident).
- Sufficient flows throughout the summer rearing period.
- Sufficient flows in Outlet Creek during spring to maintain connectivity between the lake and Bingham Creek for smolt emigration.

For the seventeen 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 relationship provides a means to predict system freshwater production for broods with adequate spawning escapements. We estimated 70,000 adult coho escaped to spawn in the Chehalis Basin in 2001 (1,409,000 smolts x 5.0% survival-to-return). We deem this level of spawning sufficient to seed the watershed.

During the coho spawning and flow correlation window (November 2 - December 15) in 2001, the minimum flow value of 705 cfs at Grand Mound occurred on November 12. Using this value, the flow relationship predicts a production of 1,978,000 smolts from 2,114-mi^2 in the Chehalis Basin (including the Wishkah River) during Spring 2003. This represents an average rate of 936 smolts/mi^2. Application of this rate to the entire Chehalis Basin (2,300-mi^2, including the Hoquiam, Johns, and Elk Rivers, and other south-side tributaries) estimates 2,152,000 coho smolts.

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

Willapa Bay

The Willapa Basin, with a total watershed area of 850 mi^2, is drained by four main river systems and a number of smaller tributaries. Little empirical smolt production evaluation work has been conducted in this system. Given the presumed high harvest rates in Willapa Bay, and the somewhat degraded condition of its freshwater habitat, it is likely that coho production/area was somewhat lower than that estimated in the Chehalis Basin. To approximate production of the 2001 brood, we selected a value of 700 smolts/mi^2. This rate, applied to the total basin area, estimates 595,000 coho smolts were naturally-produced in 2003.

Lower Columbia River

In Spring 2003, we continued monitoring smolt production from three tributaries to the lower Columbia River: Germany, Mill and Abernathy Creeks. In total, these systems, which drain an area of 80-mi^2, produced 26,000 coho smolts, a production rate of 325 smolts/mi^2. Production from Cedar Creek, a tributary to the Lewis River, was estimated at 36,700 coho smolts (pers comm. Shane Hawkins). Production/area from this 55-mi^2, lower-gradient stream system averaged 667smolts/mi^2.

As most of the 2,000 mi^2 of accessible watersheds draining into the Columbia River, downstream of Bonneville Dam (excluding the Cowlitz and Lewis River above their dams), is relatively high-gradient habitat, we applied the lower rate (325 smolts/mi^2) to 90% of the total area, and the higher rate (667 smolts/mi^2) to the remaining 10%. With this split, we estimate 718,000 coho smolts were produced. Addition of the 173,530 coho captured at Cowlitz Falls Dam and transported to the lower river (pers comm. John Serl) yields a Lower Columbia River natural coho production estimate from the Washington side of 892,000 smolts. Production/area for the Upper Cowlitz Basin, above Cowlitz Falls Dam, is estimated at 385 smolts/ mi^2. This rate, which is similar to that estimated in the Lower Columbia tributaries is the ratio of the 400,762 smolts estimated at the dam to the 1,042 mi^2 basin.

Marine Survival

Puget Sound

Background

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

Marine survival at Big Beef Creek, in terms of age-3 recruits, has varied more than ten-fold over brood years 1975-2000, from a high of 32%, to a low of 3% (1996 brood). In brood years 1988 through 1998, the marine survival rates we have measured at Big Beef Creek have represented an unknown portion of total adult recruits. This bias results from unreported and unsampled coho caught in Hood Canal net fisheries.

For brood years 1977 through 2000, marine survival of Deschutes River coho has ranged nearly a hundred-fold, from a high of 29%, to a low of only 0.3% (1996 brood). For the first eleven broods (1977-1985), survival of this 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 sharp decline was most evident with the Deschutes River population, which, over the last decade, has experienced generally lower survival rates than that of other stocks measured (Figure 7) (Table 5).

Over the nine broods (1976-1984) that we tagged wild smolts at Sunset Falls, marine survival of this stock ranged nearly three fold (8% to 22%) and averaged 16%, 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. As observed at the other monitoring stations and at hatcheries, survival of fish returning to Sunset Falls in1999 also hit an all-time low (5.2%). 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%.

Survival of Baker River coho, over eight brood years (1989-1996), has ranged just over two-fold, from a high of 13.8%, to a low of 5.7%. While survival of Baker River coho appears to generally track the other stocks we have measured (Figure 7), over these broods it has exhibited a biennial pattern, with odd-numbered brood years experiencing higher survivals than even-numbered brood years (Table 5). As with the other stations, Baker River coho returning in 1999 had the lowest marine survival measured thus far (5.7%). Due to a loss of key staff, coded-wire tagging at Baker Dam ceased in 2000 and 2001. As a result, marine survival estimates for this stock returning in 2001 and 2002 are unavailable. We resumed tagging at Baker Dam in 2002, which enables estimating marine survival of the 2000 brood, returning in 2003. Although tag recoveries from fisheries are not yet available, based on the currently estimated 5.8% survival-to-return, we project marine survival for this brood at 8%.

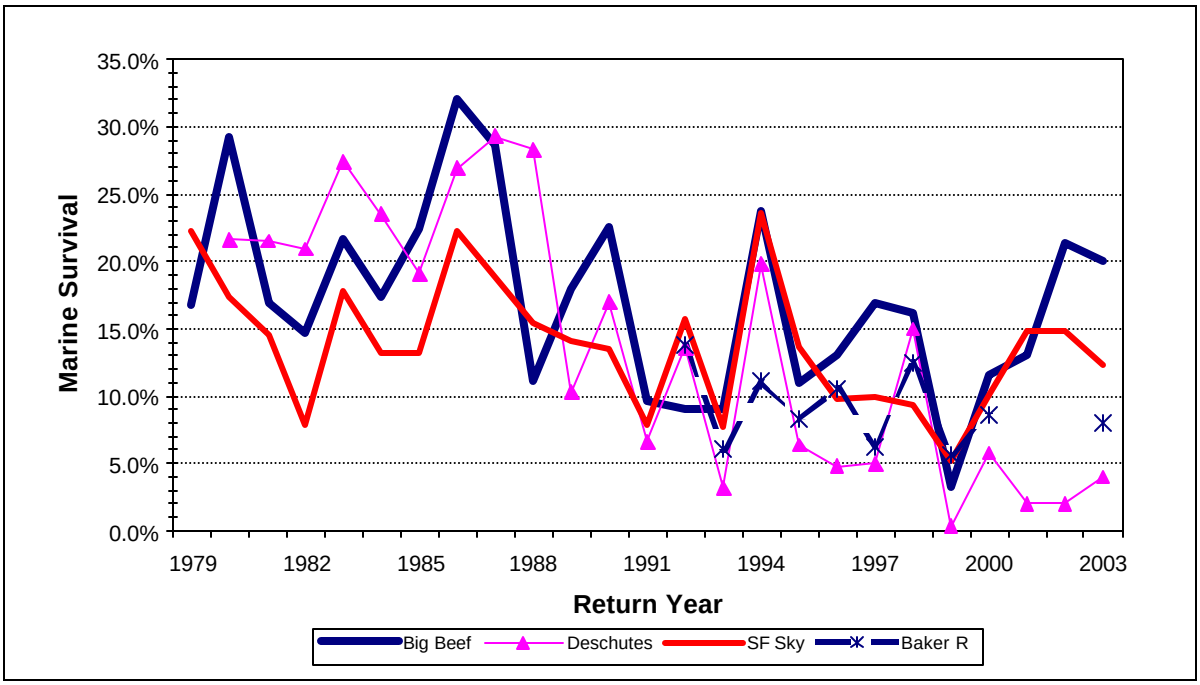

Figure 7: Marine Survival of wild coho (age-3) measured at four Puget Sound streams.

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	Count
1975	1978	13.3									
1976	1979	16.7		22.3					19.5		2
1977	1980	29.2	21.6	17.3					22.7		3
1978	1981	16.9	21.5	14.5					17.6		3
1979	1982	14.7	20.9	7.9					14.5		3
1980	1983	21.7	27.4	17.8					22.3		3
1981	1984	17.4	23.5	13.2					18.0		3
1982	1985	22.4	19.1	13.2					18.2		3
1983	1986	32.0	26.9	22.3					27.1		3
1984	1987	28.6	29.3	18.9					25.6		3
1985	1988	11.1	28.3	15.5					18.3		3
1986	1989	18.0	10.3	14.1					14.2		3
1987	1990	22.5	17.0	13.5					17.7		3
1988	1991				9.7	6.6	7.9			8.0	3
1989	1992				9.1	13.6	15.8	13.8		13.1	4
1990	1993				9.1	3.2	7.7	6.0		6.5	4
1991	1994				23.8	19.8	23.6	11.1		19.6	4
1992	1995				11.0	6.4	13.7	8.3		9.9	4
1993	1996				13.0	4.8	9.8	10.6		9.6	4
1994	1997				17.0	5.0	10.0	6.3		9.6	4
1995	1998				16.1	15.0	9.3	12.5		13.2	4
1996	1999				3.2	0.3	5.2	5.7		3.6	4
1997	2000				11.5	5.8	10.1	8.6		9.0	4
1998	2001				13.1	2.0	14.8	n/a		10.0	3
1999	2002				21.4	2.0	14.8	n/a		12.7	3
2000	2003				20.0	4.0	12.3	8.0		11.1	4
	Average	20.3	22.3	15.9	13.7	6.8	11.6	9.2	19.6	10.2	
	Min	11.1	10.3	7.9	3.2	0.3	5.2	5.7	14.2	3.6	
	Max	32.0	29.3	22.3	23.8	19.8	23.6	13.8	27.1	19.6	
	Count	13	11	12	13	13	11	9	12	11	

Predicting 2001 Brood Marine Survival

Correlating jack returns to Big Beef Creek with same-brood survival-to-adults (ocean age-3) indicates a significant relationship over the entire dataset (Figure 8). Using this correlation, the tagged wild jack return rate in 2003 of 1.0% (254 jacks from 25,444 smolts tagged in 2003), predicts an adult marine survival rate of 10.9%. Over the last four broods (1997 through 2000), however, adult marine survival has exceeded values predicted by the long-term adult:jack survival model. Over these four broods, tagged-adult recruits per tagged-jack return have increased each year from 21.7 to 44.8, and averaged 30. These rates are two to four times higher than the average (11.3) over the previous nineteen broods (Figure 9).

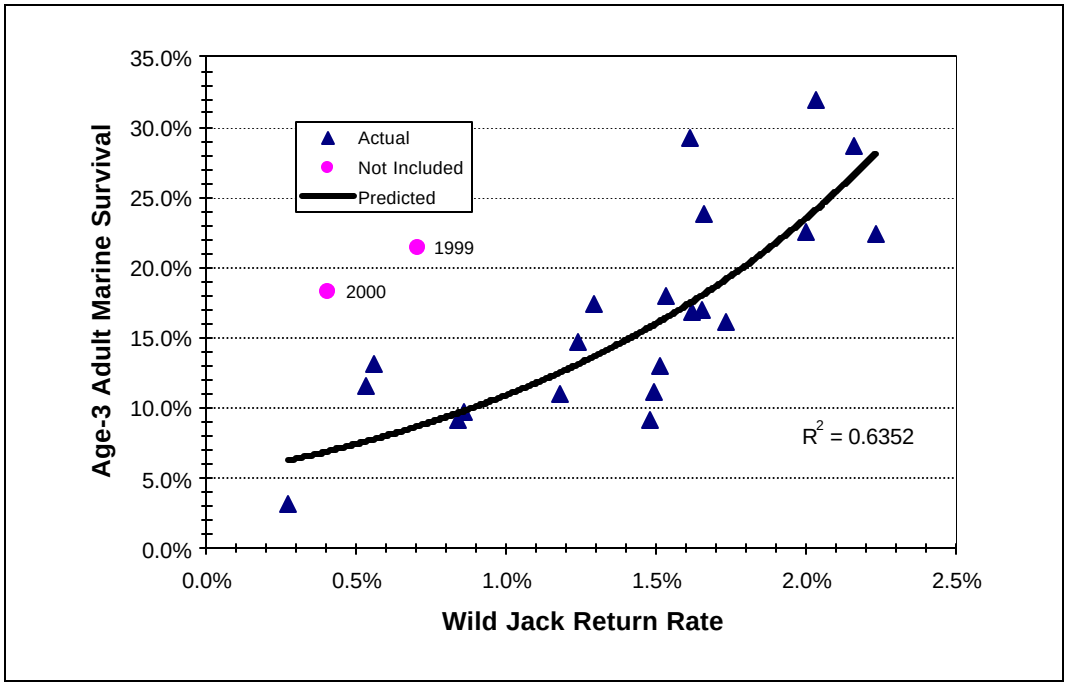

Figure 8: Wild coho adult marine survival, relative to same-brood jack return rates, Big Beef Creek, brood years 1970 through 1998.

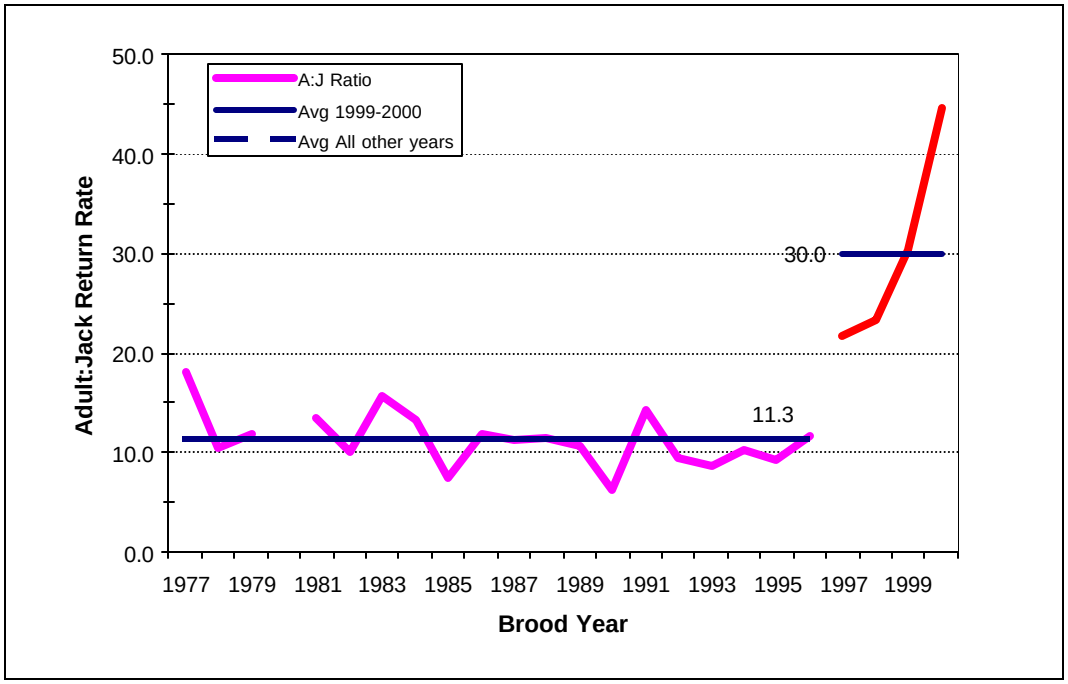

Figure 9: Ratio of adult recruits to jack returns, by brood year, Big Beef Creek tagged wild coho.

These significant positive deviations in the adults:jack return ratio indicates that the long-term correlation model is no longer appropriate for predicting marine survival (Table 6). Instead, we projected adult recruits using the average of these recent four years' adult:jack ratios (30.0). Application of this rate to the 254 tagged wild jacks that returned to Big Beef Creek in 2003 estimates 7,620 tagged wild Big Beef Creek recruits (age-3) in 2004. Relating this estimate to the 25,444 smolts tagged in 2003 predicts a marine survival rate to age-3 of 30%.

Table 6: Comparison of forecasted and measured adult marine survival for 1997-2000 brood Big Beef Creek wild coho.

Brood Year	Adult Return Year	Jack Return	Age-3 Marine Surv		
			Predicted	Actual	Diff
1997	2000	0.53%	4.4%	11.5%	-61.8%
1998	2001	0.56%	6.0%	13.1%	-54.3%
1999	2002	0.70%	7.0%	21.4%	-67.3%
2000	2003	0.41%	7.0%	19.0%	-63.2%

While the jack return to Big Beef Creek in 2003 indicates very high marine survival, we selected the more conservative, but still high, value of 20% for the 2001 brood Hood Canal coho. For other Puget Sound areas, we selected the following age-3 survival rates, which incorporate recent trends and patterns in marine survival (Table 5). These decisions reflect our belief that, absent any system-specific predictive models, the recent survival rates are more likely to indicate this brood's marine survival than the long-term average rates. In the last several 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.

- For the Skagit River and other north Puget Sound systems (Nooksack, Strait of Georgia and Samish Rivers), we used a rate of 11.3%, the average marine survival measured on the five odd-numbered brood years between 1989 and 1997 of wild coho tagged and trapped at Baker Dam (Table 5).
- For the Stillaguamish River, we selected a rate of 12%. Historically, marine survival in this system was lower than that measured in the Snohomish River.
- For the Snohomish River, Lake Washington, Green River, and East Kitsap we selected the rate of 14%.
- For the Puyallup River, we selected a rate of 10%.
- For the Nisqually River and South Puget Sound, we selected a rate of 5%.
- The Deschutes River received the lowest survival rate of 3%.

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 4.5% over 21 years (Figure 10). 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, jack returns explain over half the inter-annual variation in smolt-to-adult survival. When the data set is split into "early"- and "later"-years, the correlations improve even more (Figure 11). 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.

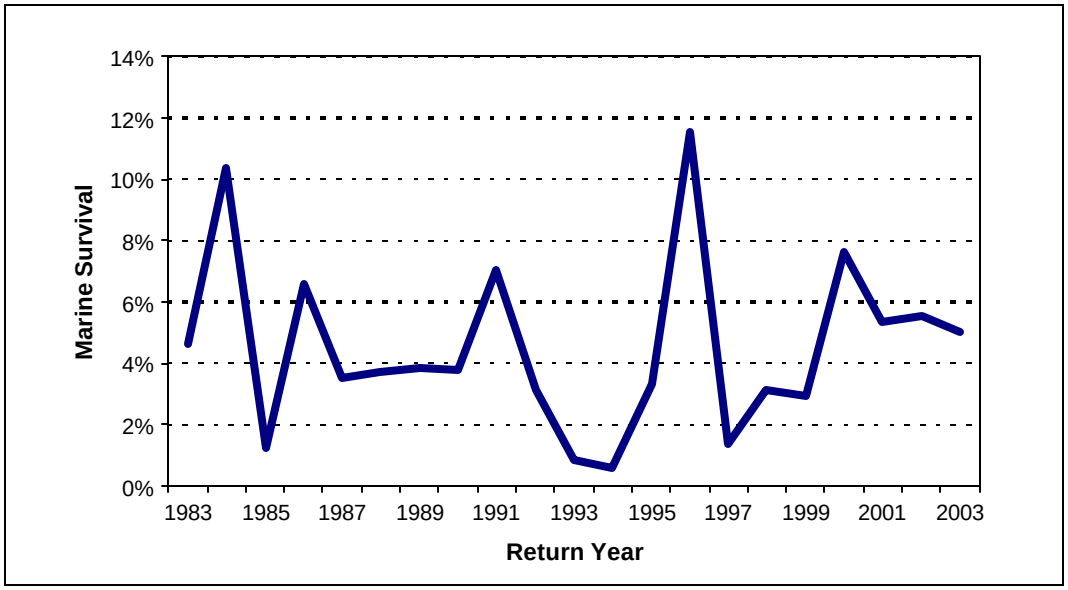

Figure 10: Marine survival of tagged wild coho from Bingham Creek.

Using the "late" years' line, we have under-forecast marine survival in five of the last seven years (Table 7). Marine survival rates in two of the last four broods (1998 and 1999) have fallen on the jack:adult relationship predicted for the "early" years (Figure 11). The 1997 and 2000 broods, however, fall on the "late years" correlation line.

With the Bingham Creek wild jack return rate in 2003 (0.1181%), marine survival for the late years' relationship is predicted at 6.0%.

Lacking an indication to the contrary, we also used 6% for all other coastal systems.

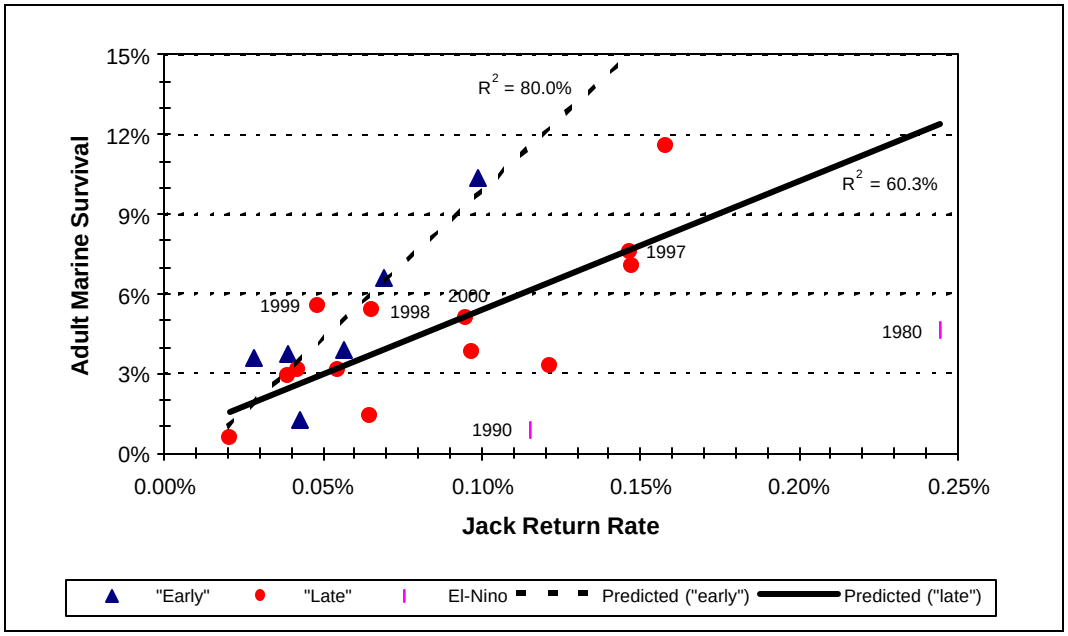

Figure 11: Jack return and adult marine survival, Bingham Creek, brood years 1980-2000.

Table 7: Forecasted and measured adult marine survival for 1993-2000 brood Bingham Creek wild coho.

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

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

Lower Columbia River

Lacking any indicators for wild coho survival in the Lower Columbia River, we selected a rate of 5%, one percentage point lower than that predicted with the Bingham Creek jack relationship.