2000 Wild Coho Forecasts
For Puget Sound & Washington Coastal Systems

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by
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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. Most of these methods rely 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 data bases were reasonably accurate however, 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 interannual 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 interannual 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 interannual comparisons within systems and annual comparisons across systems. This also should promote better understanding by stakeholders as it more directly connects coho production with habitat.

Presented in Table 1 are the forecasts of 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 "backed up" to estimate the population in terms of December Age-2 recruits. The following sections detail each estimate of smolt production and marine survival.

Table 1: Wild coho run forecasts for 2000, based on estimates of smolt production and marine survival.

Production Unit	PRODUCTION X MARINE SURVIVAL =			RECRUITS	
	Estimated Smolt Production: Spr '02	Adults (Age 3)	Dec. (Age 2)	Adults (Age 3)	Dec. (Age 2)
Puget Sound					
Primary Units					
Skagit River	703,000	8.0%	10.7%	56,240	75,249
Stillaguamish River	300,000	6.0%	7.9%	18,000	23,562
Snohomish River	900,000	6.0%	7.9%	54,000	70,686
Hood Canal	429,000	8.0%	10.6%	34,320	45,474
Straits of Juan de Fuca	223,000	6.0%	8.1%	13,380	17,983
Secondary Units					
Nooksack River	90,000	8.0%	10.7%	7,200	9,598
Strait of Georgia	16,000	8.0%	10.7%	1,300	1,706
Samish River	80,000	8.0%	10.7%	6,400	8,531
Lake Washington	111,000	3.0%	3.8%	3,300	4,259
Green River	108,000	3.0%	3.8%	3,240	4,144
Puyallup River	115,000	2.0%	2.6%	2,300	2,942
Nisqually River	20,000	2.0%	2.6%	400	512
Deschutes River	25,000	1.0%	1.3%	250	320
South Sound	86,000	2.0%	2.6%	1,720	2,200
East Kitsap	31,000	3.0%	3.8%	930	1,189
Puget Sound Total	3,237,000			202,980	268,355
Coast					
Quillayute River	135,000	6.0%	7.8%	8,100	10,530
Hoh River	88,000	6.0%	7.8%	5,280	6,864
Queets River	58,000	6.0%	7.8%	3,480	4,524
Quinault River	65,000	6.0%	7.8%	3,900	5,070
Independent Tributaries	85,000	6.0%	7.8%	5,100	6,630
Grays Harbor					
Chehalis River	500,000	6.0%	7.8%	30,000	39,000
Humptulips River	75,000	6.0%	7.8%	4,500	5,850
Willapa Bay	170,000	6.0%	7.8%	10,200	13,260
Coastal Systems Total	1,176,000			70,560	91,728
Lower Columbia Total	300,000	3.0%	3.9%	9,000	11,700
GRAND TOTAL	4,713,000			282,540	371,783

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. Smolt production has also been measured from significant portions of the Snohomish, Stillaguamish, Hood Canal, Quillayute, and Queets systems. 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 interannual variations in smolt production that we have measured (Table 2).

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 the 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 1999, we estimated 703,000 coho smolts emigrated from the Skagit River (Table 3). This estimate is based on trapping and marking wild coho in tributaries, and sampling emigrants in the lower mainstem river with floating scoop and screw traps. Over the ten years we have measured Skagit River smolt production, it has ranged from 618,000 to 1,760,000 coho smolts. Except for 1997, all of the high productions occurred on even years, while production during odd years was approximately half. We believe this pattern results from a positive interaction with adult pink salmon, which spawn only on odd-numbered years. While this relationship may be valid, for the 1995 brood, which produced the highest number of smolts since 1990, it was apparently overridden by beneficial flows during freshwater rearing. This contention is supported by the record high smolt production we also measured in two other systems in 1997.

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 we deemed were fully-seeded, 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%), mean system production was estimated at 360,000 smolts. Over these three broods, Puget Sound 60-day Low Flow Index (PSLFI) values were very near the long-term average (9.0).

Given the extremely low stream flows during Summer 1998, we believe production was below-average in 1999. The PSLFI for water year 1998 was 5.6, the second lowest value in the data set (since 1962), surpassed only by the drought of 1987 (4.7). Large systems are not as directly affected by low summer flows as small streams, so we selected a value of 300,000 smolts, 83% of the average.

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 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 mark 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. This estimate may be biased high because 450 mi^2, 26% of the 1,714 mi^2 Snohomish Basin, is inaccessible to anadromous fish. This area includes the Snoqualmie River, above Snoqualmie Falls (375 mi^2), and the Sultan River above the dam (75 mi^2). Countering this bias, however, is the fact that much of the rest of the basin is lower gradient than the watershed above Sunset Falls, and therefore, more productive.

As with the Stillaguamish, given the extremely low flows during Summer 1998, we expect that smolt production in the Snohomish Basin was somewhat below average. Therefore, we selected a value of 900,000 coho.

Hood Canal

In 1999, we trapped four streams on the eastern shore of Hood Canal: Big Beef, Stavis, Seabeck, and Little Anderson Creeks. As in previous years, Little Anderson Creek, which is heavily impacted by stormwater runoff and consequent high sediment loads, produced the lowest number of smolts. Production in all four tributaries was below average, with 20,967, 2,850, 1,146, and 257 coho smolts, respectively.

In Big Beef Creek, production from the high spawning escapement of 1,465 females upstream in 1997 was negated by the extremely low flows during late-summer 1998. The 20,967 smolts produced represent an average production rate of only 14.3 smolts/female.

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) has revised this estimate downward to 561,631 smolts. Both of these estimates were predicated upon adequate seeding and average environmental conditions. Assuming our four study streams represent coho smolt production in tributaries to Hood Canal, system production in 1999 is estimated at 428,743 and 332,996 smolts, based on T.R.28 and HCJTC, respectively. Wild coho escapements in Hood Canal in both 1997 and 1998 have been around 100,000 spawners. The run sizes which produced these escapements resulted from higher smolt production levels than

projected by the HCJTC. Consequently, for 2000, we selected the higher T.R.28-based projection, of 428,743 coho smolts (Table 4). Even this smolt projection is likely conservative because the four streams we trapped have suffered more development-caused habitat degradation than the major coho-producing systems (Dewatto, Union, and Tahuya Rivers) located further south.

Straits of Juan de Fuca

In Spring 1999, WDFW and the Lower Elwah S'Klallam Tribe continued the smolt monitoring projects initiated in 1998. In 1999, eleven Straits tributaries were trapped from (east to west) Cassalery Creek to Little Hoko River (Table 5 and Table 6). In the Dungeness system, we operated a screw trap in the mainstem and a fence trap in Mattriotti Creek, a lower-river tributary. High flows in the Dungeness River during April and May prevented continuous trapping. Consequently, we could not estimate coho smolt production in the main river with any precision.

Coho production from the eight independent streams trapped totaled 23,393 smolts for the combined wetted habitat area at summer low flow of 252,824 yds^2. We applied the average measured production rate (9.3 smolts/100 yd^2) to the total wetted habitat area (716,628 yds^2), to estimate 66,307 smolts produced from the small independent tributaries to the Straits in 1999 (Table 5). We excluded the production information collected from Mattriotti and Little Hoko Creeks from this estimate because these two streams are tributaries to larger systems, and therefore, do not represent independent streams.

To approximate production from the seven streams categorized as "large systems" (mainstem widths ∃6 yds), we applied the average smolt production ratio for the seven streams trapped in both 1998 and 1999 (26,880÷20,408 = 1.32) to the 1998 estimate. This estimates 156,763 smolts were produced from these systems (Table 6). Summing the large stream and small stream estimates projects a total production of 223,000 coho smolts.

Puget Sound Secondary Units

Nooksack River

Considering the extent of habitat degradation and underseeding due to high harvest rates, we expect natural smolt production from the Nooksack River system was well below projected potential in 1999. We used a value of 20% of the production projected by T.R.28 to estimate 90,000 smolts in 1999.

Strait of Georgia

We selected a value of 30% of the projected production (T.R.28), to estimate 16,000 smolts in 1999.

Samish River

Assuming that virtually all of the returning adult coho enumerated at the Samish Hatchery are wild fish, which scale sampling/analysis has indicated, production is typically well in excess of

the 58,000 smolts projected in (T.R.28). In some recent years, 10,000 adult coho have returned. Even at relatively low harvest rates and a high marine survivals, production would exceed 100,000 smolts, double the projected production. If harvest rates were higher and/or marine survival lower, then even more smolts were produced. We selected a value of 80,000 smolts as our best approximation of production in 1999.

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

Coho production in each of these systems is impacted by habitat degradation through development, diking, water withdrawals, and underescapement due to high, hatchery-directed harvest rates. Each of these systems also contains a dam on the mainstem, which blocks access to the upper watershed. Hatchery fry are outplanted in an attempt to mitigate for the presumed underseeding by natural spawners. While these outplants may contribute to production, it is likely that resultant smolt production is lower than would be achieved with adequate numbers of natural spawners.

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 estimated Cedar River and Bear Creek produced 37,000 and 64,100 coho smolts, respectively. Given that these systems contain some of the best habitat in the basin, we expect production rates in the other smaller, more urbanized tributaries were lower. Therefore, we applied a value of 20% of the T.R.28 production rate to the 558,185 yds^2 of wetted habitat (at summer low flow) in the unstudied tributaries to estimate 46, 888 smolts. Addition of the measured production and this approximation yields a system total to Lake Washington of 148,000 smolts in 1999. We reduced this estimate by 25%, to account for mortality in the lake, and through the Ship Canal and Ballard Locks, which results in an estimated 111,000 smolts entering Puget Sound.

We selected a value of 20% of the production projected by T.R.28 for the Green and Puyallup Rivers.

For the Nisqually River, we discounted projected production even more, with a rate of 10%. We used this lower rate based on the very low smolt production we have measured from the nearby Deschutes River. Natural coho production in the Nisqually has also suffered from very low escapement as a result of habitat degradation and poor marine survival.

Deschutes River

A number of factors have combined to severely depress production in this system: habitat degradation, particularly in the upper watershed; extreme high flows during egg incubation, low reproductive potential due to small fish size; and low escapement. In addition to these factors affecting freshwater production, escapements have declined as a result of extremely low marine survival. In the 1990s, marine survival for Deschutes coho is lower than all other Puget Sound stocks.

Based on trapping in 1999, we estimated 25,000 smolts emigrated from this system, only 11% of the production predicted in T.R.28. In 1997, the spawning escapement included 433 females and 449 males. Relating smolt production to this escapement yields 57.7 smolts/female. Typically, coho populations compensate for very low seeding rates through density-dependent survival,

producing over 100 smolts/female, as measured at the South Fork Skykomish (Figure 2). This low production probably results, in part, from the extremely low flows during Summer 1998.

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. In 1999, the Squaxin Tribe initiated smolt monitoring on three tributaries to Hammersly Inlet — Mill, Cranberry, and Goldsborough Creeks. Similar to the Deschutes, results indicate smolt production has also declined in these systems to 10-20%of the levels predicted by T.R.28.

Stream	Wetted Area (yd^2)	Smolt Production		Actual:Predicted
		Predicted	Actual	
Goldsborough Creek	170,544	71,628	12,895	18.0%
Mill Creek	133,056	55,884	5,947	10.6%
Cranberry Creek	52,096	21,880	3,909	17.9%
			Average	15.5%

Based on these results, we applied a factor of 15% to 573,770 smolts projected in T.R.28 to estimate 86,000 smolts were produced from South Sound streams in 1999.

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 study streams. Therefore, we applied a factor of 20% to the 154,973 smolts projected by T.R.28 to estimate 31,000 smolts were produced from these streams in 1999.

Coastal Systems

Quillayute River

We have measured smolt production in two sub-basins of the Quillayute River — the Bogachiel and Dickey Rivers. Over three years, 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 fry plants, and as a result, we concluded that the system was already seeded to capacity by natural spawners.

Over three years, 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 this production rate, higher than that measured in the Bogachiel, to this system's low gradient and resultant abundant summer and winter rearing habitat. Results also indicate this system was probably seeded to 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.

To estimate production in 1999, we adjusted this average production estimate by the ratio of 1999 Clearwater production to its long-term average. QFiD biologists estimated that the Clearwater River produced 27,314 smolts in 1999 (pers.comm. Dan Eastman), 44% of its previous 18-year average (61,700 smolts). Application of this rate to the average Quillayute production estimates 135,000 coho smolts were produced in 1999.

Queets River

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 severity of flow on one day during egg incubation explains over half the variation in smolt production (Figure 3).

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 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 (Figure 2). These outcomes indicate that the low escapement in 1994 was probably 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, a fraction of the value predicted by the flow relationship (72,500 smolts).

Coho smolt production for the entire Queets system is estimated at 88,000 smolts by applying the production rate measured in the Clearwater (195 smolts/mi^2) to the 450 mi^2 Queets Basin.

Hoh River

Due to the similarity and proximity of the Hoh watershed to that of the Clearwater River, we used the Clearwater rate to approximate Hoh River coho smolt production in 1999. The rate of 195 smolts/mi^2 applied to the 299 mi^2 drainage area of the Hoh system estimates 58,000 coho smolts were produced.

Quinault River

Low escapement due to high harvest rates and degraded habitat likely combined to limit natural smolt production from this system. To reflect these effects, we used the lower rate of 150 smolts/mi^2. This rate, applied to the total area in this basin (434 mi^2), estimates total production at 65,000 smolts.

Independent Tributaries

Smolt production has not been directly measured from any of the independent coastal tributaries. Application of an average production rate of 200 smolts/mi^2 to the total watershed area (424 mi^2 - Table) estimates 85,000 coho smolts were produced from these systems.

The value of 200 smolts/mi^2 was selected, slightly higher than the rate measured in the Clearwater River in 1999, for two reasons: drainage area values were not available for some of the minor tributaries, thus the total area estimate is low; and many of these systems have lower gradients than the Clearwater River and, therefore, production/area should be higher.

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

Grays Harbor

We have estimated coho smolt production from the Chehalis River system each year since the 1980 brood. This estimate relies upon annually trapping/tagging wild smolts, and CWT sampling adults caught in the Quinault Tribe's terminal net fishery in the lower Chehalis River. Resultant estimates have ranged seven-fold, from around 0.5 million to 3.5 million (Table 7). Analysis to understand the components of variation has determined that flow during spawning, explains a significant portion (59%) of the interannual variation in estimated smolt production (Figure 4).

We excluded two brood years from this analysis (1990 and 1994). Tagging on the 1990 brood was limited, and therefore, also likely not representative. 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), so although it is likely that smolt production was high on this brood, we have little confidence in this estimate. We also excluded the 1994 brood because escapement was extremely low: less than 10,000 spawners. Upon adult return in 1997, we estimated only around 503,000 smolts were produced from this

brood. This brood experienced the highest minimum flows during spawning, however, which helped compensate for the low escapement.

The flow/production relationship is even stronger than indicated by the correlation coefficient. For the three broods with production below the regression line, other important brood-specific factors were in effect.

- The 1989 brood was impacted by the severe storm which 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, which reduced egg survival and triggered mass wasting events.
- 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 (Figure 5).
- The 1982 brood may have been constrained by low escapement.

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. In 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.

Correlation of the estimates of smolt production with estimated escapements explained only 11% of the interannual variation. Analyzing flow effects during other periods — winter (incubation), spring (fry distribution), and summer (fry rearing) — also yielded insignificant correlations.

For the fifteen broods analyzed, this 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 has not produced enough smolts to obscure this effect of flow on natural production.

This relationship provides a means to predict freshwater production, **but only for broods with adequate spawning escapements**. Escapement in 1997 was extremely low. We estimate only 6,700 adult coho returned to the Chehalis Basin. As with the parent-brood (1994), flow conditions, however, were extremely favorable during spawning. Given maximum penetration into the watershed, average production/female would have been near maximum, around 150 smolts (Figure 2). This expectation is supported by the relatively high catch (32,000 smolts) in our scoop trap in 1999. Therefore, we expect that smolt production in 1999 was around 500,000 smolts. Relating this production to the 2,300 mi^2 in the Chehalis Basin yields an average rate of 217 smolts/mi^2, slightly higher than measured in the Clearwater River.

In addition to the Chehalis River watershed, the 2,550 mi^2 Grays Harbor Basin includes the 250 mi^2 Humptulips River. While we have no direct estimates for the Humptulips Basin, its smolt production in 1999 was probably not as depressed as the Chehalis. We base this expectation on

the relatively high contribution of hatchery fish to natural spawning in this system. We estimated the natural smolt production at 75,000 smolts, using a rate of 300 smolts/mi^2.

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 generally 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 1997 brood, we selected a value of 200 smolts/mi^2. This rate, applied to the total basin area, estimates 170,000 coho smolts were naturally-produced in 1999.

Lower Columbia River

To approximate the smolt production from the watersheds downstream of Bonneville Dam, we applied a rate of 150 smolts/mi^2 to the total estimated drainage area (2,000 mi^2). This rate estimates 300,000 smolts were naturally-produced from these systems.

Marine Survival

Puget Sound

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 coastwide recoveries of tagged wild coho and returns of same to complete upstream migrant trapping facilities on these systems.

Marine survival at Big Beef Creek, in terms of age-3 recruits, has varied eight-fold over brood years 1975-1996, from a high of 32%, to a low in 1999 of 4%. Over the last decade, the marine survival rates we have measured at Big Beef Creek represent an unknown portion of total adult recruits. This bias results from unreported and unsampled coho caught in Hood Canal net fisheries. For example, in 1999, the marine survival estimate of 4% represents only the return to the trap, as the net fishery in Area 12 was not monitored or sampled.

Over the same period, marine survival of Deschutes River coho has averaged 15%, ranging nearly a hundred-fold from a high of 29%, to a low of only 0.3% in 1999. Over the first nine broods (1977-1985), survival of this stock averaged 22%, similar to that of Big Beef Creek smolts (20%). Beginning with the 1986 brood, however, survival of Puget Sound coho declined, particularly the Deschutes River population. Beginning with brood year 1992, survival of Deschutes River coho declined more sharply than the other Puget Sound stocks (Figure 6).

Other stocks in South Puget Sound showed similar low survival rates in 1999:

- only a few thousand adult coho returned to Squaxin Island from a release of 2 million saltwater net pen-reared smolts;
- only 18 wild coho returned to an adult trap in the fishway on Cranberry Creek, operated by the Squaxin Tribe.

Over the nine broods that we tagged wild smolts at Sunset Falls (SF Skykomish River), marine survival of this stock ranged three-fold (8% to 24%) and averaged 15%, somewhat lower than the rates estimated for Big Beef Creek and Deschutes River coho. We attribute this lower survival to the smaller size of smolts produced from this colder, higher-elevation system. Although we no longer trap and CWT wild coho smolts in this system, we approximate marine survival at Sunset Falls through applying projected harvest rates to adult returns. Relating these estimates of run size to the average smolt production we measured with full seeding (276,000 smolts), approximates marine survival. Survival in 1999 (5.2%) was lower than in any of the previous 20 years.

Survival of Baker River coho (beginning with the 1989 brood), has ranged three-fold, from a high of 14%, to a low of 5%, and appears to generally track the other stocks we have measured (Figure 6). Over these eight broods, Baker River survival alternates, with odd-numbered brood years experiencing higher survival than even-numbered brood years. As with the other stations, survival of Baker River coho in 1999 was the lowest measured thus far (4.8%).

Correlating jack returns to Big Beef Creek with same-brood survival-to-adults indicates a strong relationship (Figure 7). However, we believe this correlation underestimates adult marine survival, given the aforementioned bias in measuring adult survival. Based on this relationship, the tagged wild jack return rate in 1999 of 0.56% predicts an adult marine survival rate of 4.4%. Because we believe this rate is biased low, we selected a rate of 8% for predicting Hood Canal marine survival.

For predicting 1997 brood marine survival in other Puget Sound areas, we selected the following rates, which incorporate recent trends and patterns in marine survival (Table 8). This decision reflects our belief that the recent survival rates are more likely to indicate this brood's marine survival than the long-term average rates.

- For the north Sound systems (Nooksack through the Skagit River), we selected a rate of 8%, down from the average marine survival rate (11.8%) for the four odd-numbered brood years measured thus far at the Baker River.
- For the Stillaguamish and Snohomish Rivers, we selected a rate of 6%, lower than the average of the last two brood years (1995-1996) estimated at Sunset Falls (7.2%).
- Due to the extreme low survival of Deschutes coho, we selected rates which declined (from north to south) from 3% for the Lake Washington, Green River and East Kitsap production areas, and 2% for the Puyallup and Nisqually Rivers and South Puget Sound, to 1% for the Deschutes River.

Straits of Juan de Fuca

We currently lack any direct measurement of marine survival in tributaries to the Straits of Juan de Fuca. Observations at Snow Creek and spawning ground information from other systems, however, indicate marine survival in this region is historically lower than that of inner Puget Sound coho. Given the generally lower survival of coastal stocks relative to Puget Sound stocks, we expect that coho emigrating from Straits tributaries experienced survival rates which are intermediate between Puget Sound and the coast. Given our high prediction of marine survival of coastal stocks in 2000, however, we elected to use the coastal rate (6%).

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 17 years (Figure 8). Over all broods measured, the relationship between jack returns and same-brood adult marine survival is poor (Figure 9). However, when the two El Niño broods are excluded jack returns explain over half the interannual variation in adult survival. When the data set is split into early- and later-years, the correlations improve even more (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. Because we are unable to predict the ocean conditions which produce this response, we should discount the marine survival predicted from broods with high jack return rates to avoid overestimating run size.

Based on the relationship developed for the recent years (Figure 10), the wild jack return rate to Bingham Creek in 1999 of 0.15% predicts an adult marine survival to the ocean (age 3) of 7.6%. This rate may underestimate the marine survival of other, non-Chehalis Basin, coastal stocks if the differential survival problem, which has long impacted Chehalis Basin coho, has not been resolved. Presently this remains uncertain, although the high survival of some recent returns (notably in 1991 and 1996) indicate that substantial progress on reducing this problem may have been achieved. Although we expect that near-shore marine environmental conditions and/or predator populations varied somewhat along the coast, both of which would influence survival rates, because of the high jack return rate in 1999, we expect marine survival will be above average coastwide. Using the jack-to-adult relationship for the early years predicts a record high adult marine survival of 15%.

Not only do we expect high marine survival for the 1997 brood, in three of the last four broods, we have underestimated marine survival:

Brood Year (i)	Return Year (i+3)	Adult Marine Survival		Error
		Predicted	Actual	
1993	1996	5.4%	11.6%	-115%
1994	1997	3.0%	1.4%	53%
1995	1998	1.0%	3.1%	-210%
1996	1999	2.0%	2.5%	-24%

The predicted values in this table were the rates we forecasted, based on the correlations developed pre-season. For this reason, they vary relative to the present regression line (later brood years: 1987 through 1996). The direction of this error may indicate that the relationship between jacks and adults is trending toward that represented by the steeper line, which fit the early broods' data (1981 through 1986) better (Figure 10). The 1996 brood results are preliminary as of January 2000. Also the 2% value includes an upward adjustment of 0.6% from that predicted by the regression (1.4%).

The indication of high marine survival is supported by the return of 49 wild jacks to the Elk Creek trap in 1999. Over the 16 years we have trapped this stream, returns have averaged 45 jacks, and ranged from 2 to 108 jacks. Given the extremely low smolt production in 1999, the return of an average number of jacks is consistent with an above-average marine survival.

To preclude overestimating survival, we selected a rate of 6% to represent coastwide marine survival.

Lower Columbia River

Given the expectation for slightly higher marine survival for lower-river hatchery coho, we selected a rate of 3% to estimate survival of naturally-produced smolts

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	22	14	11,510	45,634	4.0	24,448	1,746	1,2,3,4,5
Bingham Creek	18	35	15,280	71,708	4.7	28,554	816	2,3
Deschutes River[a]	20	130	5541	133,198	24.0	62,906	484	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	77,554	818	6
Bogachiel River[b]	13	129	48,962	61,580	1.3	61,580	417	6
Clearwater River	19	140	35,000	99,354	2.7	95,000	428	1,4,5
Stillaguamish River	3	540	203,072	379,022	1.9	379,000	511	6
Skagit River[c]	10	1,918	617,600	1,884,700	2.8	1,759,600	507	1,2,3,8
Chehalis River	17	2,114	502,918	3,592,275	7.1	3,592,275	913	1,2,3,4
Total		5,469						
Mean							733	
Weighted Mean[d]							382	

[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

Table 3: Estimation of wild coho smolt production, Skagit River 1999.

	Number	Formula
Total mainstem trap catches	9,861	
Baker River	-128	
Skagit Hatchery/Lake Shannon	-1,320	
Wild coho captured (c)	**8,413**	
RVs recaptured (r)	279	$N = \frac{(m+1)(c+1)}{(r+1)}$
RVs released (m)	22,546	
Total production (N)	**677,537**	
Variance (Var)	1.57E+09	$Var = \frac{(m+1)(c+1)(m-r)(c-r)}{(r+1)^2(r+1)}$
Standard Deviation (sd)	39,563	
Coefficient of Var (CV)	5.84%	CV = sd/N
Confindence Interval (CI)	77,544	CI = +/- 1.96(sd)
Estimated coho production		
Skagit River	677,537	
Baker River	25,159	
Total estimated production	702,696	
Upper CI (95%)	755,081	
Lower CI (95%)	599,993	

Notes: Estimated Baker recoveries: visually identified ad-marks (85) times the tag expansion factor (25,156 ÷ 17,136 = 1.4682) = 125 total tagged and unmarked Baker River smolts in the catch.
Hatchery ad-marked and unmarked smolts total from counts obtained by visual identification at trapping (1,308 Skagit Hatchery + 12 brands from Baker Lake = 1,638). Baker Lake numbers from Puget Sound Energy (October 12, 1999).

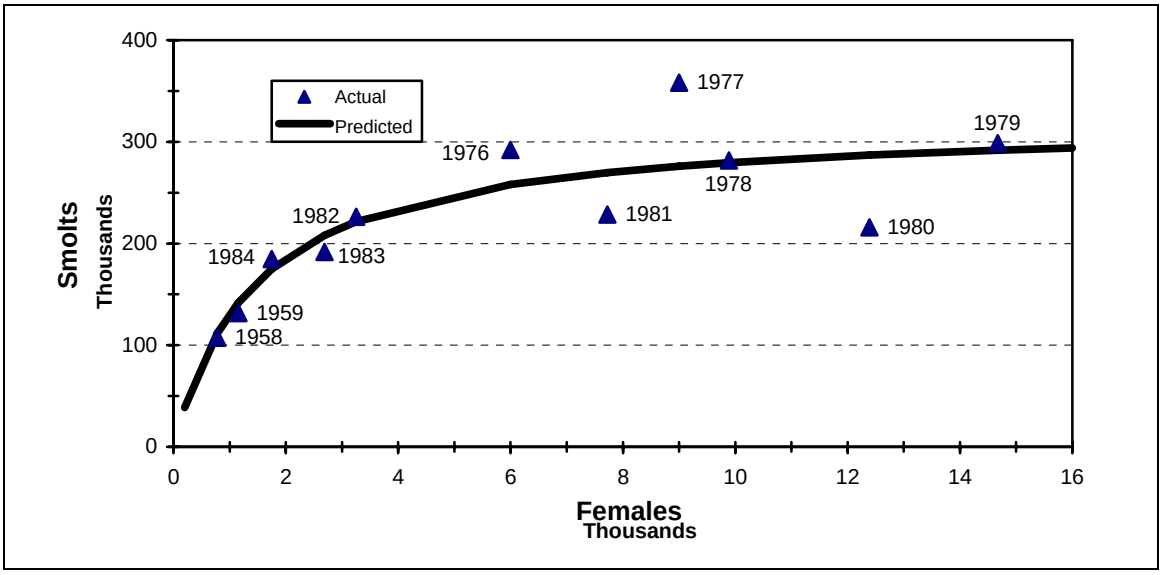


Figure 1: SF Skykomish River wild coho spawners and recruits, by brood year.

Table 4. Actual and projected wild coho smolt productions in Hood Canal 1999.

Stream	Projected Smolts		Actual Production 1999	Ratio Actual:Projected	
	Zillges	HCJTC		Zillges	HCJTC
Big Beef Creek	38,586	29,638	20,967	54%	71%
Little Anderson Creek	5,100	3,190	257	n/a	n/a
Seabeck Creek	10,497	6,564	1,146	11%	17%
Stavis Creek	5,027	3,144	2,850	57%	91%
Subtotal	59,210	42,536	25,220	43%	59%
Total Hood Canal	1,006,577	[a] 561,631	**Est. 1999 Production**	428,743	332,996
Projected proportion (Subtotal/Total)	5.9%	7.6%			

[a] Includes catch area 9A tributaries (7,027 smolts).

Table 5. Measured and projected wild coho smolt production in small Straits of Juan de Fuca systems (mainstem <6 yards), 1999.

Small Streams	Wetted Habitat (yd^2)	Coho Smolt Catch	Production Rate (Smolts/100 yd^2)	Projected Smolts/yd^2
Matriotti Creek	10,560	4,910	46.5	
Little Hoko Creek	37,664	4,313	11.5	
Cassalery Creek	3,960	189	4.8	
Bell Creek	4,224	1,094	25.9	
Siebert Creek	51,040	1,426	2.8	
Ennis Creek	18,304	717	3.9	
Tumwater Creek	4,576	35	0.8	
Salt Creek	83,072	10,711	12.9	
McDonald Creek	34,672	4,453	12.8	
Deep Creek	52,976	4,768	9.0	
Subtotal	252,824	23,393	9.3	
Total Independent Tribs	716,628		9.3	66,307

Table 6. Estimated and projected wild coho smolt production in larger Straits of Juan de Fuca systems (mainstem widths ≥6 yards), 1999.

Large Systems	Watershed Areas (mi^2)	Average Production (mi^2) in 1999	Projected Smolt Production	
			1998	1999[a]
Dungeness River	198.0	253	50,000	65,857
Morse Creek	46.6	253	11,790	15,529
Lyre Creek	66.0	253	16,698	21,993
Pysht River	44.4	253	11,233	14,796
Clallam River	31.6	253	7,995	10,530
Hoko River	51.2	253	12,954	17,062
Sekiu River	33.0	253	8,349	10,997
Total	470.8		119,018	156,763

[a] Based on the average 1999:1998 smolt production ratio (26,880 ÷ 20,408 = 1.32) for the seven streams trapped both years.

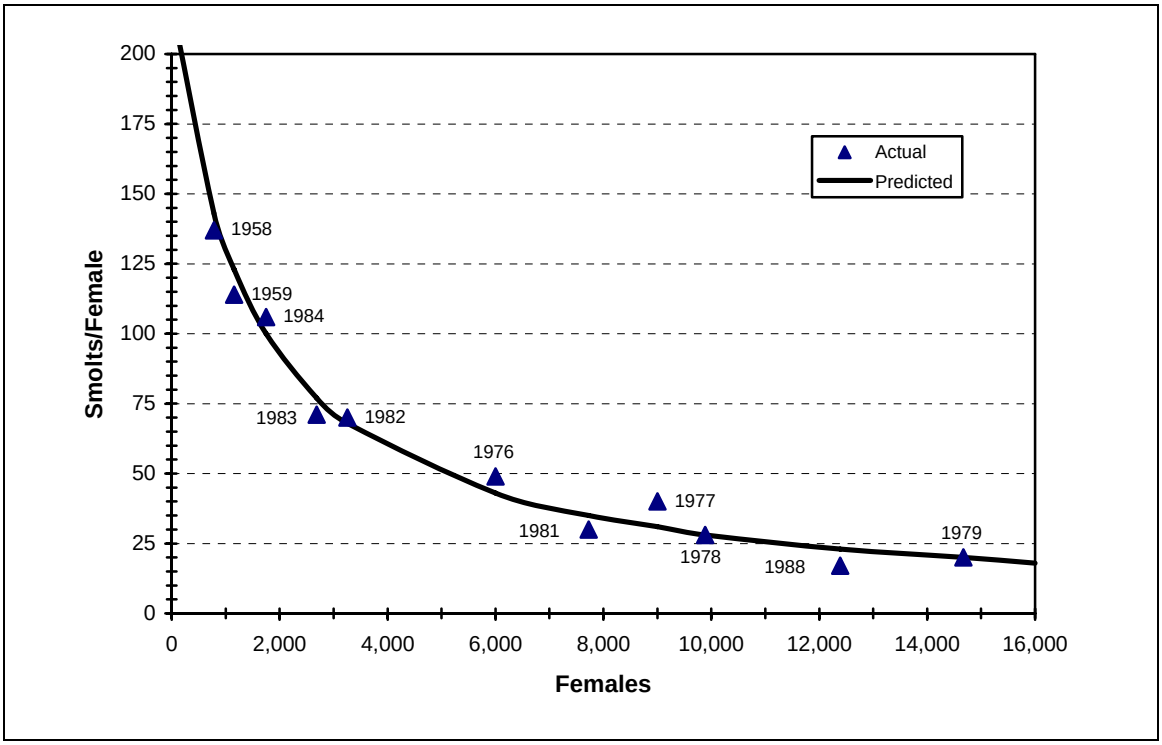


Figure 2: Productivity as a function of spawner abundance, SF Skykomish River wild coho.

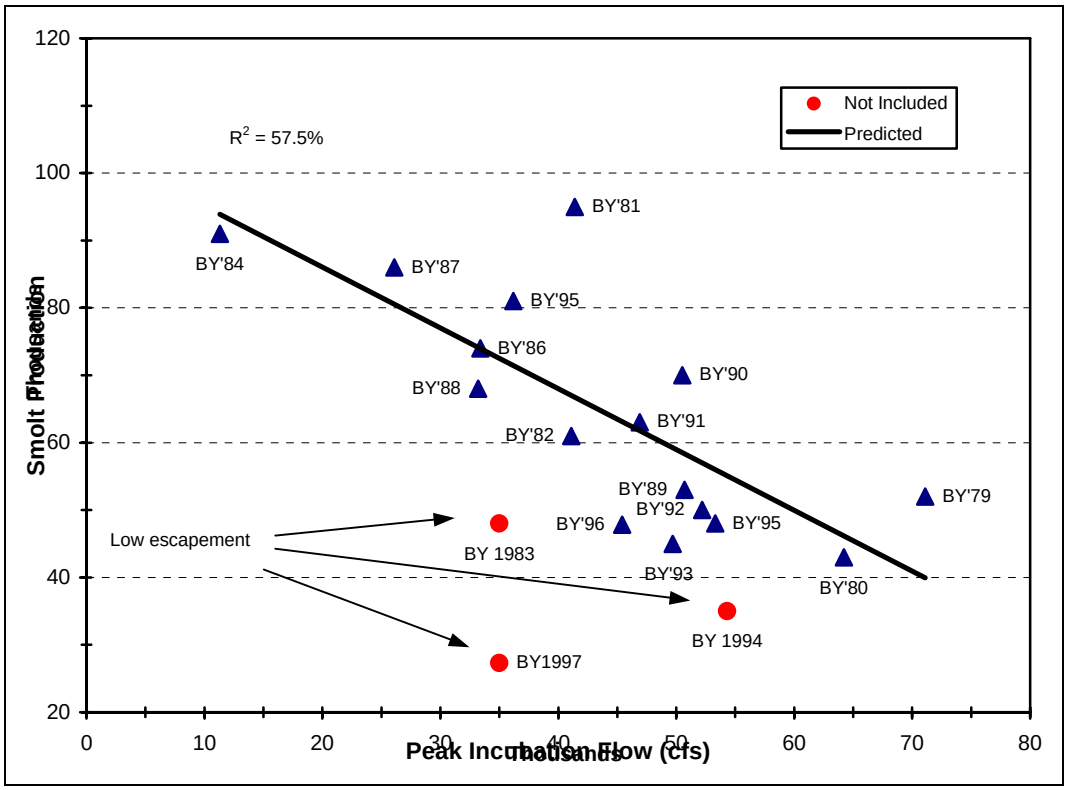


Figure 3: Clearwater River wild coho smolt production and Queets River flow, during egg incubation, brood years 1979-1996 (regression does not include low-escapement broods and brood years 1981).

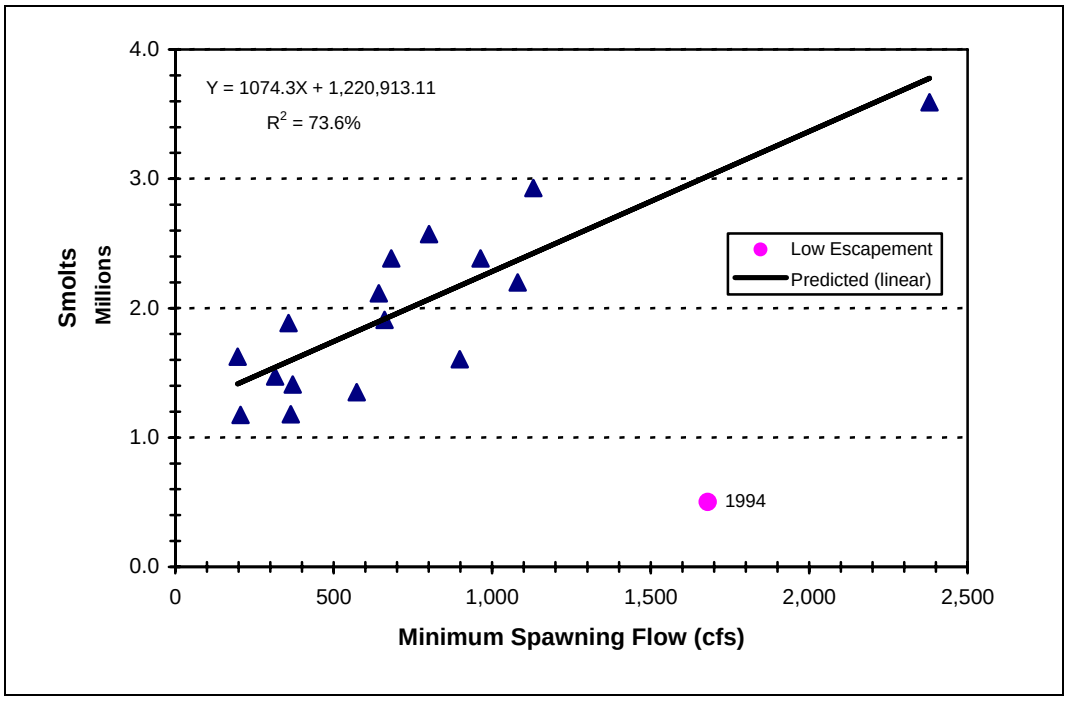


Figure 4: Coho smolt production as a function of minimum spawning flow, November 1 through December 15, Chehalis River at Grand Mound, brood years 1980-1996.

Table 7: Estimation of wild coho smolt production from the Chehalis Basin, via back-calculation. These estimates assume expanding tag recoveries accurately reflect the numbers of hatchery and wild tags caught.

				ESTIMATION OF WILD TAG RATE					WILD SMOLT TAGGING				ESTIMATED SMOLT PRODUCTION				
				A	B	C	D	E	F	G	H	I	J	K			
Br. Yr.	Tag Yr.	Rtn. Yr.		Total Catch	Est. Hatch.	Wild Catch (A-B)	# Est. W-tags	Tag Inc. (D/C)	Number Tagged	Mort Adj.	Tag Rtnt'n	Adj. Tag Grp (FGH)	Total Smolts (I/E)	SE Sqrt(Var.)	95% Conf. Interval Low (J-(1.96*K))	95% Conf. Interval High (J+(1.96*K))	CV (K/J)
1980	1982	1983		10,115	3,669	6,446	104	1.61%	47,711	0.84	0.96	38,474	2,384,657	207,638	1,977,688	2,791,627	8.71
1981	1983	1984		5,196	1,432	3,764	93	2.47%	78,839	0.84	0.96	63,576	2,573,110	250,223	2,082,672	3,063,547	9.72
1982	1984	1985		6,991	4,025	2,966	164	5.53%	110,020	0.84	0.96	88,720	1,604,536	118,303	1,372,662	1,836,410	7.37
1983	1985	1986		19,600	6,548	13,052	481	3.69%	96,687	0.84	0.96	77,968	2,115,683	86,032	1,947,061	2,284,305	4.07
1984	1986	1987		23,129	4,810	18,319	272	1.48%	74,547	0.84	0.85	53,338	3,592,275	173,901	3,251,429	3,933,121	4.84
1985	1987	1988		3,856	1,490	2,366	39	1.65%	59,861	0.84	0.96	48,272	2,928,496	431,352	2,083,047	3,773,945	14.73
1986	1988	1989		13,824	10,367	3,457	112	3.24%	54,285	0.84	0.96	43,775	1,351,175	118,427	1,119,058	1,583,293	8.76
1987	1989	1990		27,251	17,824	9,427	210	2.23%	44,889	0.84	0.96	36,198	1,624,967	94,459	1,439,829	1,810,106	5.81
1988	1990	1991		45,211	22,073	23,138	690	2.98%	69,701	0.84	0.96	56,207	1,884,804	54,055	1,778,856	1,990,753	2.87
1989	1991	1992	A	12,111	7,745	4,366	213	4.88%	71,460	0.84	0.96	57,625	1,181,184	75,188	1,033,816	1,328,553	6.37
			B	12,111	10,197	1,914	213	11.13%	71,460	0.84	0.96	57,625	517,816	32,590	453,940	581,693	6.29
			C	12,111	8,971	3,140	213	6.78%	71,460	0.84	0.96	57,625	849,500	54,146	743,375	955,626	6.37
1990	**1992**	**1993**	**B**	**10,153**	**4,702**	**5,451**	**16**	**0.29%**	**21,125**	**0.84**	**0.96**	**17,035**	**5,803,680**	**1,060,259**	**3,725,572**	**7,881,787**	**18.27**
1991	1993	1994	S	5,375	3,666	1,709	30	1.76%	32,027	0.84	0.96	25,827	1,471,254	241,154	998,591	1,943,917	16.39
1992	1994	1995		23,903	11,755	12,148	263	2.16%	64,035	0.84	0.96	51,638	2,385,157	126,262	2,137,683	2,632,631	5.29
1993	1995	1996		26,824	8,898	17,926	527	2.94%	42,812	0.84	0.96	34,524	1,174,326	34,813	1,106,093	1,242,560	2.96
1994	1996	1997		700	607	93	7	7.53%	46,942	0.84	0.96	37,854	502,918	141,640	225,304	780,532	28.16
1995	1997	1998		7,819	3,170	4,649	154	3.31%	78,462	0.84	0.96	63,272	1,910,068	143,826	1,628,168	2,191,967	7.53
1996	1998	1999		6,836	2,030	4,806	181	3.77%	102,667	0.84	0.96	82,791	2,198,298	153,884	1,896,685	2,499,911	7.00
1997	1999	2000		8,300	3,706	4,594	292	6.36%	43,788	0.84	0.96	35,311	555,538	29,146	498,411	612,665	5.25
1998	2000	2001		10,436	7,077	3,359	214	6.37%	111,313	0.84	0.96	89,763	1,408,940	90,601	1,231,363	1,586,518	6.43
1999	2001	2002		12,202	7,355	4,847	131	2.70%	69,069	0.84	0.96	55,697	2,060,798	167,161	1,733,162	2,388,434	8.11

Estimate A: Assumes Simpson (late) and Satsop Springs fish survived and contributed 1/2 the rate as Simpson (normal) hatchery stock.

Estimate B: Assumes Simpson (late) and Satsop Springs fish survived and contributed at the same rate as Simpson (normal) hatchery stock.

Estimate C: Average of Estimates A&B.

Estimate S: Hatchery/ Wild Catch estimates based on scale analysis

Excludes BY 1990	
1,837,273	avg
502,918	min
3,592,275	max
19	count

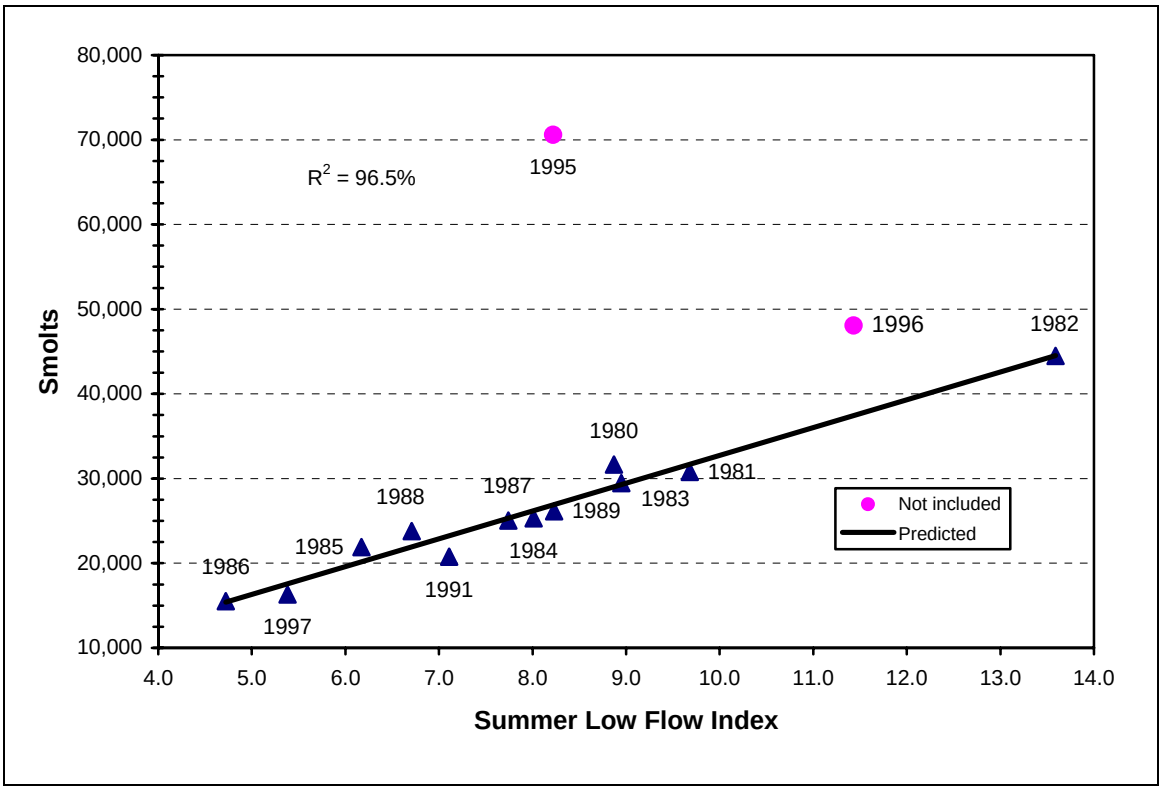


Figure 5: Wild coho smolt production vs. Puget Sound summer low flow, Bingham Creek, brood years 1980-1997 (broods 1990 and 1992 & 1996 omitted).

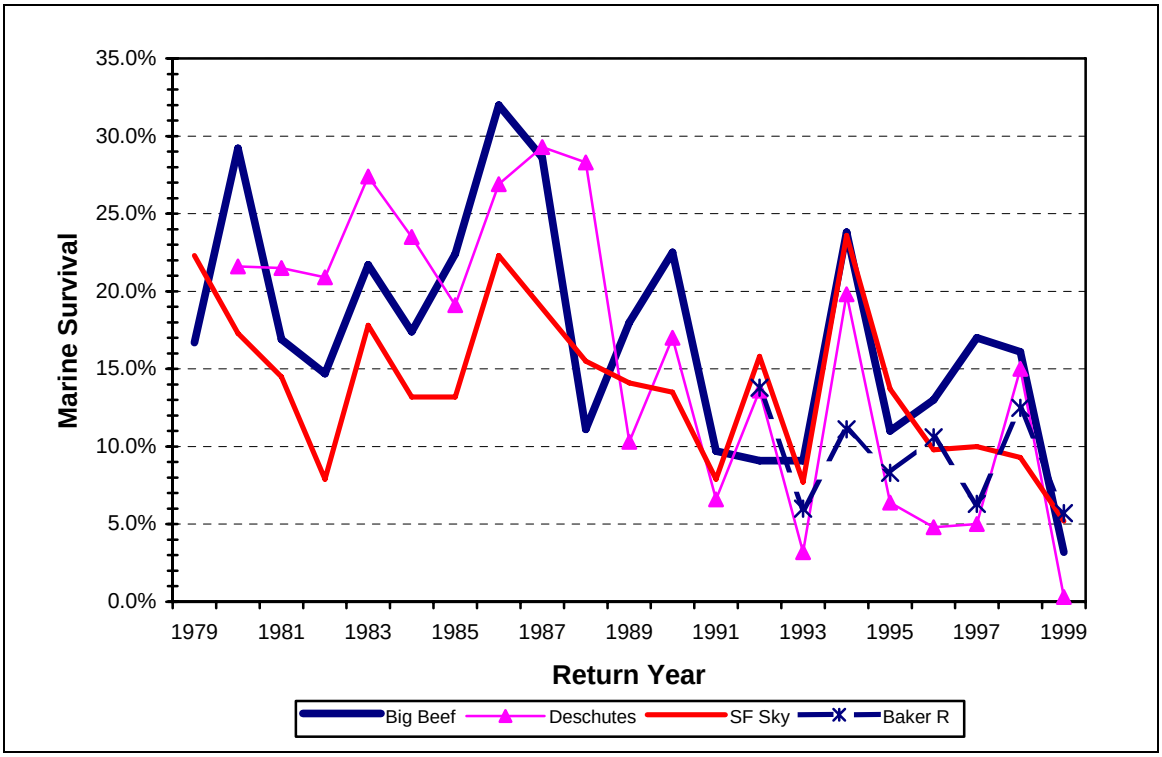


Figure 6: Marine Survival of wild coho (age-3) measured at four Puget Sound streams.

Table 8: Comparison of marine survival (age 3) between Big Beef Creek, Deschutes River, SF Skykomish River, and Baker River wild tagged coho.

Year Brood	Rtn	Big Beef	Des River	SF Sky	Big Beef	Des River	SF Sky	Baker River	Average Early	Average 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
	Average	20.3	22.3	15.9	12.4	8.3	11.4	9.3	19.6	10.3	
	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	9	9	9	8	12	9	

Notes:

Marine survival for the SF Skykomish 1981 brood is estimated ([mean ratio of the average BBC + Deschutes survival]/SF Skykomish survival, by year]); because a portion of the adult return would not enter the fishway.

SF Skykomish marine survival for the 1985 brood and later is estimated ([adult returns/escapement rate]/276,000 smolts).

Marine survival for the Big Beef Creek 1994 brood is underestimated due to large, unreported/unsampled catches in the terminal area. Without Puget Sound mixed net and seine recoveries, 14.1% of tagged smolts were estimated captured in fisheries and escapement. These data, along with observations of the terminal net fishery, indicate total survival would be considerably higher.

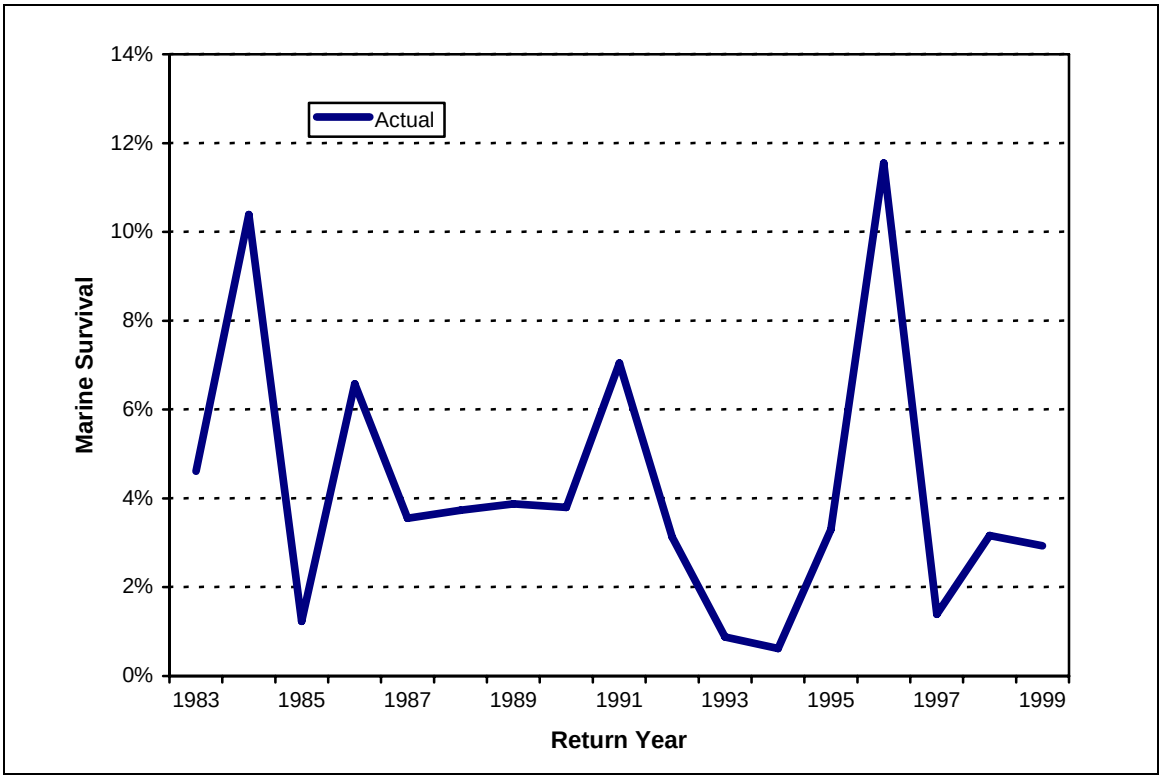
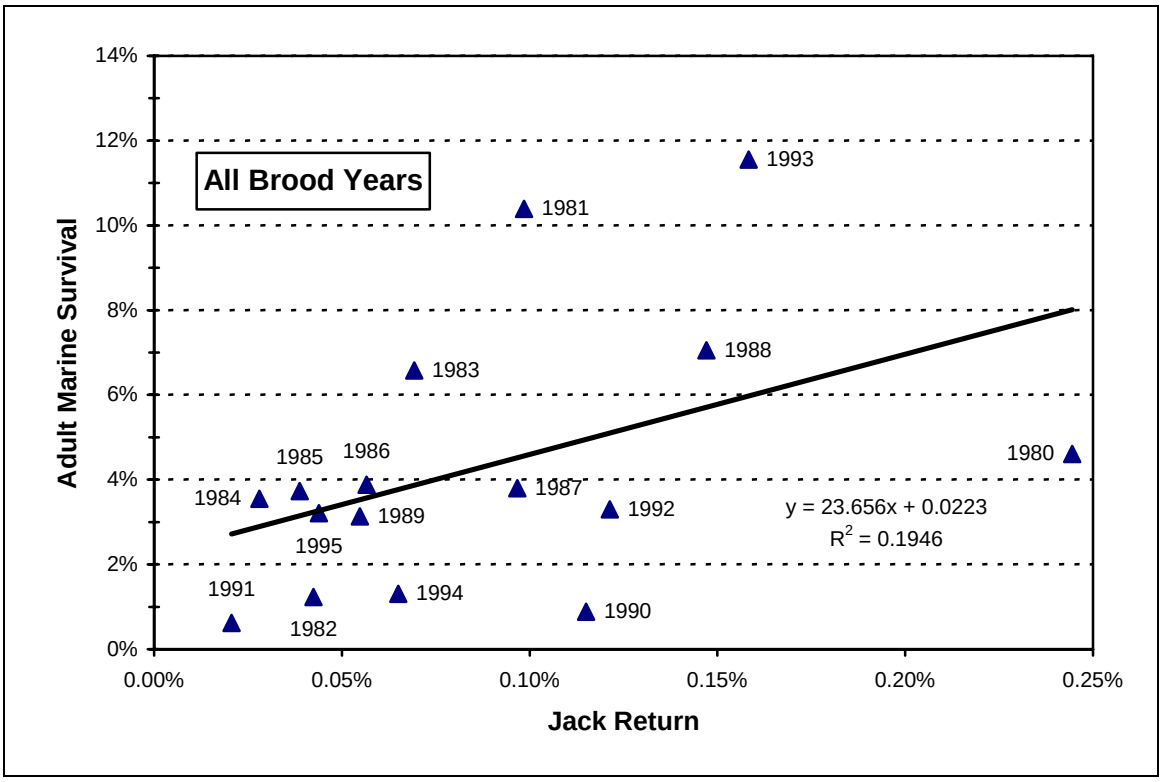


Figure 7. Marine survival of tagged wild coho from Bingham Creek.


All Brood Years
Adult Marine Survival
Jack Return
14%
12%
10%
8%
6%
4%
2%
0%
0.00%
0.05%
0.10%
0.15%
0.20%
0.25%
1993
1981
1988
1983
1985
1986
1980
1984
1987
1992
1989
1995
1991
1994
1990
1982
y = 23.656x + 0.0223
R2 = 0.1946

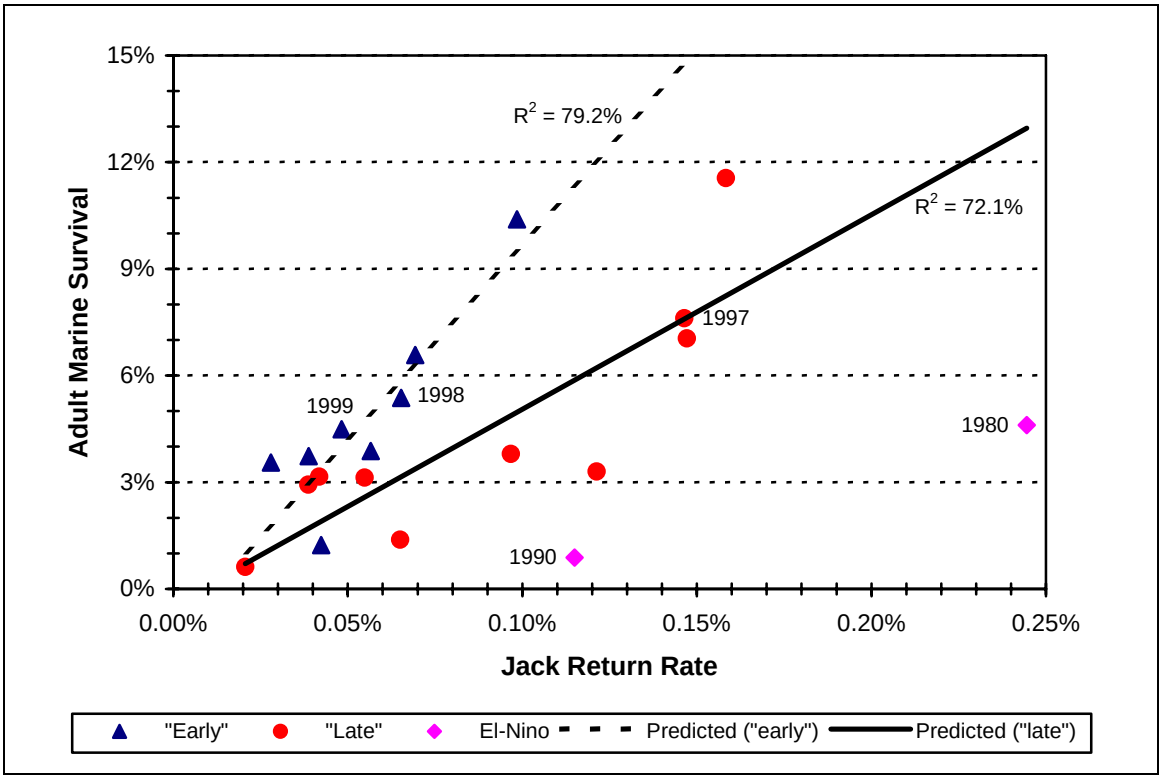


Figure 8: Jack return and adult marine survival, Bingham Creek, brood years 1980-1999.