STATE OF WASHINGTON
DEPARTMENT OF FISH AND WILDLIFE
RESOURCE ASSESSMENT DIVISION

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TO: Distribution List

FROM: Dave Seiler, Fish Biologist
Resource Assessment Division

SUBJECT: **WILD COHO FORECASTS**

Attached for your consideration, and information, are my 1996 wild coho run forecasts for all Washington state production areas outside the Columbia River. These estimates are based primarily on the results of our long-term research and monitoring program.

I look forward to an open discussion of these and any other forecasts, and any and all comments, criticisms and suggestions will be welcome. You may call me at (360) 902-2784.

DS:dht

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STATEWIDE WILD COHO FORECASTS FOR 1996

Runsize forecasts for wild stocks are the most important element of the joint state-tribal pre-season planning process for Washington State coho 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 account for catches in intercepting fisheries. Even if the runsize data bases were reasonably accurate however, in systems that are adequately seeded, coho forecasts based solely on estimated escapement have little or no predictive value. This is because 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 the forecast post season is 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 <u>the</u> 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, the department and tribes have made substantial investments in monitoring smolt populations in a number of basins. These data have been incorporated into some forecasts, but 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 can be used for estimating marine survival.

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 one starts with a known -- the number of smolts released.

Fisheries are 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 I term "primary" management units, will be used to determine the extent and shape of fisheries, production from all the other freshwater habitat units can also be approximated by extrapolating measured 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 Tables 1a and 1b are the forecasts of coho run size derived by combining estimates of natural smolt production and predictions of marine survival for all Puget Sound and Coastal production areas. The resultant 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 1a. Preliminary wild coho run forecasts for Puget Sound in 1996, based on estimates of smolt product and marine survival.

Production Unit	FRESHWATER PRODUCTION X			MARINE SURVIVAL		= RECRUITS	
	Projected Smolt Prod. (Zillges)	Est. Actual Smolt Prod. Spr. 1995	Ratio Actual/ Projected	Adults (Age 3)	Dec. (Age 2)	Adults (Age 3)	Dec. (Age 2)
Primary Units							
Skagit River	1,371,058	727,000	**53.02%**	10%	13%	72,700	97,200
Stillaguamish River	864,094	320,000	**37.03%**	10%	13%	32,000	42,560
Snohomish River	2,027,497	1,186,000	**58.50%**	15%	20%	177,900	236,607
Hood Canal	1,006,577	392,000	**38.94%**	17%	23%	66,640	89,298
Straits of Juan de Fuca	443,098	133,000	30.00%	7%	9%	9,310	12,494
Secondary Units							
Nooksack River	451,275	135,000	30.00%	10%	13%	13,500	18,063
Strait of Georgia	51,821	26,000	50.00%	10%	13%	2,600	3,479
Samish River	57,923	100,000	172.64%	10%	13%	10,000	13,380
Lake Washington	768,740	231,000	30.00%	15%	20%	34,650	47,124
Green River	416,129	125,000	30.00%	15%	20%	18,750	25,500
Puyallup River	556,243	167,000	30.00%	15%	20%	25,050	34,068
Nisqually River	200,314	60,000	30.00%	15%	20%	9,000	12,240
South Sound	544,498	212,000	38.94%	17%	23%	36,040	49,014
East Kitsap	154,973	60,000	38.94%	17%	23%	10,200	13,872
Deschutes River	219,574	25,000	**11.39%**	17%	23%	4,250	5,780
Puget Sound Total	9,133,814	3,899,000	42.69%			522,590	700,679

Note: Ratios in bold indicate actual estimates derived from production evaluation studies.

Table 1b. Preliminary wild coho run forecasts for Washington Coastal Systems in 1996, based on estimates of smolt production and marine survival.

Production Unit	F/W PROD Estimated Smolt Prod. Spr. 1995	X MARINE SURVIVAL Adults (Age 3)	Dec. (Age 2)	= RECRUITS Adults (Age 3)	Dec. (Age 2)
Coast					
Quillayute River	239,000	7%	9%	16,730	21,749
Hoh River	96,000	7%	9%	6,720	8,736
Queets River	145,000	7%	9%	10,150	13,195
Quinault River	90,000	7%	9%	6,300	8,190
Independent Tributaries	170,000	7%	9%	11,900	15,470
Grays Harbor					
Chehalis River	1,564,000	5%	7%	78,200	101,660
Humptulips River	170,000	7%	9%	11,900	15,470
Willapa Bay	340,000	7%	9%	23,800	30,940
Coastal Systems Total	2,814,000			165,700	215,410

Independent Tribs =	Stream Name	Drainage Area
	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
		424

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. Total system smolt production has also been estimated for the Stillaguamish and for the Chehalis Basin which comprises 90% of the Grays Harbor system. Smolt production has been measured from significant portions of the Snohomish, Hood Canal, Quillayute, and Queets. Production from several tributaries to the Straits has also been measured. In aggregate, this work has produced a body of information that describes wild coho carrying capacity among these systems, largely as a function of habitat quality and quantity. Seeding levels, environmental effects (flows), and human-caused habitat degradation explain some of the observed interannual variations in smolt production (Table 2).

While annual smolt monitoring in each system, as presently conducted on the Skagit River would be optimal, sufficient information exists to approximate production in systems currently unmeasured. The method of extrapolating measured results to estimate total production will vary, as it depends on the data available. Within Puget Sound, Zillges (1977) provides a ready means of transferring smolt production monitoring results among basins (as detailed below). Additionally, and for coastal systems, smolt production in unmeasured systems can be approximated on the basis of smolt production/mi^2 rates.

Puget Sound Primary Units -- Managed for Natural Escapement

Skagit River. Spring 1995 was the sixth year of estimating total smolt production in this system. 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. We estimated 727,000 coho smolts emigrated past the traps in 1995 (Table 3). In the previous five years, production has ranged from 618,000 to 1,129,000, and averaged 817,000 coho smolts.

Stillaguamish River. We estimated smolt production from the Stillaguamish River upstream of RM 16 in three years (1981-1983). Production ranged from 203,000 to 379,000, and averaged 276,000 coho smolts. Expanding for the portion of the projected smolt production (Zillges 1977) downstream of this point (23%), mean production is estimated at 360,000 smolts. As the 1995 Skagit estimate indicated lower than average production (89%), we used this rate to reduce the average Stillaguamish estimate to 320,000 smolts in 1995.

Snohomish River. We measured smolt production from the South Fork Skykomish River over nine brood years (1976-1984). This basin comprises 20.7% of the Snohomish River system's drainage area. Excluding the three year's in which escapement was artificially reduced, production averaged 276,000 smolts. Expansion of this estimate to the entire system calculates an average total production of 1,333,000 coho smolts. Reducing this production by the ratio of 1995 Skagit production to its average for the previous five years (89%) estimates 1,186,000 smolts.

Hood Canal. In 1995, we trapped and estimated a total of 23,057 coho smolts were produced from four Hood Canal streams (Big Beef, Little Anderson, Seabeck, and Stavis Creeks-see table below). This production represents 39% of that projected in Zillges (1977). Application of this rate to the entire projected Hood Canal smolt production estimates 392,000 coho. An alternative expansion method uses the ratio of the adult return to Big Beef Creek to total estimated Hood Canal wild escapement. This value has averaged around 5% in recent years (Figure 1). Expanding Big Beef Creek production by this rate estimates total Hood Canal production at 331,000 smolts. We believe that the former estimate is more accurate but likely also conservative. This contention is based on observations indicating that habitat is more degraded in tributaries to northern Hood Canal than in the streams to the south that account for much of the Canal's production (Dewatto, Union, and Tahuya Rivers). If this assessment is true, then actual smolt production is even higher than estimated herein.

Stream	Projected Smolts	Actual Production	Ratio Actual/Projected
Big Beef Creek	38,586	16,567	42.94%
Little Anderson Creek	5,100	779	15.27%
Seabeck Creek	10,497	1,326	12.63%
Stavis Creek	5,027	4,385	87.23%
Total	59,210	23,057	38.94%

Straits of Juan de Fuca. Lacking a representative index stream, we selected a value of 30% to reduce the projected production (Zillges 1977). We chose this rate, lower than the 39% measured in Hood Canal, to reflect in part the very low stock status observed at Snow Creek. Application of this rate to the projected production potential of 443,098 estimates 133,000 coho smolts.

Puget Sound Secondary Units -- Managed for Hatchery Harvest Rates

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 1995. We used a value of 30% of the projected value (Zillges 1977) to estimate production at 135,000 smolts in 1995.

Strait of Georgia. We selected a value of 50%, based on the actual-to-projected ratio estimated for the Skagit River.

Samish River. Assuming that virtually all of the returning adult coho enumerated at the Samish Hatchery are wild fish, then smolt production is well in excess of the value projected in Zillges (1977). In some recent years, 10,000 adult coho have returned. Even at a relatively low harvest rate of 50% and a high marine survival of 20%, production would be estimated at 100,000 smolts. This value is almost double the projected production. If harvest rates were higher and/or marine survival lower, then even more smolts were produced. For 1995, we used 100,000 as our best estimate.

Lake Washington, Green River, Puyallup River, and Nisqually River. Coho production in each of these systems are impacted by habitat degradation through urbanization, water withdrawals, and underescapement due to high, hatchery-directed harvest rates. Each of these systems also contains a major dam on the mainstem. Hatchery fry are outplanted in an attempt to mitigate for the presumed underseeding by natural spawners. While these outplants may contribute to increasing net production, it is likely that resultant production is lower than would be produced from adequate numbers of natural spawners. Therefore, we applied the value of 30%, lower than that measured at the Hood Canal streams, to the projected production (Zillges 1977).

South Sound and East Kitsap. As these streams are similar in size and character to those trapped in Hood Canal, we applied the production ratio measured in the Canal streams (39%) to the values projected for the tributaries to South Sound and East Kitsap.

Deschutes River. Based on trapping in 1995, we estimated 25,000 coho smolts emigrated from this system. The Deschutes has experienced severe habitat degradation in the upper watershed and low escapements. Even considering these factors, however, the very low actual production relative to the projected value (11%) contributes to our conservative estimates for the systems in which we did not directly estimate production.

Coastal Units

Quillayute River. Smolt production has been measured 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 average production/mi^2 at 417 smolts. 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 over-wintering habitat. Results also indicate this system was 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 521 mi^2 of the Quillayute watershed, excluding the Dickey River Basin. 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.

Attaining average production, however, is dependent on achieving adequate seeding. If the total system escapement estimated in 1993 of 4,165 adults is accurate, then it is unlikely that 300,000 smolts were produced, as this would equate to an average productivity of 147 smolts/female -- a high value relative to that measured statewide (Figure 2).

To estimate the likely level of smolt production in 1995, we developed a hypothetical spawner/recruit relationship for the Quillayute River. This relationship, based on the research conducted at Sunset Falls, S.F. Skykomish River (Figure 3), models two levels of carrying capacity -- 400,000 and 500,000 smolts. Using the S.F. Skykomish productivity parameter and these carrying capacities, production resulting from 2,080 females is estimated at 213,000 and 239,000 smolts, respectively (Figure 4). This approach and these estimates assume that escapement was accurately estimated in 1993.

Relating these two estimates to the total Quillayute River drainage area (629 mi^2) yields average production rates of 339 and 380 smolts/mi^2. These values are only slightly higher than the rate (321) measured for the Clearwater River in 1995. Use of this rate estimates total production at 202,000 smolts.

Queets River. Smolt production has been measured from the Clearwater River each Spring since 1981. Over these 15 broods, coho smolt production has ranged two-fold between extremes, from around 43,000 to 95,000. Estimates of parent spawners have ranged six-fold, from around 300 to over 1,900 females but have explained none of the variation in smolt production. 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 half the variation in smolt production (Figure 5).

In 1995, the Quinault Tribe estimated 45,000 coho smolts were produced from the Clearwater River. As this estimate is near the lowest on record, it indicates that freshwater survival was poor and/or seeding was low. Expansion of the 1995 Clearwater production rate of 321 smolts/mi^2 rate to the entire Queets system (450 mi^2) estimates total production at 145,000 smolts. Quinault Tribal biologists may favor alternative means of expanding the Clearwater estimate.

Hoh River. Due to the similarity and proximity of the Hoh watershed to that of the Clearwater River, the smolt production/mile rate estimated in the latter system was used to approximate Hoh River coho smolt production in 1995. The rate of 321 smolts/mi^2 times the drainage area of 299 mi^2 in the Hoh system estimates 96,000 coho smolts were produced.

Quinault River. Low escapement due to hatchery harvest rates and degraded habitat likely combined to limit natural smolt production from this system. To reflect these effects, the relatively low rate of 200 smolts per square mile was selected. This rate times the total area in this basin (434 mi^2) estimates total production at around 90,000 smolts.

Independent Tributaries Smolt production has not been directly measured from any of the independent coastal tributaries. Application of an average production rate of 400 smolts/mi^2 to their combined watershed area (424 mi^2-Table 1) estimates 170,000 coho smolts were produced from these systems. The value of 400 smolts/mi^2 was selected, slightly higher than the value measured in the Clearwater River in 1995 for several reasons. First, drainage area values were not available for some of the minor tributaries, thus the total area estimate is low. Second many of these systems are lower gradient than the Clearwater River and therefore production per area should be higher. Finally, escapements may have been better in these systems because most are too small to warrant terminal fisheries.

Grays Harbor Coho smolt production from the Chehalis River system has been measured each brood since the 1980 brood through wild smolt trapping/tagging and CWT sampling in the Quinault terminal net fishery in the lower Chehalis River. Resultant estimates have ranged threefold, from around one million to over three million (Table 4). Analysis to understand the components of variation has determined that over these 11 broods only one variable, flow during spawning, explains a significant portion of the interannual variation in estimated smolt production (Figure 6). An even better fit (R^2 = 64% vs 54%) was achieved with a binomial curvilinear regression model (Figure 7). Moreover, there is reason to believe that this relationship may be even stronger than indicated by the correlation coefficients. For each of the three points that lie well below the regression line other important brood specific factors were in effect.

- The 1989 brood was likely impacted by the severe storm which produced extremely high flows on January 10, 1990. On this date, the Chehalis River flooded over Interstate-5. This storm also triggered mass wasting events in many watersheds.
- The 1986 brood was undoubtedly reduced by the effects of the devastating drought of summer 1987 which resulted in the lowest production on record from Bingham Creek (Figure 8).
- 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 the watershed is a function of flow. In very dry Falls, such as the 1987 drought, adult spawners simply cannot distribute as widely and as high in tributaries as they can in wetter years.

Correlation of estimated escapement with the estimates of smolt production explained only 11% of the variation. Other flow periods, winter (incubation), spring (fry distribution) and summer (fry rearing) also yielded insignificant correlations. We excluded the 1990 brood from all of these analyses because tagging on this brood was limited and therefore, also 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 was quite high (1,130 cfs), however, so it is likely smolt production was high on this brood.

For the eleven broods analyzed, this flow correlation indicates that natural seeding rates have been adequate. It also appears that the fry planting program has not produced enough smolts to obscure the effect of flow on spawners. Additional analysis may result in a better understanding of the effects of flows on Chehalis River coho production.

This relationship provides a means to predict freshwater production. Flows during Fall 1993 were very low and therefore, we expect smolt production was also low. Based on the minimum flow value (206 cfs) recorded at Grand Mound on November 15, 1993, the model predicts 1,439,000 smolts were produced from the Chehalis Basin. Relating this production estimate to the drainage area in the basin (2,114 mi^2 which includes the Wishkah River) estimates average production/area in 1995 at 680 smolts. In addition to the Chehalis River watershed, the 2,550 mi^2 Grays Harbor Basin includes the watersheds of the Hoquiam River (90 mi^2), the Humptulips River (250 mi^2), and the watersheds of other, primarily southside watersheds (John's and Elk Rivers) that account for the remaining 96 mi^2. Application of the production rate estimated for the Chehalis River to the entire drainage area estimates a total of 1,734,000 smolts were produced in 1995. For purposes of the forecast, the Humptulips portion (170,000) smolts was separated and the Hoquiam and southside tributaries were added to the Chehalis production to estimate 1,564,000 smolts were produced from these systems.

Willapa Bay. The Willapa Basin, with a total 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, the generally degraded condition of the habitat, and the environmental conditions affecting the 1993 brood, it is likely that coho production from this basin was lower than that of the adjacent Grays Harbor system. To approximate production in 1993 we selected a value of 400 smolts/mi^2. This value applied to the total basin area estimates 340,000 coho smolts were naturally produced in 1995.

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, and (as of the 1989 brood) Baker River. Marine survival, in terms of age 3 recruits, has varied from 10% to over 30% at Big Beef Creek, and averaged near 20%. In some recent years, we have measured low survival for Deschutes River coho, but believe these estimates are biased because of low sampling rates in certain fisheries and low numbers of smolts tagged. Marine survival measured at Sunset Falls (SF Skykomish) also ranged three-fold (8% to 24%), and has averaged 15%, somewhat lower than the rates estimated for Big Beef Creek and Deschutes River coho. We attribute this lower survival to the smaller smolts produced from this colder, higher-elevation system. Survival of Baker River coho appears to track that of the other stations so far (Figure 9).

In addition to within-brood survival, ocean exploitation rates are also correlated among these three stocks (Figure 10). This suggests that while differences in survival may exist among Puget Sound wild coho stocks, survival for all stocks tends to rise and fall in response to ocean conditions. The importance of this observation is that rates measured for selected stocks can be extrapolated to estimate survival of smolts produced in other systems.

Presently, no correlation with ocean environmental conditions has been found to explain the observed inter-annual variation in marine survival. Clearly, the ocean was in an altered state during the ocean entry period for brood years 1988 through 1990. Prior to this period, we had not measured any consecutive low survival years in Puget Sound. Correlation between jack returns and same-brood survival-to-adults at the only stations where jacks are reliably enumerated (Big Beef Creek and Deschutes River) has not indicated any relationship. Lacking a useful indicator of marine survival, forecasts must rely on a combination of recent average rates and judgement regarding ocean conditions.

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 considerably lower than that of inner Puget Sound coho.

Coast

The wild coho trapping and tagging conducted annually at Bingham Creek (Grays Harbor) since the 1980 brood represents the only measurement of marine survival on the Washington Coast. Marine survival (age 3) of wild Bingham Creek coho has ranged fifteen-fold, from 0.6% to 10%, and averaged 4% over 13 years (Figure 11). Although highly variable, marine survival is also somewhat predictable. Tagged jack returns correlated with same brood adult survival explains some of the inter-annual variation in marine survival. Over all years and including all broods, however, the relationship is poor (Figure 12). When the data set is split into early- and later-years the correlation improves especially if the El Niño broods are excluded from the correlation (Figure 13). In these broods (1980 and 1990) adult survival was very low relative to the high jack returns. This phenomenon has been observed elsewhere on the coast, notably in the Oregon Production Index.

Based on the relationship developed for the recent years, the return of 15 tagged wild jacks to Bingham Creek in 1995 predicts an adult marine survival to the ocean (age 3) of 5.4%. This value is our best estimate for the Chehalis River system. Chehalis Basin coho have generally had a marine survival rate at around half that of Humptulips wild coho, although in some recent broods this discrepancy has decreased (Figure 14). For predicting survival of Humptulips River coho and other coastal stocks we selected a rate of 7% which equates to a differential survival ratio for the Chehalis of 75%.

ESTIMATION OF NON-LANDED AND NATURAL MORTALITY RATES FOR 1996 COHO FORECASTS

Marine Survival

Coho forecasts developed for the model describe each managed cohort in terms of December Age 2 recruits. These forecasts are developed by multiplying smolt production estimates by a forecasted marine survival rate to account for losses to the cohort as a result of natural mortality to December Age 2. Historical marine survival rates can be used to develop a range of rates for use in forecasting. Historical marine survival rates are often derived from fishery and escapement tag sampling. The basic form for deriving these rates from sampling data is the following:

$$MSR_l = \frac{Sum\ of\ Expanded\ Recoveries}{Tagged\ Smolts}$$

where: MSR_l is the basic marine survival rate derived from tag recoveries

If smolt production is multiplied by this basic marine survival rate, an estimate of landed catch plus escapement is the product. This is essentially the output from the FRAM model. To provide an input forecast to the model, the basic rate must be adjusted to a December Age 2 marine survival rate by incorporating non-landed mortality and natural mortality occurring after December Age 2 recruitment. Remember that for a number of wild coho stocks, the basic marine survival rates are empirically derived from known smolt production levels, landings, and escapements. What is less well understood are the number of non-landed and natural mortalities that occur after recruitment. Therefore, if non-landed and natural mortality adjustments to the basic marine survival rates are derived from the FRAM model calibration values, the resulting rate will yield December Age 2 recruitment forecasts that, when run through the model, will yield catch plus escapements that are similar to those forecasted from the empirically derived basic marine survival rates. Since the catch plus escapement values found using the empirically derived rates are expected to be fairly realistic, deriving non-landed and natural mortality rates from the model is the most reasonable way of estimating these parameters. The following section describes how these adjustments were derived from the FRAM model.

Natural and Non-Landed Mortality Adjustments

Final FRAM pre-season model runs 9426 and 9538 were used to estimate non-landed and natural mortalities occurring after recruitment for each management unit. These two years were chosen because they represent the most recent suite of regulations and allow for comparison of rates between years. Non-landed mortality and natural mortality estimates were generated for each Puget Sound management unit (i.e., Nooksack/Samish, Skagit, Stilly/Sno, South Sound, Hood Canal, and Strait). Since the rates were used to adjust marine survival primarily for wild stocks, South Sound rates were estimated using only the South Sound Normal stock component.

The model has the ability to provide monthly natural mortality rates and fishery specific non-landed mortality rates; however, this level of resolution was not felt to be appropriate for this use since the size of the cohort in any month and the power of the fishery in any time cell can be highly variable. Non-landed and natural mortality rates were therefore simply rolled up across months and fisheries for each stock.

Total non-landed mortalities were calculated for each stock by subtracting modeled total landed catch from modeled total fishery mortalities across all fisheries. Natural mortality was calculated by subtracting total fishing mortality and escapement from recruits for each stock. The natural mortality estimate was also checked independently by calculating monthly natural mortality using monthly cohort size and escapement data provided in the FRAM model's population statistics report.

The resulting estimates of non-landed and natural mortality for each stock were divided by recruitment to yield non-landed and natural mortality rates that were fairly consistent between stocks and years (Table). However, since these rates would be used to adjust basic marine survival rates that yield landed catch plus escapement, the estimates of non-landed and natural mortalities for each stock were also divided by the stock specific catch plus escapement to provide a rate that would back the basic marine survival rate to a December Age 2 rate (Table 1). These rates can be used to adjust historical tag sample derived estimates of marine survival to December Age 2 marine survival estimates as shown in the following equation:

$$MSR_2 = MSR_1 + MSR_1 \; x \; (nl + n)$$

Where: MSR_2 is the final marine survival rate,
nl is non-landed mortality divided by catch plus escapement, and
n is natural mortality after recruitment divided by catch plus escapement.

Mortality Rates used to calculate coho Dec Age 2 recruits from forecasts of catch + escapement

1994 Mortality Rates (mortality/(catch+esc))

	Nook	Skagit	Still/Sno	SSnd	Hood	Strts
Non-Landed Mortality	0.048	0.034	0.034	0.052	0.028	0.041
Natural Mortality	0.291	0.304	0.296	0.312	0.312	0.301
Total Mortality	0.339	0.337	0.331	0.364	0.340	0.342

1995 Mortality Rates (mortality/(catch+esc))

Non-Landed Mortality	0.040	0.029	0.031	0.043	0.026	0.035
Natural Mortality	0.297	0.307	0.299	0.313	0.314	0.306
Total Mortality	0.337	0.336	0.330	0.356	0.340	0.341

94-95Average

Non-Landed Mortality	0.044	0.031	0.033	0.047	0.027	0.038
Natural Mortality	0.294	0.305	0.298	0.313	0.313	0.304
Total Mortality	0.338	0.337	0.330	0.360	0.340	0.342

1994 Mortality Rates (mortality/recruits)

	Nook	Skagit	Still/Sno	SSnd	Hood	Strts
Non-Landed Mortality	0.036	0.025	0.026	0.038	0.021	0.030
Natural Mortality	0.217	0.227	0.223	0.229	0.233	0.225
Total Mortality	0.253	0.252	0.249	0.267	0.254	0.255

1995 Mortality Rates (mortality/recruits)

Non-Landed Mortality	0.030	0.022	0.023	0.032	0.019	0.026
Natural Mortality	0.222	0.230	0.225	0.231	0.234	0.228
Total Mortality	0.252	0.252	0.248	0.262	0.253	0.254

94-95Average

Non-Landed Mortality	0.033	0.023	0.024	0.035	0.020	0.028
Natural Mortality	0.220	0.228	0.224	0.230	0.233	0.226
Total Mortality	0.253	0.252	0.248	0.265	0.254	0.255

Rates derived using final Fram pre-season runs for 1994 and 1995. Non-Landed mortality was found by subtracting total fishing mortality from total catch. Natural mortality was calculated by subtracting total fishing mortality plus escapement from Dec Age 2 recruits.

Table 2.
Summary of coho smolt production evaluations in ten Western Washington streams, and sources of interannual variation.

Stream	Number of Years	Watershed Area (mi^2)	SMOLT PRODUCTION Range Low	SMOLT PRODUCTION Range High	Ratio Hi/Lo	Average Production	Prod./Area	Identified Sources of Variation (see key)
Big Beef Creek	17	14	11,510	45,634	4.0	24,203	1,729	1, 2, 4, 5
Bingham Creek	13	35	16,153	44,567	2.8	26,473	756	2
Deschutes River	15	130	9,718	130,090	13.4	75,723	582	1, 2, 4, 5
SF Skykomish River	9	362	181,877	353,981	1.9	249,442	689	7
Dickey R.	3	87	61,717	77,554	1.3	71,189	818	6
Bogachiel River	3	129	48,962	61,580	1.3	53,751	417	6
Clearwater River	13	140	42,918	94,817	2.2	65,354	467	1, 4, 5
Stillaguamish River	3	540	203,072	379,022	1.9	275,940	511	6
Skagit River	5	1,918	617,605	1,129,123	1.8	817,380	426	6
Chehalis River	10	2,114	1,181,135	3,592,275	3.0	2,124,263	1,005	1, 2, 3, 4
Total		5,469						
Mean							740	
Wt'd Mean							692	

Notes: Skagit River total drainage area = 3,093 mi^2; 1,175 mi^2 are inaccessible above dams.
Deschutes River total drainage area = 160 mi^2; 30 mi^2 are inaccessible above Deschutes Falls.
Watersheds for Dickey and Bogachiel Rivers are estimated areas above trap locations.
Weighted mean by watershed area.

Key:
1. Winter flows - egg scour
2. Summer flows - rearing habitat
3. Fall flows - spawner distribution
4. Seeding
5. Habitat damage
6. no factors identified (measurement error may account for some of the variation).
7. experimental escapement reduction.

Table 3. Estimation of wild coho smolt production, Skagit River, 1995.

Total mainstem trap catches	27,764	$N = \frac{(m+1)(c+1)}{(r+1)}$
Baker River	-531[a]	
Skagit Hatchery	-10,079[b]	$Var = \frac{(m+1)(c+1)(m-r)(c-r)}{(r+1)^2(r+1)}$
Subtotal	-10,610	
Wild coho (c)	17,154	
LVs recaptured (r)	768	$CV = \frac{sd}{N}$
LVs released (m)	31,076	
Total Production (N)	693,272	
variance (Var)	5.8221×10^{-8}	$CI = \pm 1.96(sd)$
standard deviation (sd)	24,129	
Coefficient of Var. (CV)	3.48%	
Confidence Interval (CI)	±47,242	

Estimated coho smolt production	
Skagit River	693,272
Baker River	33,388
Total production	726,660
Upper CI (95%)	773,953
Lower CI (95%)	679,367

[a] Estimated: Baker recovery rate from 389 tags read from a sample of 536 (389 tags read; 92 Baker wild and 297 Skagit hatchery = .2365 x 1,415 total ad-marks captured = 335 estimated Baker wild tags in the catch x 33,388/21,060 wild Baker expansion = 531 estimated total wild Baker River smolts.

[b] Hatchery smolt total from counts obtained at trapping.

Table 4.

Estimation of wild coho smolt production from the Chehalis Basin, via backcalculation. These estimates assume expanded 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 (Var.)^2	95% Conf. Interval Low (J-(1.96*K))	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%	74,847	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%	59,860	0.84	0.96	48,271	2,928,447	431,344	2,083,012	3,773,882	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%	71,457	0.84	0.96	57,623	1,181,135	75,185	1,033,773	1,328,497	6.37
			B	12,111	10,197	1,914	213	11.13%	71,457	0.84	0.96	57,623	517,795	32,589	453,921	581,669	6.29
			C	12,111	8,971	3,140	213	6.78%	71,457	0.84	0.96	57,623	849,465	54,143	743,344	955,585	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

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

				ESTIMATION OF WILD TAG RATE IN SAMPLE					WILD SMOLT TAGGING				ESTIMATED SMOLT PRODUCTION				
				A	B	C	D	E	F	G	H	I	J	K			
Br. Yr.	Tag Yr.	Rtn. Yr.		Total Sample	Est. Hatch.	Wild Sample (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 (Var.)^2	95% Conf. Int. Low (J-(1.96*K))	High (J+(1.96*K))	CV (K/J)
1980	1982	1983		3,704	1,813	1,891	37	1.96%	47,711	0.84	0.96	38,474	1,966,341	296,094	1,385,996	2,546,686	15.06
1981	1983	1984		2,103	604	1,499	33	2.20%	78,839	0.84	0.96	63,576	2,887,881	463,141	1,980,124	3,795,638	16.04
1982	1984	1985		2,411	1,565	846	57	6.74%	110,020	0.84	0.96	88,720	1,316,793	162,021	999,233	1,634,354	12.30
1983	1985	1986		6,573	2,071	4,502	162	3.60%	96,687	0.84	0.96	77,968	2,166,751	160,285	1,852,593	2,480,910	7.40
1984	1986	1987		7,311	1,543	5,768	85	1.47%	74,847	0.84	0.85	53,338	3,619,454	359,559	2,914,719	4,324,189	9.93
1985	1987	1988		1,471	475	996	15	1.51%	59,860	0.84	0.96	48,271	3,205,201	716,147	1,801,554	4,608,849	22.34
1986	1988	1989		4,116	3,791	325	34	10.46%	54,285	0.84	0.96	43,775	418,442	63,967	293,067	543,816	15.29
1987	1989	1990		8,630	5,185	3,445	71	2.06%	44,889	0.84	0.96	36,198	1,756,392	190,861	1,382,305	2,130,478	10.87
1988	1990	1991		13,978	6,614	7,364	210	2.85%	69,701	0.84	0.96	56,207	1,970,988	123,797	1,728,346	2,213,630	6.28
1989	1991	1992	(B)	4,228	3,467	761	76	9.99%	71,457	0.84	0.96	57,623	576,987	60,813	457,794	696,181	10.54
1990	1992	1993	(B)	3,554	1,450	2,104	6	0.29%	21,125	0.84	0.96	17,035	5,973,677	1,692,854	2,655,683	9,291,670	28.34
1991	1993	1994	(S)	1,611	1,099	512	9	1.76%	32,027	0.84	0.96	25,827	1,469,245	391,628	701,655	2,236,835	26.66

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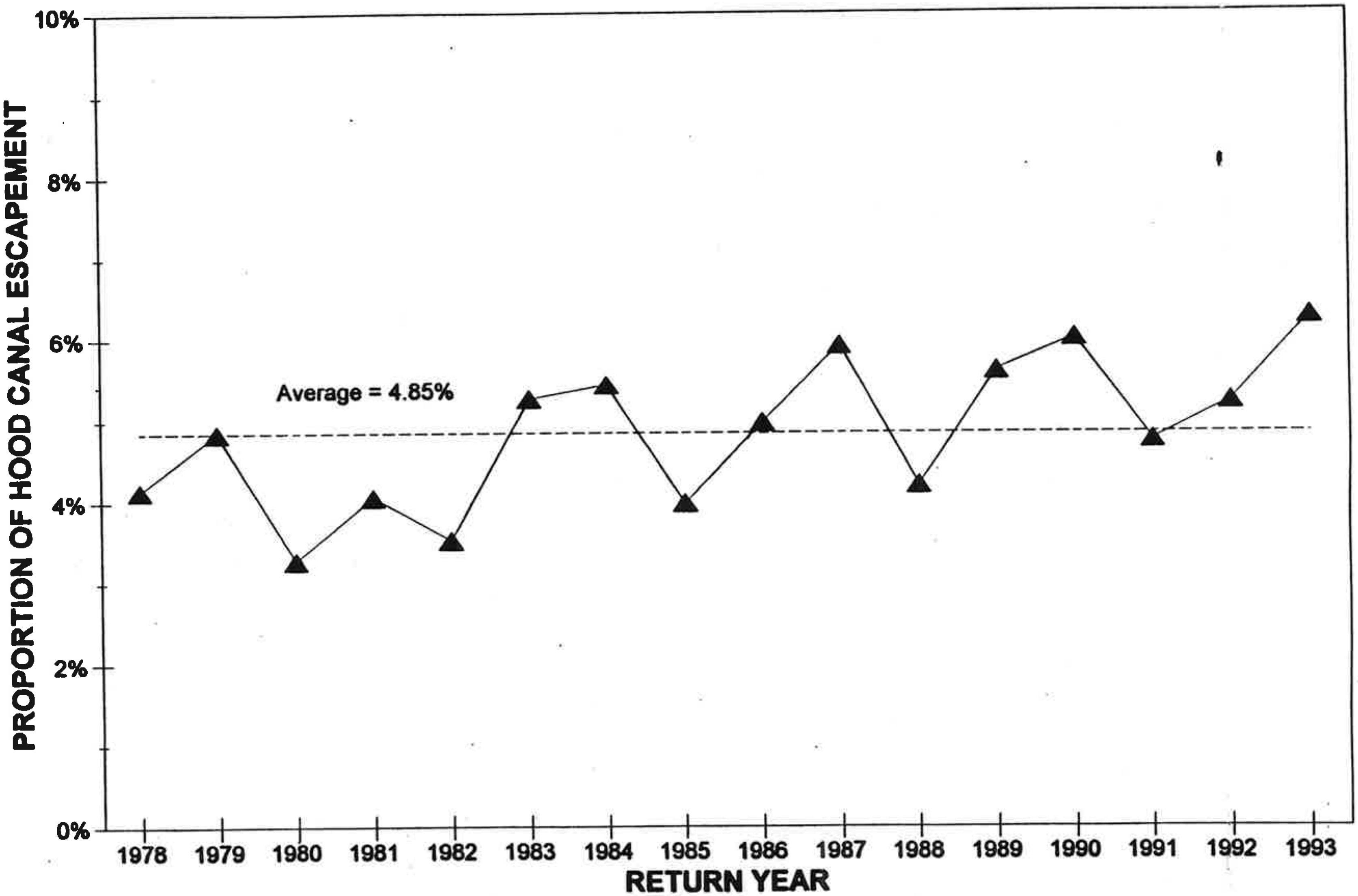
(rev. 01/10/96)

FIGURE 1

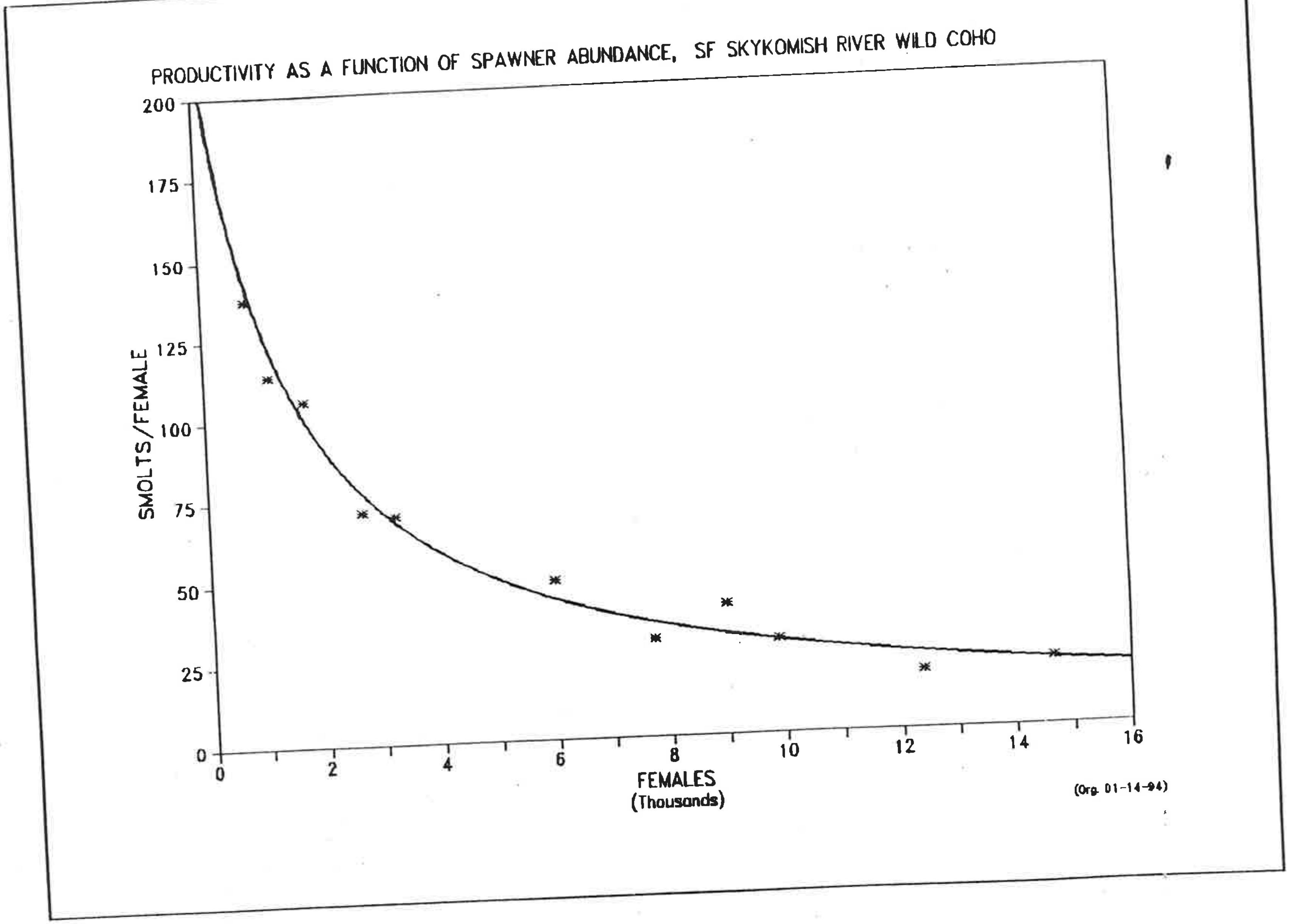
COHO ESCAPEMENT TO BIG BEEF CREEK RELATIVE TO EST. HOOD CANAL ESCAPEMENT



(org. 12/19/92)

rev. 06/15/94)

FIGURE 2



PRODUCTIVITY AS A FUNCTION OF SPAWNER ABUNDANCE, SF SKYKOMISH RIVER WILD COHO
SMOLTS/FEMALE
200
175
150
125
100
75
50
25
0
0
2
4
6
8
10
12
14
16
FEMALES
(Thousands)
(Org. 01-14-94)

FIGURE 3

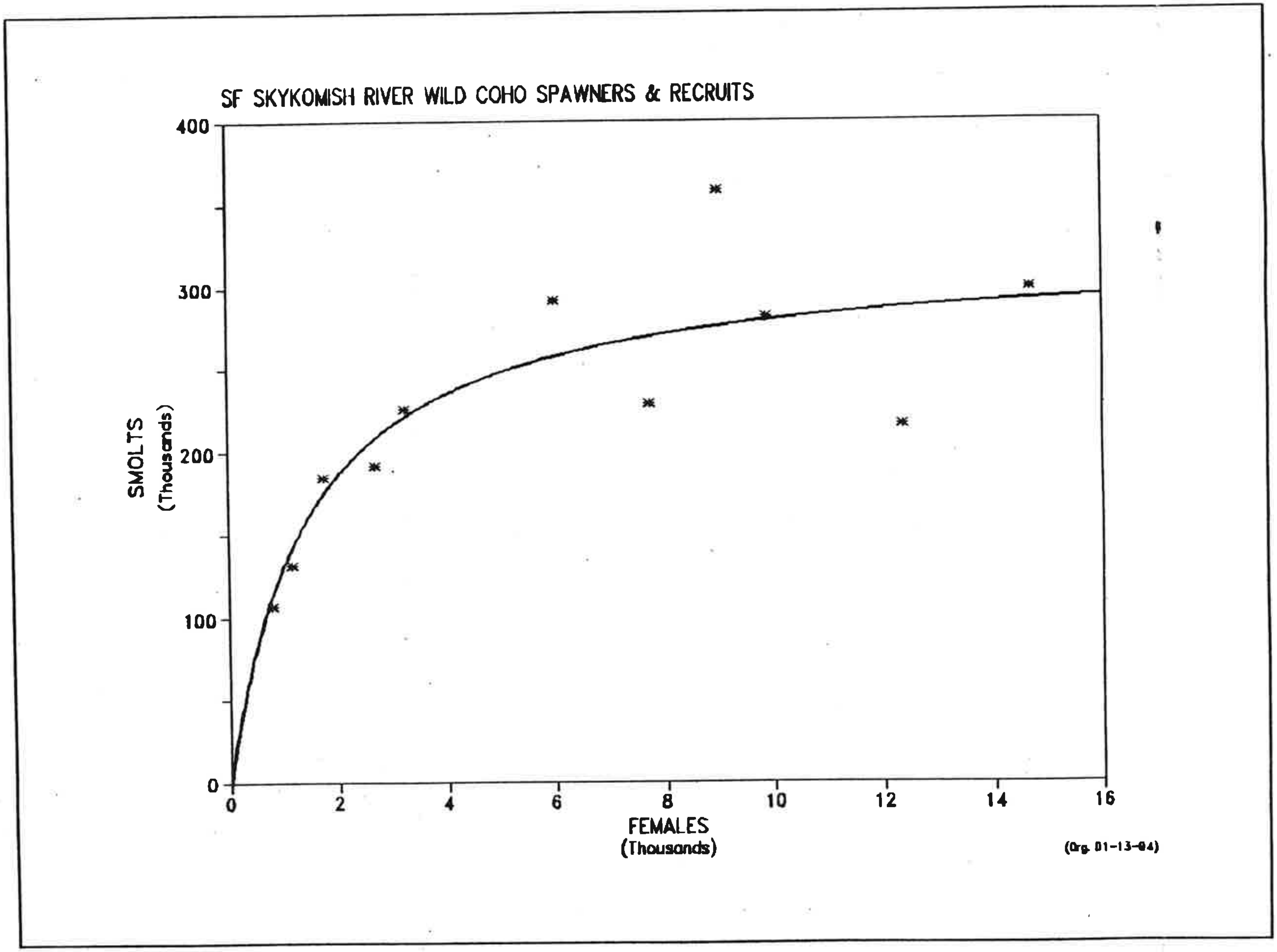
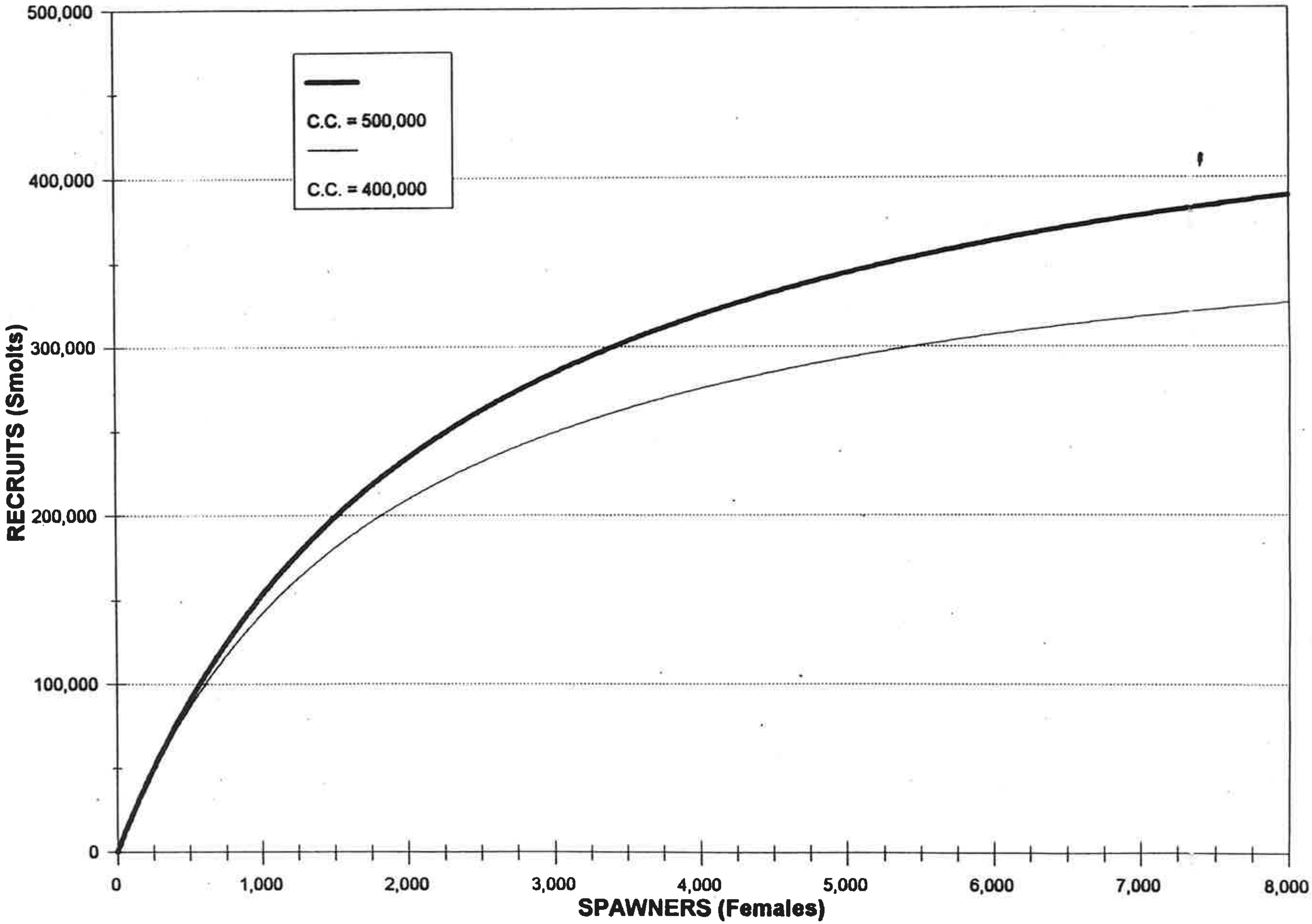

SF SKYKOMISH RIVER WILD COHO SPAWNERS & RECRUITS
SMOLTS
(Thousands)
400
300
200
100
0
0
2
4
6
8
10
12
14
16
FEMALES
(Thousands)
(Org. 01-13-94)

FIGURE 4 SPAWNER/RECRUIT RELATIONSHIP QUILLAYUTE RIVER COHO



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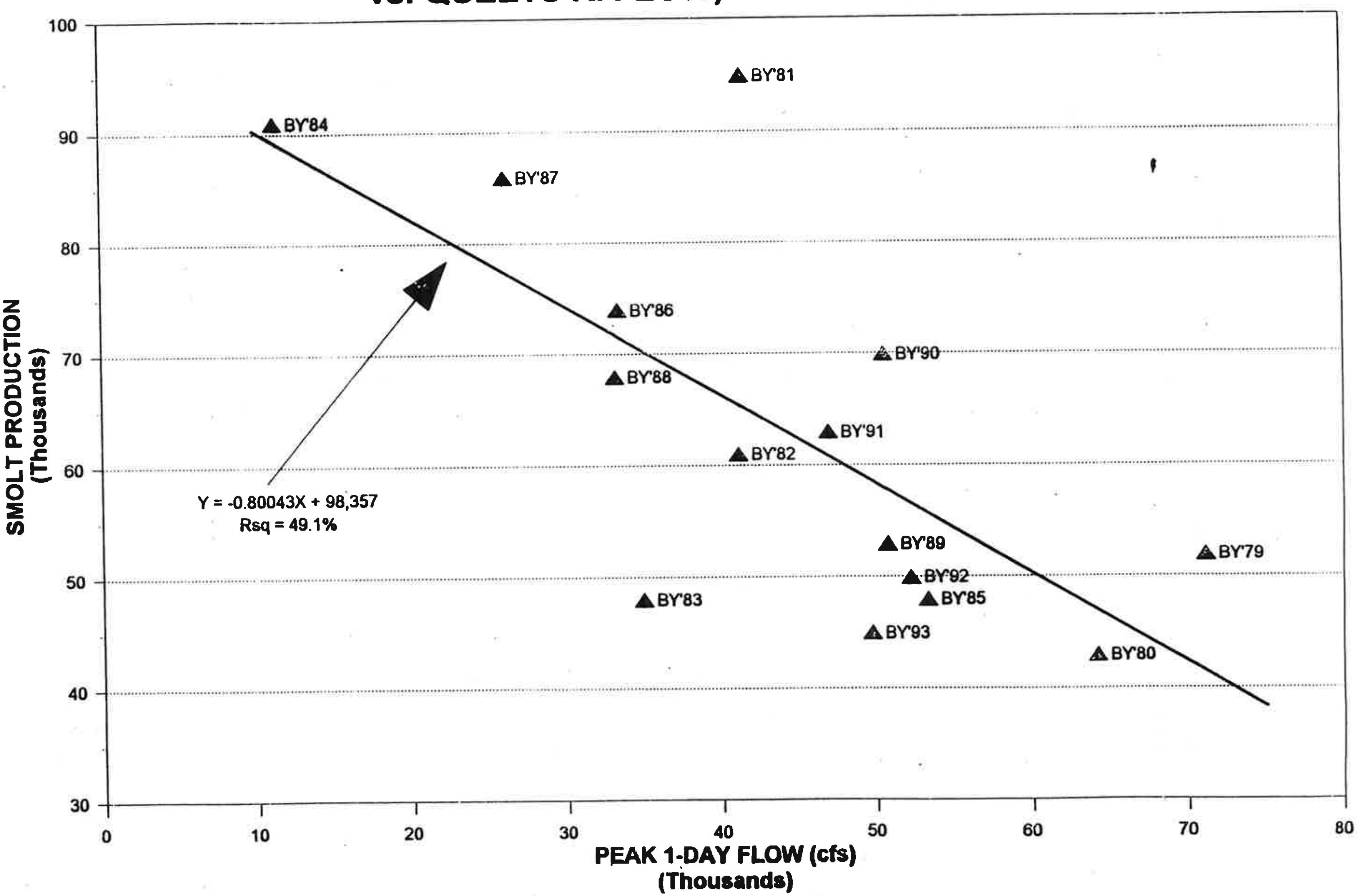
(rev 01/02/96)

FIGURE 5

CLEARWATER R. COHO SMOLT PRODUCTION vs. QUEETS R. FLOW, DEC 15 - MAR 31



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(rev. 01/08/96)

FIGURE 6

COHO SMOLT PRODUCTION & FLOW (cfs)
CHEHALIS RIVER, BROOD YEARS 1980-1991

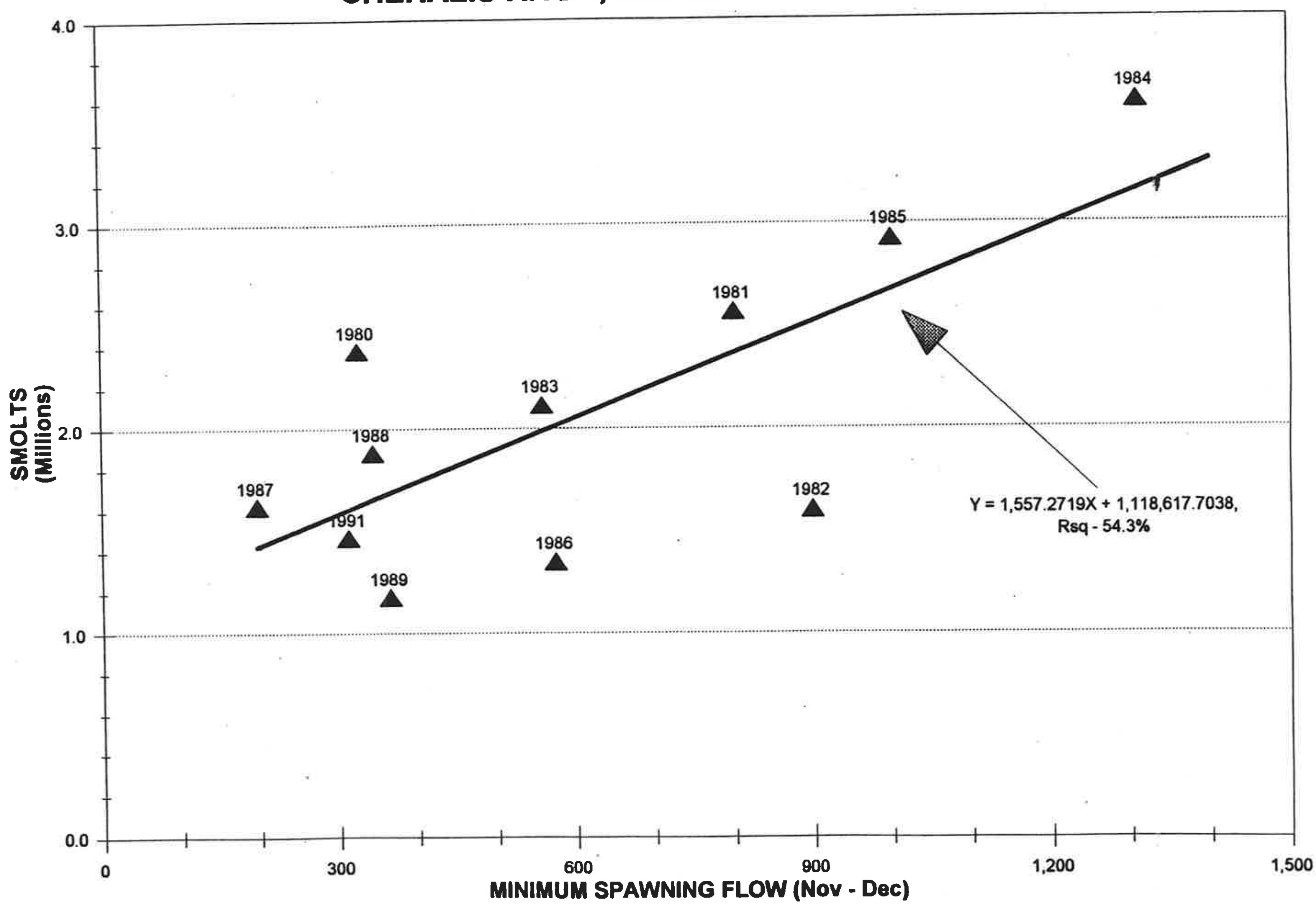
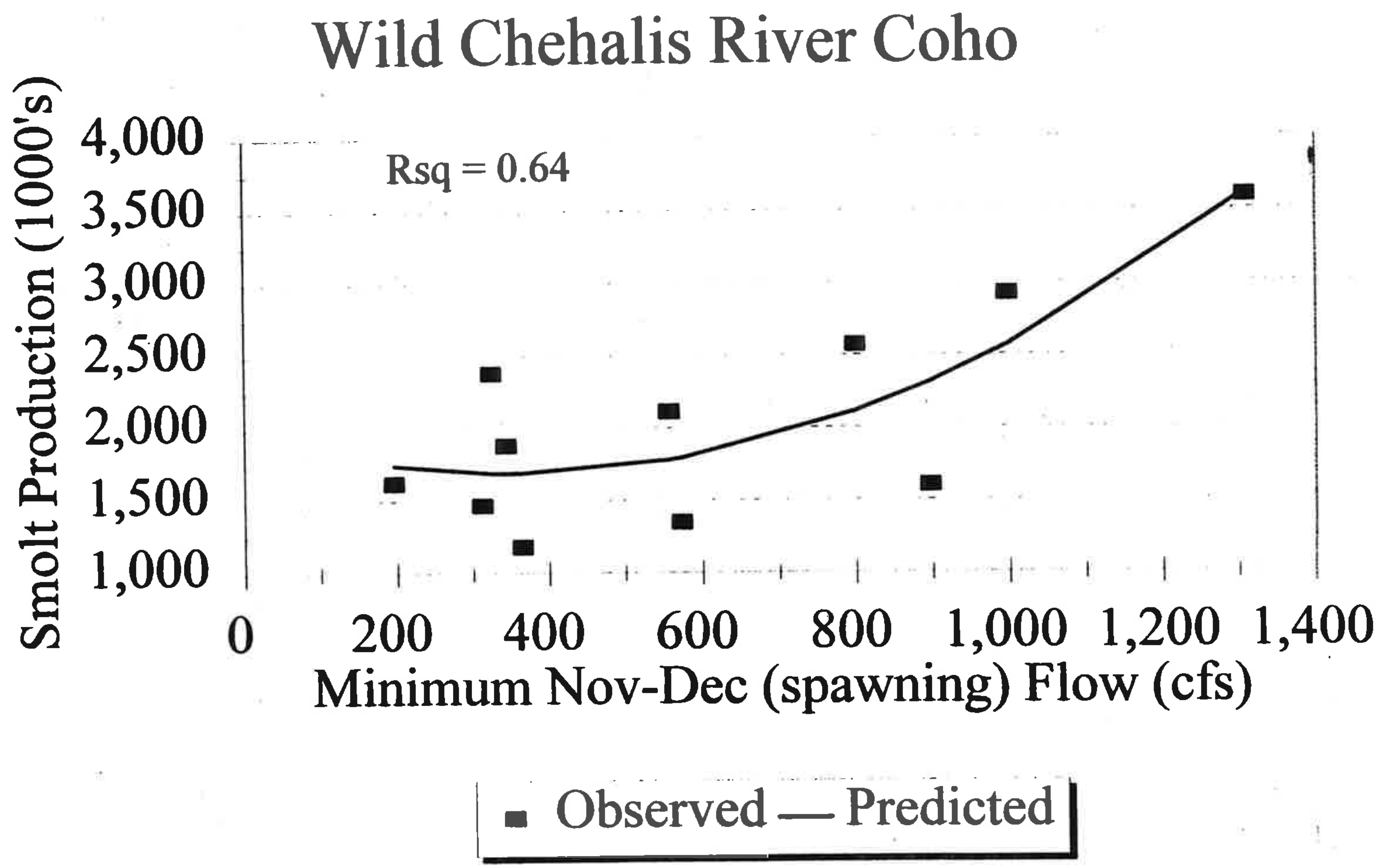


FIGURE 7



Note: Flow measurements taken at the Grand Mound gage

Figure xxx. Binomial curvilinear regression of minimum November - December (spawning) flow to coho smolts produced in the Chehalis River.

FIGURE 8
SMOLT PRODUCTION VS. SUMMER LOW FLOW BINGHAM CREEK BROOD YEARS 1980-1991

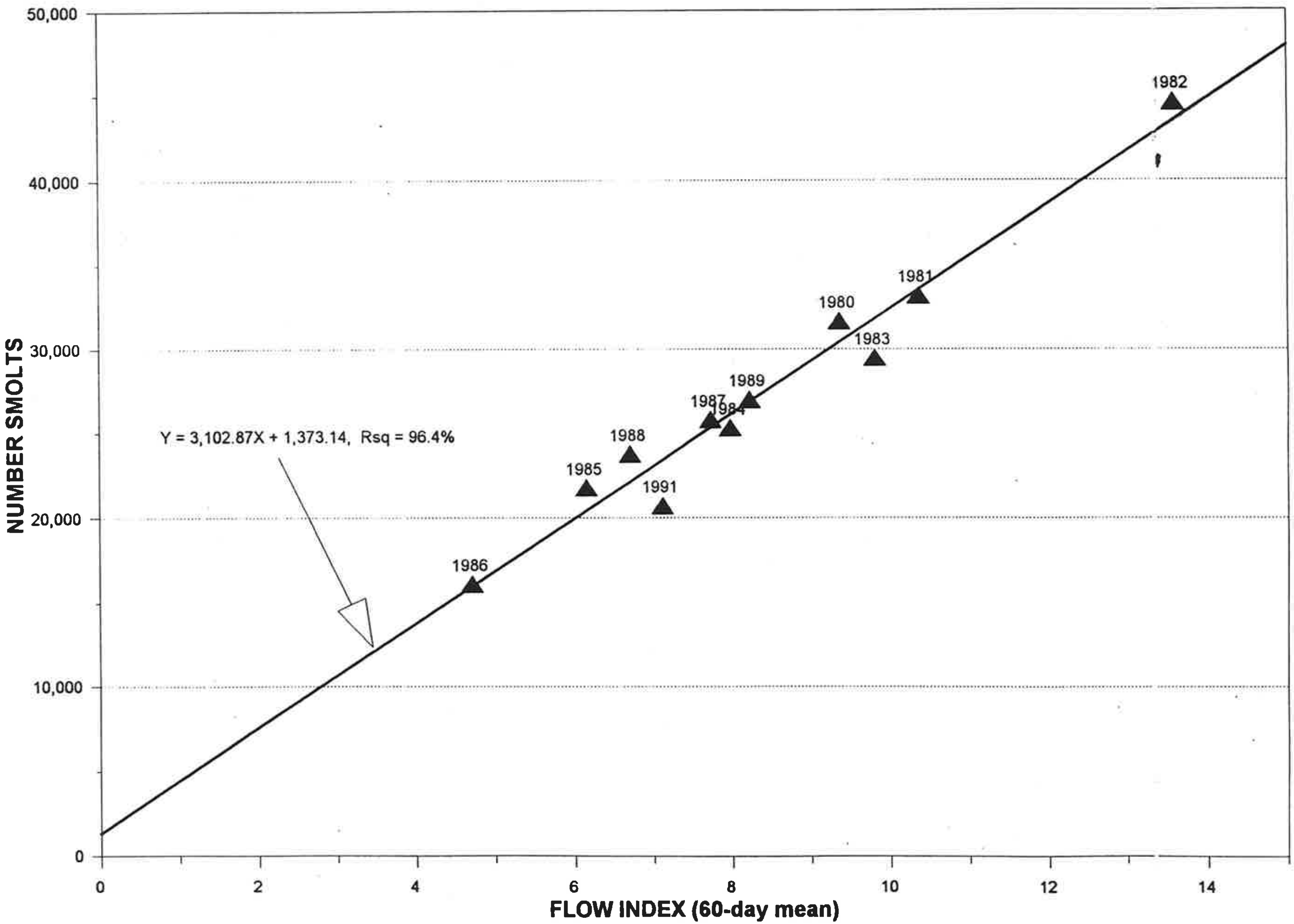
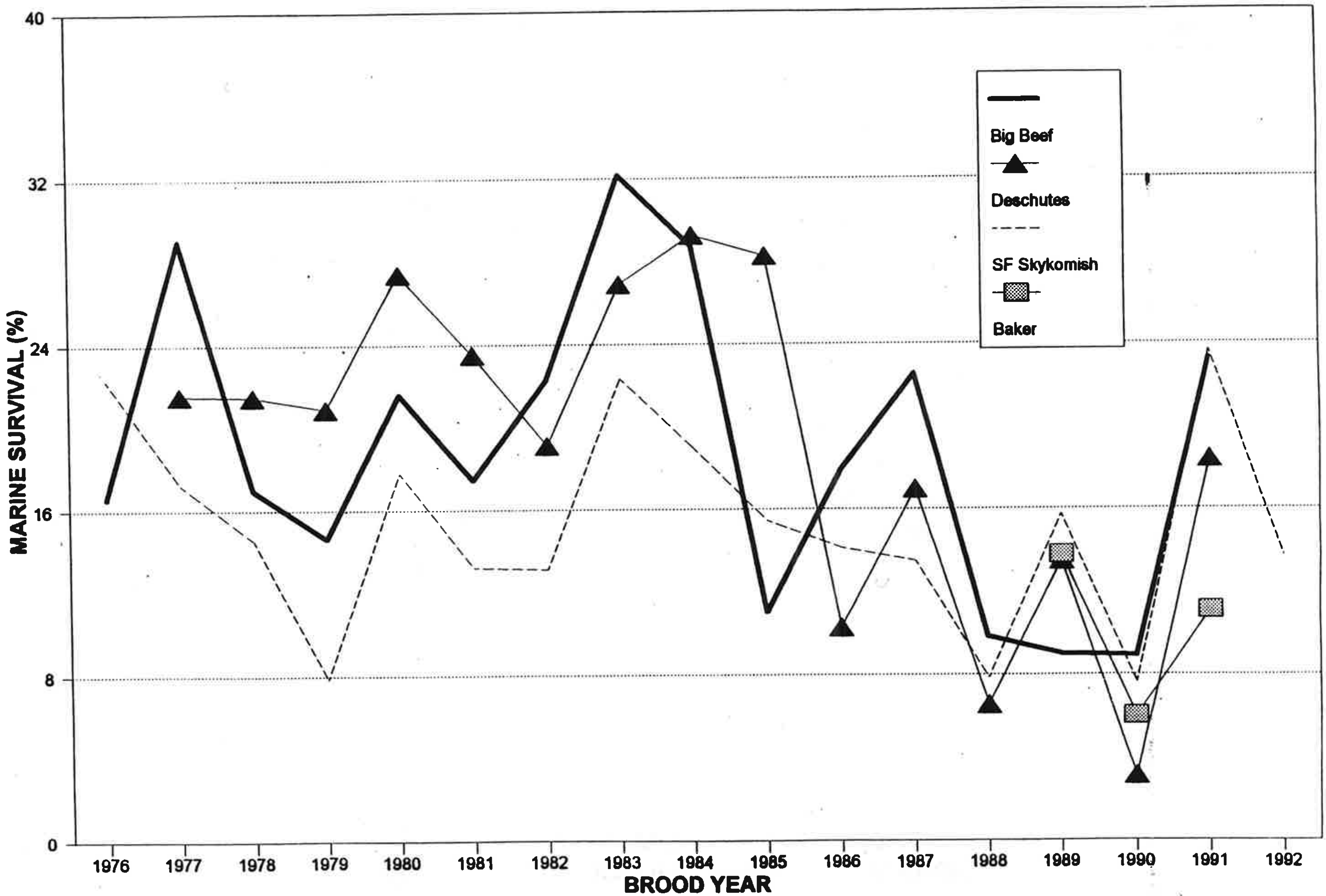


FIGURE 9

MARINE SURVIVAL: PUGET SOUND WILD COHO (age 3)



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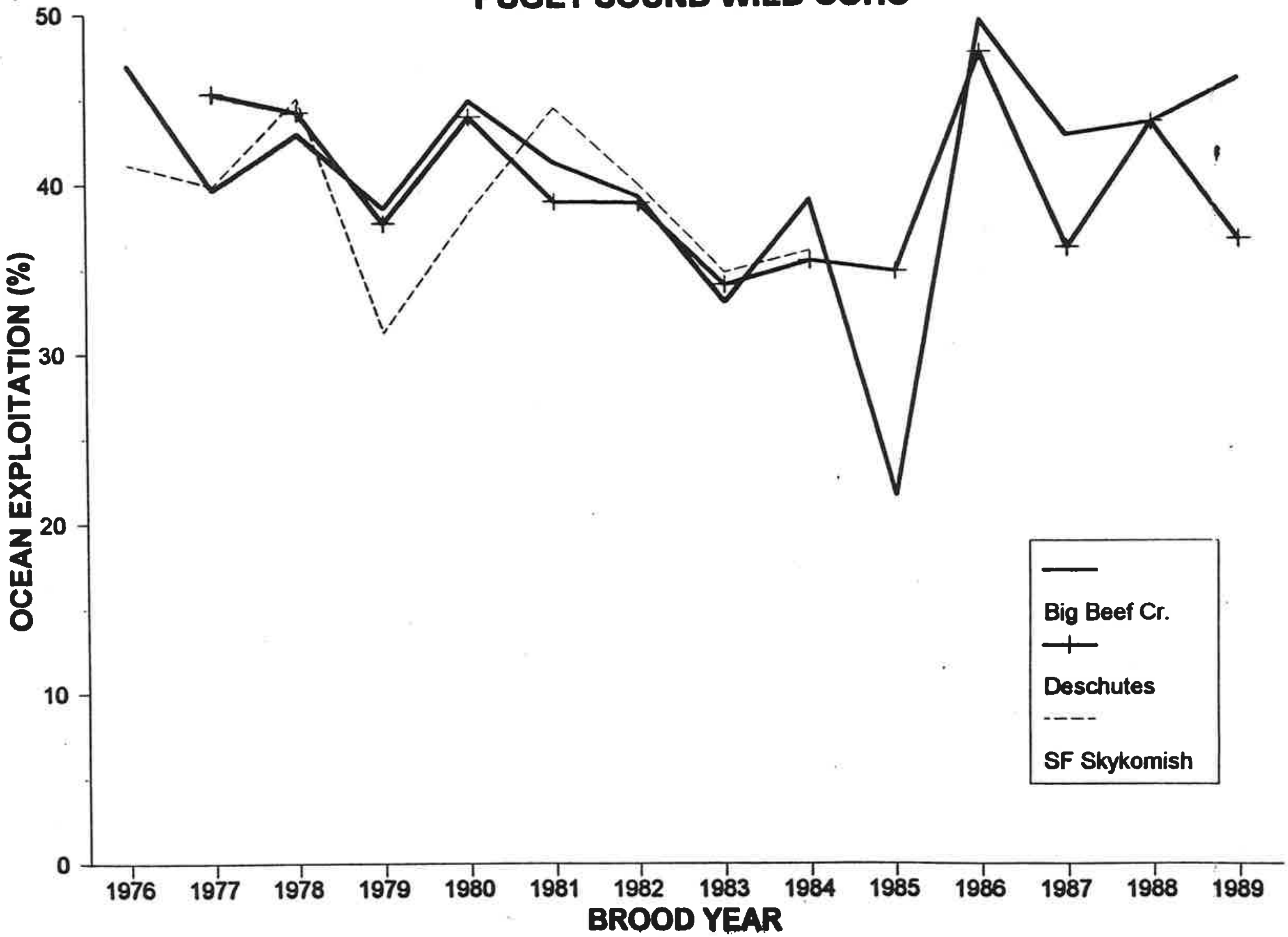
(rev. 01/03/96)

FIGURE 10

OCEAN EXPLOITATION RATES: PUGET SOUND WILD COHO



(org. 12/21/93)

(rev. 06/16/94)

FIGURE 11

MARINE SURVIVAL
BINGHAM CREEK TAGGED WILD COHO

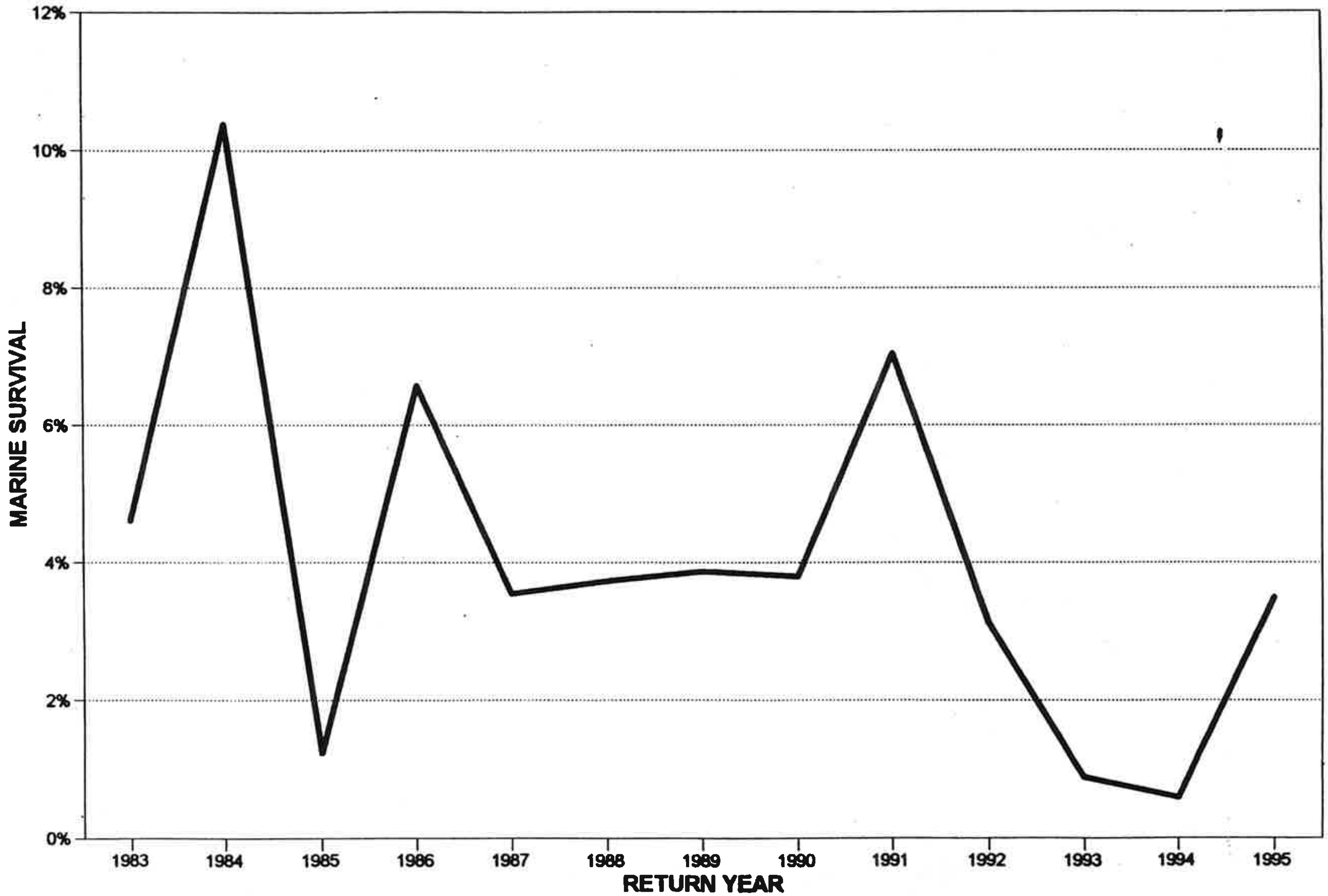
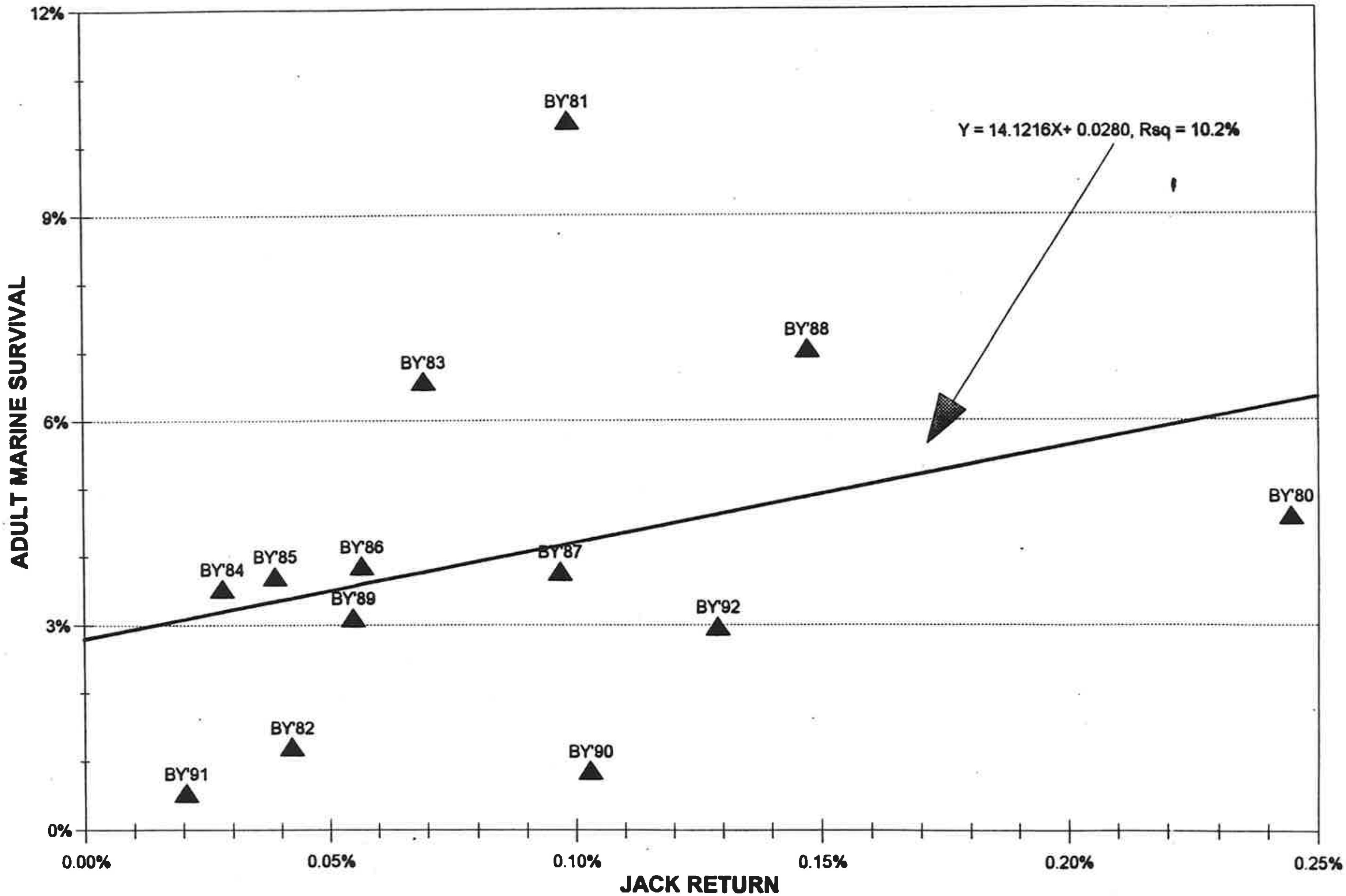


FIGURE 12

RELATIONSHIP BETWEEN JACK RETURN & ADULT MARINE SURVIVAL, BINGHAM CREEK



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(rev. 12/26/95)

FIGURE 13

RELATIONSHIP BETWEEN JACK RETURN & ADULT MARINE SURVIVAL, BINGHAM CREEK

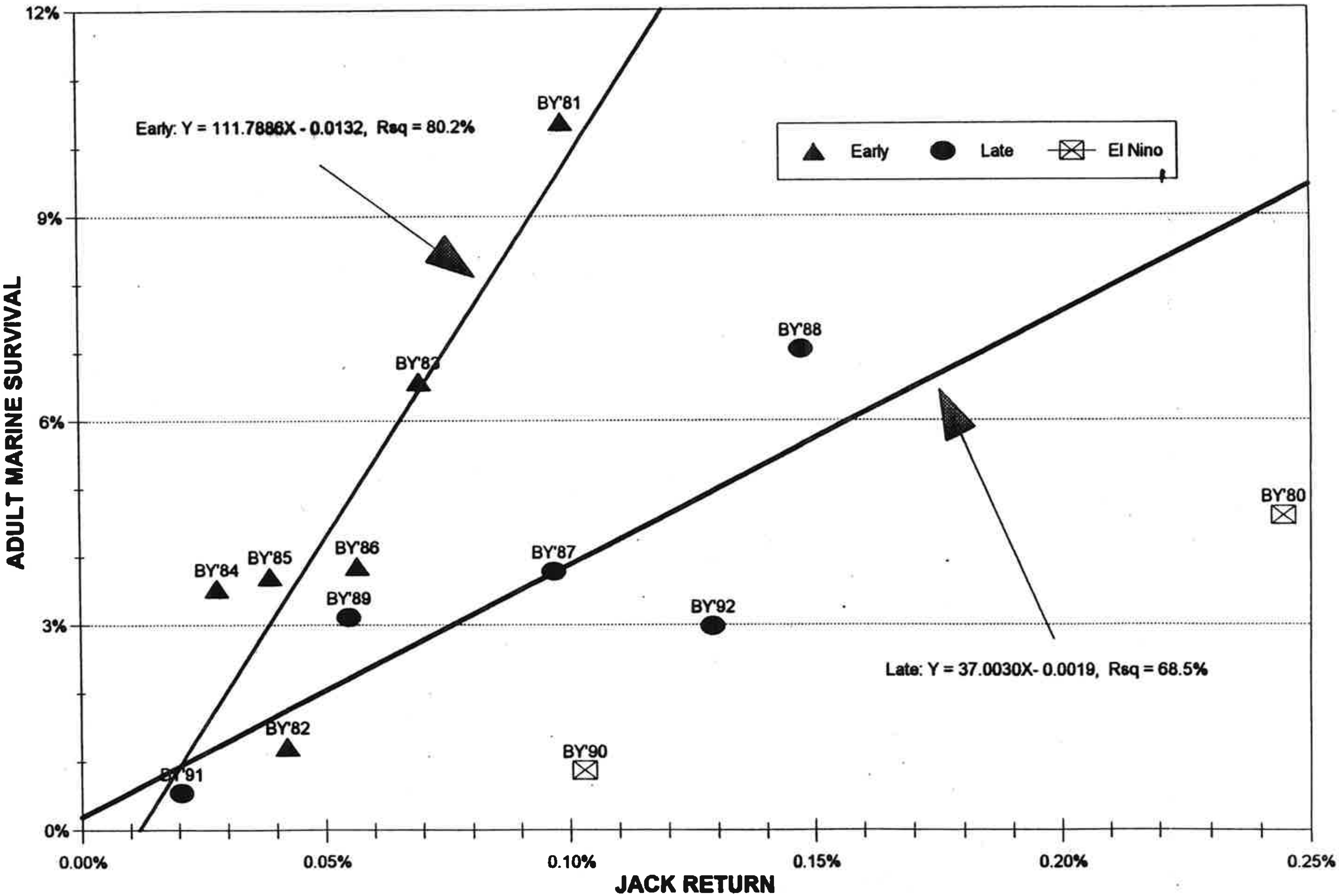

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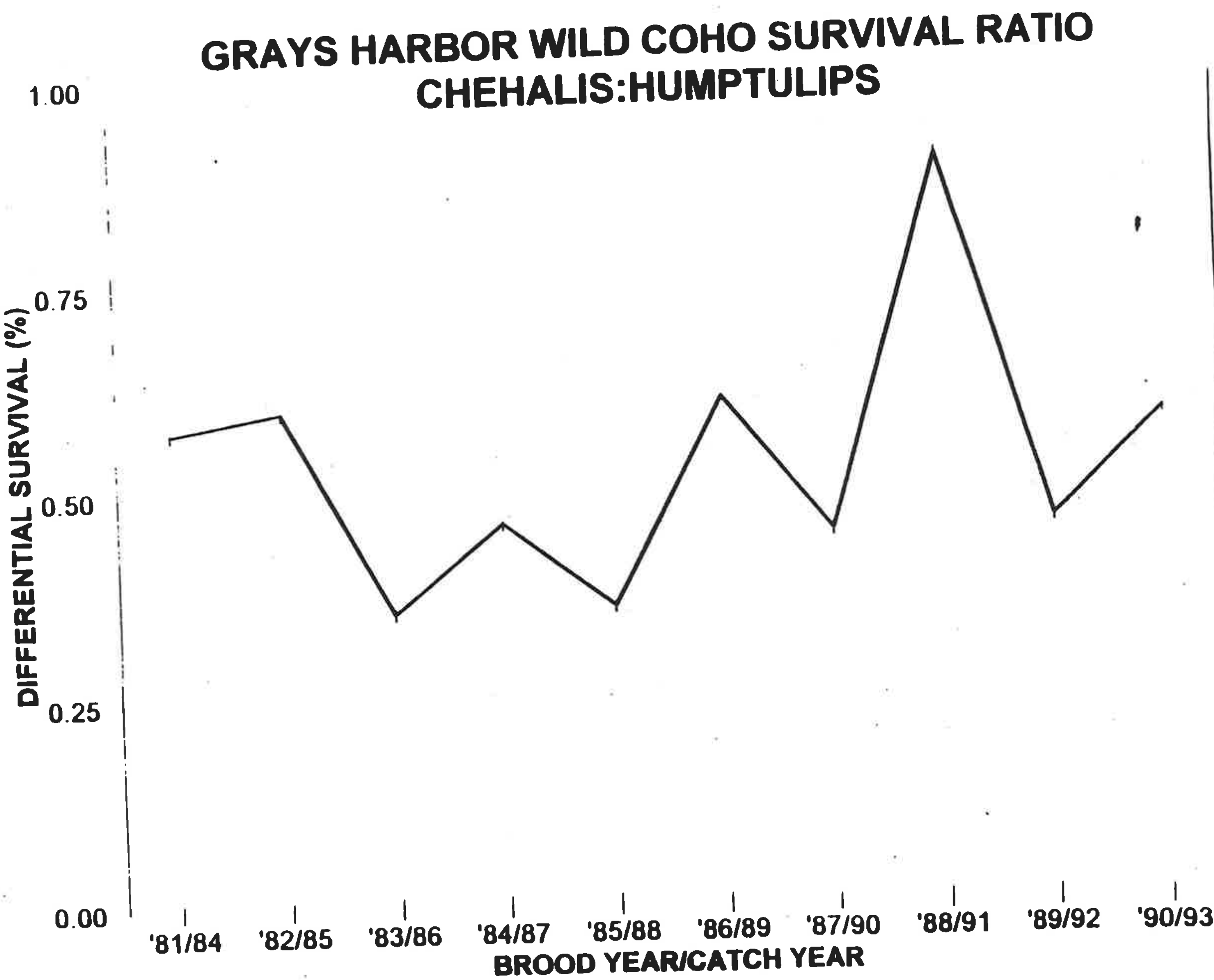
FIGURE 14



(rev 04/27/94)