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Forecast for southern British Columbia coho salmon in 2000

L. Blair Holtby
Kent Simpson
Ron W. Tanasichuk
James R. Irvine

Fisheries and Oceans Canada
Stock Assessment Division
Science Branch
Pacific Biological Station
Nanaimo, B.C. V9R 5K6

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Abstract

This research paper documents forecasts of marine survival, abundance and distribution for the coho salmon of southern British Columbia (interior Fraser including the Thompson River, lower Fraser, Strait of Georgia, and West Vancouver Island) for return year 2000.

Marine survival: Recommendations for the marine survival forecast for the five hatchery indicators and one wild coho indicator are given in the following Table. For populations around the Strait of Georgia and in the Fraser River, survivals are forecast to be either unchanged or higher in 2000 compared to those observed in 1999. Survival will remain poor throughout southern BC and survival is forecast to improve at Black Creek only because survivals were particularly poor there in 1999. In 1999, the sibling-regression models generally performed better than the statistical models so both models have been tabulated in the following Table. The two forecasts are similar only for the Big Qualicum hatchery population and there is no apparent geographic pattern to the forecast survivals. Two survival forecasts are presented for Robertson Creek coho on the west coast of Vancouver Island. The sibling regression forecast is similar to forecasts made over the past two years, which have tended to be too optimistic. The euphausiid model outperformed the sibling model in 1999 and provides a forecast for 2000 that is considerably lower than the forecast from the sibling regression. Survival of West Vancouver Island (wVI) coho might have been well below average for fish entering the ocean in 1999.

indicator	best model	$\hat{S}_{2000}$	(50% CI)	change relative to observed survival for 1999 return	$\hat{S}_{2000}$ (sibling)	(50% CI)
Big Qualicum	LLY[1]	0.015	(0.006–0.04)	same	0.012	(0.007–0.021)
Quinsam	LLY	0.01	(0.006–0.016)	same	0.026	(0.013–0.066)
Chilliwack	RAT3[2]	0.014	(0.008–0.025)	same	0.008	(0.005–0.013)
Inch Creek	LLY	0.019	(0.009–0.040)	same	0.040	(0.024–0.066)
Black Creek	3YRA[3]	0.033§	(0.024–0.046)	higher		–
Robertson Creek	sibling regression	0.033§	(0.023–0.046)	higher		–
Robertson Creek	euphausiid	0.019	(0.015–0.023)	lower		–

§ The similarity of the forecasts for Black Creek and Robertson Creek is coincidental and is not a typographic error.

Abundance forecast: Without fisheries information, forecasting abundance is highly problematic, and because we are using time-series models the forecast is dependent on the highly uncertain estimates of abundance in 1998 and 1999. Although the observed abundance of the Strait of Georgia-Fraser River (StG-Fr) aggregate in 1999 (3.3×10^5) was well above the forecast (2.0×10^5; 50% CI: 1.5×10^5–2.8×10^5), the RAT3 model continues to be the best performing model. The RAT3 model forecast of the abundance of the StG-Fr aggregate in 2000 is 2.5×10^5 (50% CI: 1.8×10^5–3.4×10^5) or 15% of the long term average abundance of 1.6×10^6.

The estimated abundance of the wVI aggregate in 1999 (2.6×10^5) was considerably less than the forecast abundance (4.5×10^5; 50% CI: 3.1×10^5–6.5×10^5). The estimate of abundance is consistent with preliminary escapement records, which indicate that there were declines in abundance in 1999 compared to 1998 (-29% for swVI streams and –49% for nwVI streams relative to 1998 (KS, unpublished and preliminary data). The 3YRA forecast for wVI abundance in 2000 is 2.7×10^5 (50% CI: 2.0×10^5–3.7×10^5) or 48% of the overall average abundance of 5.7×10^5.

[1] LLY – Like Last Year
[2] RAT3 – Average 3-year trend
[3] 3YRA – 3-year average

The estimated total abundance of interior Fraser coho in 1999 was 2.1×10^4 or 62% of the forecast abundance. The abundance forecast for interior Fraser coho for 2000 is 2.2×10^4, or 20% of the long term mean abundance. Thus, the forecast is for continued depression with little change from the last three years. Brood year escapements in the Lower and South Thompson were respectively the lowest and second lowest on record since records began. Since there is no indication of improved marine survival, continuation of poor escapement is likely in those areas and it is unlikely that total stock size will increase in 2000.

Distribution forecast: In the hypothetical circumstance of historical patterns of fishing, the predicted proportion of catch inside the Strait of Georgia (p_{inside}) would be 0.31 (50%CI 0.21–0.44), which can be characterized as a moderately strong outside distribution. The confidence interval suggests that an extreme outside year ($p_{inside} < 0.2$) is less likely than a return to a "normal" distribution ($p_{inside} > 0.4$). This forecast of distribution is based on incomplete salinity data.

Résumé

Le présent document de recherche traite des prévisions de la survie en mer, de l'abondance des effectifs et de la répartition du saumon coho du sud de la Colombie-Britannique (bassin supérieur de Fraser River, y compris Thompson River, bas Fraser, détroit de Georgie et l'ouest de l'île de Vancouver) pour l'année de remonte 2000.

Survie en mer – Des recommandations relatives à la prévision de la survie en mer des cinq stocks d'élevage et de un stock sauvage de saumon coho servant d'indicateurs sont présentées dans le tableau ci-après. On prévoit que les taux de survie des populations du détroit de Géorgie et de Fraser River demeureront inchangés ou augmenteront en 2000, par rapport à 1999. Les taux de survie resteront faibles dans l'ensemble du sud de la C.-B.; on prévoit que la survie du coho de Black Creek s'améliorera, mais seulement parce qu'elle était particulièrement faible en 1999. En 1999, les modèles de régression des espèces jumelles ont généralement mieux fonctionné que les modèles statistiques; les résultats des deux types de modèles sont présentés dans le tableau ci-après. Les deux modèles ne donnent des prévisions semblables que pour la population provenant de l'écloserie Big Qualicum. Les prévisions des taux de survie ne présentent aucune tendance géographique évidente. Deux prévisions du taux de survie sont présentées pour le saumon coho de Robertson Creek, sur la côte ouest de l'île de Vancouver. La prévision donnée par la régression des espèces jumelles est semblable aux prévisions faites pour les deux années précédentes, qui avaient tendance à être trop optimistes. Le modèle fondé sur les euphausiacés, qui a mieux fonctionné que le modèle des espèces jumelles en 1999, prévoit un taux de survie pour 2000 très inférieur à la prévision découlant de la régression des espèces jumelles. La survie des saumons cohos de l'ouest de l'île de Vancouver (wVI) qui sont entrés en mer en 1999 pourrait avoir été bien en deçà de la moyenne.

Stock indicateur	Meilleur modèle	$\hat{S}_{2000}$ (IC de 50 %)	Écart par rapport au taux de survie observé pour la remonte de 1999	$\hat{S}_{2000}$ (IC de 50 %) (espèces jumelles)
Big Qualicum	LLY[4]	0,015 (0,006–0,04)	inchangé	0,012 (0,007–0,021)
Quinsam	LLY	0,01 (0,006–0,016)	inchangé	0,026 (0,013–0,066)
Chilliwack	RAT3[5]	0,014 (0,008–0,025)	inchangé	0,008 (0,005–0,013)
Inch Creek	LLY	0,019 (0,009–0,040)	inchangé	0,040 (0,024–0,066)
Black Creek	3YRA[6]	0,033[§] (0,024–	supérieur	–

[4] LLY – Like Last Year (comme l'année dernière)
[5] RAT3 – Average 3-year trend (tendance moyenne sur trois ans)

Stock indicateur	Meilleur modèle	$\hat{S}_{2000}$ (IC de 50 %)	Écart par rapport au taux de survie observé pour la remonte de 1999	$\hat{S}_{2000}$ (IC de 50 %) (espèces jumelles)
		0,046)		
Robertson Creek	Régression des espèces jumelles	0,033§ (0,023–0,046)	supérieur	–
Robertson Creek	Euphausiacés	0,019 (0,015–0,023)	inférieur	–

§ Les prévisions identiques pour Black Creek et Robertson Creek sont une coïncidence; il ne s'agit pas d'une erreur typographique.

Prévision de l'abondance – En l'absence de renseignements sur des pêches, il est très difficile de prévoir l'abondance des stocks, et comme nous utilisons des modèles fondés sur des séries chronologiques, la prévision dépend des estimations très incertaines obtenues pour 1998 et 1999. Bien que l'effectif observé du stock combiné du détroit de Géorgie et de Fraser River (StG-Fr) en 1999 ($3{,}3\times10^5$) était bien supérieur à la prévision ($2{,}0\times10^5$; IC de 50 % : $1{,}5\times10^5$–$2{,}8\times10^5$), le modèle RAT3 est toujours celui qui fonctionne le mieux. La prévision de l'effectif du stockcombiné StG-Fr donnée par le modèle RAT3 pour 2000 est de $2{,}5\times10^5$ (IC de 50 % : $1{,}8\times10^5$–$3{,}4\times10^5$), soit 15 % de la valeur moyenne à long terme ($1{,}6\times10^6$).

L'estimation de l'abondance du stock combiné de wVI en 1999 ($2{,}6\times10^5$) était très inférieure à l'abondance prévu ($4{,}5\times10^5$; IC de 50 % : $3{,}1\times10^5$–$6{,}5\times10^5$). Cette estimation est en accord avec les données préliminaires sur les échappées, qui indiquent que l'abondance a baissé de 1998 à 1999 (-29 % pour les cours d'eau du sud-ouest de l'île de Vancouver et -49 % pour les cours d'eau du nord-ouest de l'île (KS, données préliminaires non publiées). La prévision 3YRA de l'abondance du stock wVI en 2000 est de $2{,}7\times10^5$ (IC de 50 % : $2{,}0\times10^5$-$3{,}7\times10^5$), soit 48 % de l'abondance moyen global ($5{,}7\times10^5$).

L'estimation de l'abondance total de saumons coho dans le bassin supérieur du Fraser en 1999 était de $2{,}1\times10^4$, soit 62 % de la prévision. La prévision de l'abondance pour 2000 est de $2{,}2\times10^4$, soit 20 % de l'abondance moyen à long terme. On prévoit donc que l'appauvrissement se maintiendra avec peu de changement par rapport aux trois dernières années. Les échappées des jeunes de l'année dans la basse Thompson et la Thompson-Sud étaient respectivement les plus basses et les deuxièmes plus basses depuis que l'on recueille ces données. Comme rien n'indique que la survie en mer s'améliore, les échappées continueront sans doute d'être faibles dans ces régions et la taille totale des stocks n'augmentera probablement pas en 2000.

Prévision de la répartition – Dans l'hypothèse du maintien de la répartition historique de la pêche, la proportion prévue des prises dans le détroit de Géorgie (p_{inside}) serait de 0,31 (IC de 50 % : 0,21–0,44), ce que l'on peut qualifier de répartition modérément forte à l'extérieur de ce bassin. L'intervalle de confiance laisse croire qu'une année de répartition à l'extérieur exceptionnellement forte (p_{inside}<0.2) est moins probable qu'un retour à une répartition « normale » (p_{inside}>0.4). Cette prévision de la répartition des prises est fondée sur des données de salinité incomplètes.

[6] 3YRA – 3-year average (moyenne sur trois ans)

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1. Introduction

Forecasts of the marine survival rate, the ocean distribution and the ocean abundance of southern British Columbia coho in 2000 are presented in this research paper. The methods we used in developing the forecasts of marine survival rate and ocean distribution are similar to those used in previous research papers (Holtby et al. 1999, Holtby and Kadowaki 1998, Kadowaki et al. 1996, Kadowaki 1997).

2. Data Sources and treatments

2.1 Interior Fraser including the Thompson River

The interior Fraser is defined as the Fraser River watershed above Hell's Gate and includes the Thompson River, the largest watershed within the Fraser River system. Coho originate in four sub-regions within the interior Fraser:

1. South Thompson - mainstem South Thompson River and tributaries upstream from the confluence of the North Thompson River;
2. North Thompson - mainstem North Thompson River and tributaries of it;
3. Lower Thompson - mainstem Thompson and tributaries downstream from the confluence of the North and South Thompson including the Nicola watershed; and
4. Fraser/non-Thompson – Fraser River and tributaries upstream of the Fraser Canyon excluding the Thompson (Irvine et al. 1999b).

The Lower Thompson and the Fraser/non-Thompson sub-regions have been combined in this report and are collectively referred to as the 'Fraser/lower Thompson'.

An 'abundance' time series and an 'average-stream' time series were used for forecasting. Both were derived from an escapement time series (Irvine et al. 1999a, b) that consists chiefly of estimates made during visual surveys. Streams included in the two time series are indicated in Table 11. The 'average-stream' sets are more inclusive than they were in 1999 because the number of observations required for inclusion was relaxed to 50% of the potential maximum number of observations. The 'abundance' time series includes all of the streams within each sub-region where there were at least two observations of escapement. Missing counts in all included streams that were estimated using a procedure described in the following paragraph. The 'abundance' time series includes wild and enhanced coho. Consequently, this time series might not reflect patterns of abundance in wild populations because a high proportion of Thompson coho originates in systems that have received sustained and substantial enhancement (Figure 9). The 'average-stream' time series is derived from escapement to wild streams only, and does not include estimates of missing counts. Derivation of this time series is explained three paragraphs below.

The survey effort expended in many systems during 1998 and 1999 exceeded the effort given in previous years. In 1998 and 1999, escapement estimates to those streams were adjusted to reflect historical survey efforts (Irvine et al. 1999b). For this forecast document, escapement in all of the streams was adjusted upward to estimate actual escapement. For streams where estimates of the adjustment scalar were available for both 1998 and 1999, the geometric mean of the scalar was applied to historical escapement estimates in all previous years. For streams where only one estimate of the adjustment scalar was available or no estimate of the scalar was available, the geometric mean scalar for the aggregate over both years was applied to historical escapement estimates. A very large scalar for Shuswap River (lower) in 1998 was excluded from the average. After scaling, catch and total return were estimated from the escapement time series for each censused stream using a time series of exploitation rates derived from all available Thompson CWT releases (Holtby et al. 1999; Irvine et al. 1999a)[7]. From the time series of total returns by stream, returns in years when no escapement count had been made were estimated simultaneously for all streams using a contingency table approach described by Brown[8] (1974). All streams that had at least two estimates were included. The time series of total returns used to estimate missing counts excluded the enhanced streams within each sub-region. However, in 1996 for the Eagle River and 1997 for both the Eagle and Salmon rivers in the S. Thompson, technical difficulties led to under-estimates of escapement in these two enhanced systems. Total 1996 and 1997 returns to these systems were estimated using the contingency table approach applied to the time series from non-enhanced streams. Abundance was then summed within the North and South Thompson sub-regions and the Fraser/lower Thompson sub-region, and these sub-totals were summed to get the estimate of overall interior Fraser abundance.

The time series of exploitation rates for the Thompson were taken from MRP recoveries for a variety of releases from 1986 to 1997 and revised escapement estimates (Irvine et al. 1999a, b). Estimates prior to 1986 were the arithmetic average of measured values from 1986 to 1996. Estimated exploitation in 1998 was approximately 7%, as previously reported (Irvine et al. 1999b). The estimated exploitation rate in 1999 is 5%. This preliminary value is based on known changes to fisheries in 1999, particularly the change to non-retention of unmarked coho in the Washington Area 5 recreational fishery.

Generation of the 'average-stream' time series begins with the scaled escapement time series prior to estimation of missing values. Only non-enhanced streams where escapement counts had been made in at least 50% of the years in the period 1975 to 1999 were included in this analysis. First, the escapement (E) in each stream i was scaled to the maximum escapement recorded in that stream across all years t:

$$p_{i,t} = \frac{E_{i,t}}{\max\left(E_i\right)} \tag{1}$$

[7] This will be discussed in more detail in the interior Fraser coho assessment document to be presented in May 2000.
[8] Using an Excel macro provided by Jim Blick, Alaska Department of Fish and Game, Juneau, AK.

Then the $p_{i,t}$ were averaged across streams i within each year t to give a time series $p_{\bar{i},t}$ or p_{max}. The average stream escapement was then constructed by multiplying p_{max} by the average of $\max(E_i)$ made across the i streams. Finally, catch and total return were estimated using the exploitation rate time series.

2.2 Strait of Georgia, lower Fraser and WCVI hatcheries

Preliminary catch and escapement data[9] for coded-wire tagged coho from the Big Qualicum River, Quinsam River, Chilliwack River, Inch Creek and Robertson Creek hatchery stocks and Black Creek wild indicator were obtained from the Mark Recovery Program (MRP) data base maintained at the Pacific Biological Station in Nanaimo, B.C. and from program sources within HEB (pers. comm. S. Lehmann, HEB Vancouver) and the Stock Assessment Division (KS). Smolt releases in 1998 and 1999 included CWT-adipose clipped and CWT-only components. Freshwater sport recoveries of CWT'd coho from the Chilliwack and Inch Creek hatcheries were added to the escapement rather than treated as catch to better represent the exploitation rate on wild stocks, which were not exposed to intense terminal fisheries. Only externally marked fish were retained in these fisheries and in 1999, the catch of age-2 (jack) coho was estimated separately from the age-3 fish.

Survival rate estimates are based only on CWT-ad fish. Mortality that occurred outside of any retention fisheries on marked fish was ignored but it is thought to have been small. Fisheries exploitation rates on unmarked fish were assumed to have been a proportion of the exploitation rates on marked fish corresponding to the release mortality in the particular fishery. In Canadian sport fisheries, 10% mortality was assumed. In Alaska, all coho were retained and 100% mortality was assumed. Black Creek is a wild indicator stream and no fish from there were given an adipose clip. To estimate survival and exploitation rates for Black Creek coho, we assumed that the encounter rates for marked Quinsam and Black Creek coho were the same. Exploitation in WA fisheries is known to be small and was not estimated.

2.3 Salinity data

Salinity data for the Chrome Island and Sisters lighthouses in the Strait of Georgia were obtained from R. Perkin, Institute of Ocean Sciences, Sidney, BC. At the time of writing data were available to February 20. The average value for February was obtained by averaging daily values for each lighthouse and then averaging the two lighthouse values.

[9] These data must be considered unreliable at the time of writing.

3. Forecasting Models and Retrospective Analysis of Predictive Power.

3.1 Forecasting models

In this document, we forecast marine survival rates (s), catch distribution (p_{inside}) and stock size or abundance (A). All of these variables are forecast using four quasi-time series models. In each model the variable being forecast (v_t) is first transformed so that

$$Z_t = \Im(v_t) \tag{2}$$

The Log transformation was used for abundance. The Logit transformation[10] was applied to proportions such as s or p_{inside}. The four models can then be described as follows:

mnemonic	model	Equation
LLY ("Like Last Year")	$Z_{t+1} = Z_t + \varepsilon_t$	(3)
3YRA (3-year average)	$Z_{t+1} = \frac{\sum_{k=t-2,t} Z_k}{3} + \varepsilon_t$	(4)
RAT1 (1 year trend)	$Z_{t+1} = \frac{Z_t^2}{Z_{t-1}} + \varepsilon_t$	(5)
RAT3 (average 3-year trend)	$Z_{t+1} = \frac{\sum_{k=t-2,t} Z_k / Z_{k-1}}{3} Z_t + \varepsilon_t$	(6)

For each model, we assume that the error term is normally distributed $\left(\varepsilon \sim N(0,\sigma^2)\right)$ and is independent of time. For estimating uncertainty in the forecast value (Z_{t+1}), an estimate of σ^2 was obtained for the distribution of observed minus predicted for years $1\ldots t$.

The differences between the four models are summarized in the following Table:

		years used in prediction	
		1	3 (≈ 1 cycle)
Allows projection of trends?	NO	LLY	3YRA
	YES	RAT1	RAT3

Marine survival rates were also predicted using a “sibling-regression” model, where the total return of age-3 fish (R_3^{BY+3}) is predicted from the observed age-2 male escapement (R_2^{BY+2}, ‘jacks’):

$$\log_e R_3^{BY+3} = b \log_e R_2^{BY+2} + a \tag{7}$$

Survival (s_{smolt}) was then calculated by dividing the age-3 return by the number of smolts released (N_{smolt}).

Catch distribution or the proportion of the catch (p_{inside}) that would be caught in waters inside the Strait of Georgia under fishing patterns observed prior to 1997 was estimated using the model:

$$Logit(p_{inside}) = bS + a \tag{8}$$

where S is the average February surface salinity at Chrome Island and Sisters in BY+3[11]. Confidence limits around forecasts in the case of the latter two models were determined using linear regression analysis.

3.2 Retrospective analyses

To compare the performance of the forecast models we computed both the Root Mean Square Error (*RMSE*):

$$RMSE = \sqrt{\overline{\left(v_{observed,t+1} - v_{predicted,t+1}\right)^2}} \tag{9}$$

and the Mean Absolute Deviation (*MAD*):

$$MAD = \overline{\left|\left(v_{observed,t+1} - v_{predicted,t+1}\right)^2\right|} \tag{10}$$

Note that this calculation is performed in the variable space and not in the transformed (equation 1) space.

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[10] $Z_t = \log {v_t}/{1 - v_t}$

[11] BY is the brood year. The progeny of fish spawning in year 1 are caught and spawn in year 4 or BY+3.

4. 1999 Marine Survival Estimates and forecast performance

Preliminary marine survival rates for the five hatchery indicators and Black Creek, a wild indicator, are presented in Table 1 and Figure 1. Survivals may have been slightly higher than these estimates because catch and release mortality from non-retention fisheries in southern British Columbia and Washington were not included. Marine survival in 1998 and 1999 are compared in the following Table.

	marine survival		
system	1998	1999	relative change
Quinsam	0.021	0.010	-52%
Black Creek	0.048	0.017	-65%
Big Qualicum	0.003	0.015	400%
Chilliwack	0.021	0.014	-33%
Inch Creek	0.005	0.019	280%
average StG-Fr	0.020	0.015	-23%
Robertson	0.038	0.021	-45%

Survival rates at Big Qualicum and Inch Creek improved considerably from 1998 to 1999 but remained very poor. Survivals at all of the other sites fell in 1999 relative to 1998 and were uniformly poor. The decrease seen at Black Creek is of particular concern. Preliminary indications of escapement to streams around the Strait of Georgia and the west coast of Vancouver Island are variable but suggest that survivals of wild coho were likely poor throughout the inside areas of southern British Columbia (sBC).

The performance of the 1999 forecasts (Holtby et al. 1999) is summarized in the following Table, in Table 2 and on Figure 1. Survival at Robertson Creek was well predicted by the euphausiid model and sibling-regression model but was over-forecast by the time-series model. Survival at Black Creek was much poorer than predicted and was only about the fourth percentile of the CI around the forecast survival. Marine survival at Big Qualicum and Inch were much greater than predicted by the statistical models and were well outside the confidence intervals of the forecasts. The sibling forecasts were better than the time series forecasts at both of those hatcheries and were good forecasts at the remaining two hatcheries.

	Quinsam	Black	Big Qualicum	Chilliwack	Inch	Robertson Creek§
observed survival in 1999	0.01	0.017	0.015	0.014	0.019	0.021
sibling forecast	0.011	–	0.031	0.018	0.013	0.029
%obs. of forecast	91%	–	48%	78%	146%	72%
quasi TS model	LLY	3YRA	LLY	RAT3	LLY	LLY
forecast	0.021	0.042	0.0032	0.017	0.0052	0.038
%obs. of forecast	47%	41%	469%	83%	365%	55%

§ The euphausiid forecast of marine survival was 0.021.

4.1 Biologically based forecast for wVI coho

Marine survival of Carnation Creek coho appears related to early-ocean growth rates (Holtby et al. 1990), which are probably dependent on the amount of available food. Although juvenile coho feed on many species of zooplankton in their first few months in the ocean, euphausiids are the most important food item (Healey 1978; Petersen et al. 1982; Brodeur 1989; Brodeur and Pearcy 1990; Morris and Healey 1990; Brodeur et al. 1992). Euphausiid populations within Barkley Sound have undergone marked declines in recent years (RWT, unpubl. data), which prompted us to examine the relationship between the abundance of *Thysanoessa spinifera* in Barkley Sound in the smolt year with marine survival of Robertson Creek coho.

Collection and processing protocols for euphausiids are fully described in Tanasichuk (1998). The measure of abundance used here is the average biomass (mg dry weight) per m^2 during June through August of the smolt year (BY+2) of animals ranging in total length from 9 to 12 mm. This is the size range of susceptibility to juvenile coho (Petersen et al.1982). The period over which the euphausiid biomass was averaged was June to August. This is a shorter period than the June through October period averaged in the 1999 forecast document (Holtby et al. 1999). Eight observations were available (Table 5).

After appropriate transformations of the Robertson Creek marine survival data (Table 1) and the euphausiid biomass data (Table 5), a strong relationship can be found between survival and biomass (Figure 4). The change in averaging period for euphausiid biomass significantly improved the relationship with Robertson Creek coho survival:

$$\sin^{-1}\sqrt{s} = 0.192\left(1-e^{-0.0397E}\right) \qquad (11)$$

$$(N = 8;\ \text{adj. } r^2 = 0.81;\ P < 0.001)$$

where s is marine survival and E is euphausiid biomass (see Table 5).

4.2 Marine Survival Rate Forecast

Survival forecasts and associated confidence intervals are shown for the sibling regressions in Table 3, for the time-series models in Table 4 and for the euphausiid model at Robertson Creek in Table 6. The survival forecasts made by the best performing model and associated 50% confidence intervals are summarized in the following Table.

indicator	best model	$\hat{S}_{2000}$	(50% CI)	$\hat{S}_{2000}$ (sibling)	(50% CI)
Big Qualicum	LLY	0.015	(0.006–0.04)	0.012	(0.007–0.021)
Quinsam	LLY	0.01	(0.006–0.016)	0.026	(0.013–0.066)
Chilliwack	RAT3	0.014	(0.008–0.025)	0.008	(0.005–0.013)
Inch Creek	LLY	0.019	(0.009–0.040)	0.040	(0.024–0.066)
Black Creek	3YRA	0.033	(0.024–0.046)	–	
Robertson Creek	sibling regression	0.033	(0.023–0.046)	–	
Robertson Creek	euphausiid	0.019	(0.015–0.023)	–	

The survival outlook for the hatcheries on the Strait of Georgia and in the lower Fraser is mixed but is generally poor. The survival of Black Creek coho is forecast to be 3.3%, but this model significantly over-forecast survival in 1999. For Robertson Creek coho, the single outside indicator, survival is expected to be either similar to survivals in recent years (sibling-regression model) or lower then in recent years (euphausiid model). The sibling model has over-forecast in the past two years while the euphausiid model accurately predicted survival in 1999.

5. Forecast of distribution

Variable proportions of the catch of coho originating in systems around the Strait of Georgia have been caught in the sport, troll and net fisheries that have operated within the Strait (Kadowaki 1997; Simpson et al. 1997). Distribution is expressed as the proportion of the catch of hatchery indicator stocks taken in fisheries wholly within the Strait of Georgia (p_{inside}). We emphasize that forecasts of distribution are actually forecasts of catch distribution assuming average historic patterns of effort and effort distribution. Consequently, the forecast of distribution as presented here assumes continuation of those historic patterns. We assume that past distributions of catch accurately reflected the actual distributions of coho in sBC. There was little or no catch of coho in the inside waters of southern British Columbia during 1998 or 1999. Consequently, there has been no estimate of p_{inside} since 1997 and the time series models that were developed in 1998 cannot be applied (Holtby and Kadowaki 1998). However, we note that the salinity model outperformed the time-series models by a large margin.

Surface salinities at two stations located in the central Strait of Georgia (Sisters and Chrome Island) are correlated with p_{inside}. Salinity in February of the year of return (brood year + 3) is the best predictor of p_{inside}. In Kadowaki (1997), the mean of the Chrome Island and Sisters Island February salinities was used to generate the distribution forecast, while in Kadowaki et al. (1996) and Holtby and Kadowaki (1998) the salinity at Chrome Island was used. We have reverted to the average of Chrome Island and Sisters. The differences between the predictions are small and of no practical significance.

The average salinity of the two stations to the third week of February is 28.04‰. Where GSsal is the average of the average February salinity at Chrome Island and Sisters:

$$\text{logit}(\hat{p}_{inside}) = 1.002\,GSsal - 28.9$$

(N=23; adj. adj. r^2 = 0.69; P << 0.001)

Figure 5 shows the fitted relationship and a probability plot of the confidence interval for p_{inside}. Confidence levels are tabulated in Table 7. A predicted value of 0.31 could be characterized as a moderately strong outside distribution. The confidence interval suggests that an extreme outside year (p_{inside} < 0.2) is less likely than a return to a “normal” distribution (p_{inside}>0.4). Although there is a tendency to overestimate

p_{inside} when its value is small (Figure 5), the preliminary salinity value is well above the low values (27‰) associated with strong outside distributions and marked over-prediction.

6. Forecasts of abundance

In southern British Columbia, all fisheries were managed to eliminate coho mortality wherever possible and to minimize it otherwise. Fisheries that were permitted were assigned mortality[12] ceilings based on forecasts of abundance of Strait of Georgia–Fraser (StG-Fr) and West Vancouver Island (wVI) stock aggregates. The StG-Fr aggregate includes stocks originating in streams draining into the Strait of Georgia and Johnstone Straits, including the Fraser and its tributaries. The wVI aggregate is comprised of stocks on the West Coast of Vancouver Island. Holtby and Kadowaki (1998) forecast abundance for these aggregates using fishery mortality (catch), estimates of the stock composition of the catch, and estimated mean exploitation rates. A similar method was used to forecast the abundance of coho in the WCVI troll fishing area (Kadowaki et al. 1996; Kadowaki 1997). This reconstruction could not be done in 1998 or 1999 because of the minimal catch and the profound changes to fishing patterns caused by coho conservation measures.

Our method for estimating abundance of the aggregate (A) in 1999 depends directly on past estimates of abundance. Estimates of total stock size (N_t) for individual hatcheries were made for the five indicator hatcheries. The ratio p_{ij} , was then calculated for each hatchery i in every year j possible:

$$p_{ij} = \frac{N_{ij}}{A_j} \tag{12}$$

The abundance in 1999 was then estimated for each hatchery i and for the sum of all hatcheries as:

$$A_i = \frac{N_h}{p_i} \tag{13}$$

where p_i is an average taken over either the entire time series or a recent period. This method assumes that past estimates of A and N_i were accurate and that the hatchery proportion of the total abundance has not changed.

6.1 Forecast performance in 1999

The estimate of abundance of the Strait of Georgia-Fr aggregate of 3.3×10^5 is less than the 90th percentile but well above the forecast abundance of 2.0×10^5 (Table 9). The wVI abundance of 2.6×10^5 is well below the forecast abundance of 4.5×10^5 but is greater than the 10th percentile of the CI (Table 9). We conclude that abundance was not well forecast.

[12] Mortality is the product of an assumed mortality per encounter and an encounter rate estimated from observation.

6.2 Forecast abundance in 2000

The four time series models were used to forecast abundance in 2000 for StG-Fr and wVI aggregates. In the period beginning in 1993 abundance of the StG-Fr aggregate has clearly trended downward (Figure 6). During this period the best performing model has been the RAT3 model. With this model the forecast StG-Fr abundance for 2000 is 2.5×10^5 (50% CI: 1.8×10^5–3.4×10^5; Table 10). A probability distribution of this forecast is shown in Figure 7. For the wVI aggregate, the 3YRA model was the best performer over the period 1993-1999. The forecast abundance using this model is 2.7×10^5 (50% CI: 2.0×10^5–3.7×10^5; Table 10). A probability distribution of this forecast is shown in Figure 7.

6.3 Interior Fraser coho

Although coho returning to the interior Fraser are part of the StG-Fr stock aggregate, they are considered separately because of the role they continue to play in determining salmon fisheries management in southern BC.

6.3.1 Average-streams

Forecast performance cannot be directly determined because the escapement numbers have changed, as has the stream set. However, the 'forecasts' for 1999 were redone using the current data and the same statistical models (Table 14). The observed returns were below the forecasts in all three of the sub-regions (Table 14). For the Fraser/lower Thompson and South Thompson sub-regions the returns were less than half of the forecast.

Returns to the average-stream in each of the three sub-aggregates were forecast with the 3YRA model, which continues to be the best of the four time series models. Performance statistics for the 3YRA model for each of the sub-aggregates are shown in the following Table.

Performance statistics for the 3YRA model and 'average-stream' returns.

performance measure	lower Thompson/Fraser	South Thompson	North Thompson
RMSE	6.32E+02	3.75E+02	2.94E+03
MAD	4.91E+02	2.85E+02	2.24E+03

The forecasts for 2000 are similar to the returns in 1999 (Table 15), and indicate continued depression in interior Fraser coho. The forecast return to the Fraser/lower Thompson sub-region for year 2000 is 26% of the mean return. Although the averaging period is shorter than for the other Thompson aggregates it does include the period of higher abundance in the mid- and late-1980's. The forecast return to the South Thompson sub-region is only 16% of the mean return. The time series and the 2000 forecasts are shown graphically in Figure 10.

6.3.2 Total abundance

Forecasts of total abundance were not included in the 1999 forecast document. However, the performance of the 3YRA model in forecasting total abundance in 1999 is given in Table 16 and performance statistics for the 3YRA model are given in the following Table. In 1999 total abundance was generally below the forecast abundance with the exception of the Fraser/lower Thompson sub-region (Table 16). Abundance of the North Thompson sub-region was less than half the forecast value.

Performance statistics for the 3YRA model and estimated total abundance.

performance measure	lower Thompson/Fraser	South Thompson	North Thompson	total Thompson
RMSE	3.93E+04	1.91E+04	6.78E+04	9.42E+04
MAD	2.66E+04	1.45E+04	5.44E+04	8.19E+04

The forecasts of abundance in 2000 are derived from the 3YRA model and are similar to the observed abundance in 1999 (Table 17). With the inclusion of enhanced streams in the lower Thompson/Fraser, the forecast for this sub-region is for near-mean abundance. For the entire interior Fraser, the forecast abundance is 2.2×10^4, which is 20% of the mean abundance.

7. Conclusions

7.1 Marine survival

Recommendations for the marine survival forecast for the five hatchery indicators and one wild coho indicator are given in the following Table. For populations around the Strait of Georgia, survivals are forecast to be either unchanged or higher in 2000 compared to those observed in 1999 (following Table). Survival will remain poor throughout southern BC and survival is forecast to improve at Black Creek only because survivals were particularly poor there in 1999. In 1999, the sibling models generally performed better than the statistical models so both the time series and the sibling-regression forecasts have been included in the following Table. The two forecasts are similar only for the Big Qualicum hatchery population and there is no apparent geographic pattern to the forecast survivals. Two survival forecasts are presented for Robertson Creek coho on the west coast of Vancouver Island. The sibling-regression forecast is similar to forecasts made over the past two years but is higher than the observed forecasts. The euphausiid model outperformed the sibling model in 1999 and provides a forecast for 2000 that is considerably lower than the forecast from the sibling regression. Survival of wVI coho might have been well below average for fish entering the ocean in 1999.

indicator	best model	$\hat{S}_{2000}$	(50% CI)	change relative to observed survival for 1999 return	$\hat{S}_{2000}$ (sibling)	(50% CI)
Big Qualicum	LLY	0.015	(0.006–0.04)	same	0.012	(0.007–0.021)
Quinsam	LLY	0.01	(0.006–0.016)	same	0.026	(0.013–0.066)
Chilliwack	RAT3	0.014	(0.008–0.025)	same	0.008	(0.005–0.013)
Inch Creek	LLY	0.019	(0.009–0.040)	same	0.040	(0.024–0.066)
Black Creek	3YRA	0.033§	(0.024–0.046)	higher		–
Robertson Creek	sibling regression	0.033§	(0.023–0.046)	higher		–
Robertson Creek	euphausiid	0.019	(0.015–0.023)	lower		–

§ The similarity of the forecasts for Black Creek and Robertson Creek is coincidental and is not a typographic error.

7.2 Abundance forecast

Without fisheries information, forecasting abundance is highly problematic, and because we are using time-series models the forecast is dependent on the highly uncertain estimates of abundance in 1998 and 1999. Although the observed abundance of the StG-Fr aggregate in 1999 (3.3×10^5) was well above the forecast (2.0×10^5; 50% CI: 1.5×10^5–2.8×10^5), the RAT3 model continues to be the best performing model. The RAT3 model forecast of the abundance of the StG-Fr aggregate in 2000 is 2.5×10^5 (50% CI: 1.8×10^5–3.4×10^5) or 15% of the long term mean abundance of 1.6×10^6.

The estimated abundance of the wVI aggregate in 1999 (2.6×10^5) was considerably less than the forecast (4.5×10^5; 50% CI: 3.1×10^5–6.5×10^5). The estimate of abundance is consistent with preliminary escapement records, which indicate that there were declines in abundance in 1999 compared to 1998 (-29% for swVI streams and –49% for nwVI streams relative to 1998 (KS, unpublished and preliminary data). The 3YRA forecast for wVI abundance in 2000 is 2.7×10^5 (50% CI: 2.0×10^5–3.7×10^5) or 48% of the overall mean abundance of 5.7×10^5.

The estimated total abundance of interior Fraser coho in 1999 was 2.1×10^4 or 62% of the forecast abundance. The abundance forecast for interior Fraser coho for 2000 is 2.2×10^4, or 20% of the long term mean abundance. Thus, the forecast is for continued depression with little change from the last three years. Brood year escapements in the Lower and South Thompson were respectively the lowest and second lowest on record since records began. Since there is no indication of improved marine survival, continuation of poor escapement is likely in those areas and it is unlikely that total stock size will increase in 2000.

7.3 Distribution forecast

In the hypothetical circumstance of historical patterns of fishing, the predicted proportion of catch inside the Strait of Georgia (p_{inside}) would be 0.31 (50%CI 0.21–0.44), which can be characterized as a moderately strong outside distribution. The confidence interval suggests that an extreme outside year ($p_{inside} < 0.2$) is less likely than a return to a "normal" distribution (p_{inside}>0.4). This forecast of distribution is based on incomplete salinity data.

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Table 1. Release and recovery summaries for the six indicator streams used to generate forecasts.

brood year	number of coded-wire tagged smolts	estimated return age 3	estimated return age 2 (jacks)	marine survival age 3
Big Qualicum				
1972	112427	40122	1398	0.357
1973	57425	16546	931	0.288
1974	75512	12368	1482	0.164
1975	210520	28019	5860	0.133
1976	150348	28420	1504	0.189
1977	101224	21430	621	0.212
1978	107328	12181	543	0.113
1979	55435	5705	733	0.103
1980	51984	5791	271	0.111
2981	49274	3882	643	0.079
1982	42453	2127	181	0.050
1983	191620	1207	184	0.006
1984	152273	598	71	0.004
1985	119424	1393	440	0.012
1986	77760	1079	257	0.014
1987	102747	3776	739	0.037
1988	64833	3259	277	0.050
1989	36474	2134	187	0.059
1990	37362	2492	363	0.067
1991	38235	2618	188	0.068
1992	37957	1129	48	0.030
1993	38917	6198	237	0.016
1994	37616	525	87	0.014
1995	38827	124	41	0.003
1996	40311	610	143	0.015
Chilliwack				
1980	54665	6544	891	0.120
1981	28502	4097	626	0.144
1982	100841	18866	771	0.187
1983	72194	7172	198	0.099
1984	129770	21880	555	0.169
1985	59935	10863	845	0.181
1986	68658	8646	350	0.126
1987	39250	4164	271	0.106
1988	39801	3604	233	0.091
1989	395	2239	151	0.057
1990	39797	2361	152	0.059
1991	79613	3598	134	0.045
1992	39654	1481	153	0.037
1993	39808	1577	207	0.040
1994	36256	870	75	0.024
1995	74456	1563	117	0.021
1996	37282	516	67	0.014
Inch Creek				
1983	38711	2560	26	0.066
1984	38774	3440	197	0.089
1985	19723	4007	148	0.203

brood year	number of coded-wire tagged smolts	estimated return		marine survival age 3
		age 3	age 2 (jacks)	
1986	19504	2116	22	0.108
1987	27458	2206	127	0.080
1988	38019	2690	36	0.071
1989	29367	2851	37	0.097
1990	31629	2607	91	0.082
1991	21172	1279	112	0.060
1992	20303	1116	10	0.055
1993	21540	834	90	0.039
1994	21174	226	5	0.011
1995	38707	201	12	0.005
1996	41918	790	7	0.019
Quinsam				
1975	73442	7129	2204	0.097
1976	139968	9303	3242	0.066
1977	168286	16778	2177	0.100
1978	226186	12602	2311	0.056
1979	280127	13387	3117	0.048
1980	76237	4973	501	0.065
1981	279799	15019	1343	0.054
1982	317306	27648	3443	0.087
1983	220929	17963	1530	0.081
1984	77380	6135	968	0.079
1985	42176	3352	924	0.079
1986	192294	14824	2765	0.077
1987	39362	3067	791	0.078
1988	39466	1650	299	0.042
1989	394	2317	251	0.059
1990	39411	1365	233	0.035
1991	42470	966	315	0.023
1992	43742	1098	353	0.025
1993	38947	377	129	0.010
1994	80125	953	128	0.012
1995	38827	831	643	0.021
1996	39813	384	90	0.010
Black Creek (wild indicator)				
1983	24134	3012		0.125
1984	31648	3602		0.114
1985	35640	4510		0.127
1986	74997	8500		0.113
1987	29203	3618		0.124
1988	118382	9004		0.076
1989	52351	6319		0.121
1990	49860	3161		0.063
1991	54996	3131		0.057
1992	75970	3416		0.045
1993	18152	611		0.034
1994	13736	599		0.044
1995	69996	3346		0.048
1996	24637	415		0.017
Robertson Creek				

brood year	number of coded-wire tagged smolts	estimated return		marine survival age 3
		age 3	age 2 (jacks)	
1972	44536	2954	1624	0.066
1973	44071	3411	1234	0.077
1974	55672	4007	1054	0.072
1975	51460	2507	1628	0.049
1976	43047	3776	486	0.088
1977	51019	2369	433	0.046
1978	51916	1167	307	0.022
1979	48776	974	110	0.020
1980	144742	8195	1038	0.057
1981	125895	8661	1056	0.069
1982	94740	1932	44	0.020
1983	52092	2038	85	0.039
1984	46061	1335	54	0.029
1985	41474	764	86	0.018
1986	50967	2514	412	0.049
1987	61191	5525	615	0.090
1988	43524	2569	139	0.059
1989	41773	1926	57	0.046
1990	40221	964	140	0.024
1991	38419	19	0	<0.0005
1992	36873	490	2	0.013
1993	42248	678	23	0.016
1994	43005	1312	228	0.031
1995	39566	1497	54	0.038
1996	39578	828	46	0.021

Table 2. Performance of survival forecasts for 1999. The model used, the observed survival and the forecast with confidence intervals are shown.

	Big Qualicum	Chilliwack	Quinsam	Inch Creek	Black Creek	Robertson Creek[§]
model	LLY	RAT3	LLY	LLY	3YRA	sibling
s_{smolt}	***0.015***	***0.014***	***0.010***	***0.019***	***0.017***	***0.021***
CI:1% lower ‡	0.0001	0.0023	0.004	0.0004	0.012	0.008
CI:5% lower	0.0003	0.0046	0.007	0.0010	0.018	0.012
CI:10% lower	0.0006	0.0064	0.009	0.0014	0.023	0.014
CI:25% lower	0.0013	0.010	0.013	0.0027	0.031	0.020
forecast	**0.003**	**0.017**	**0.021**	**0.005**	**0.042**	**0.029**
CI:75% lower	0.008	0.027	0.034	0.010	0.056	0.041

§: 1992 brood year was excluded from the model.
‡: In this case 1% of the observed values are expected to be less than the stated value.

Table 3. Forecast of age 3 return ($\hat{R}_3^{2000}$) and survival ($\hat{s}_{smolt}$) for 1997 brood year for the four Strait of Georgia indicators and Robertson Creek using sibling regressions. Data used are found in Table 1. The slope and intercept are for the sibling regression model (Equation 6).

	Big Qualicum	Chilliwack	Quinsam	Inch Creek	Robertson Creek
a (intercept)	1.604	2.606	1.315	5.393	5.662
b (slope)	1.102	1.018	1.045	0.519	0.367
N	25	17	22	14	24
$r^2_{adj.}$	0.75	0.72	0.82	0.42	0.60
R_2^{1999}	63	50	216	46	65
smolts released	*40367*	88756	39955	40300	40668
$\hat{R}_3^{2000}$	***479***	***728***	***1026***	***1602***	***1331***
$\hat{s}_{smolt}$	***0.012***	***0.008***	***0.026***	***0.040***	***0.033***
CI:1% lower ‡	0.002	0.002	0.002	0.006	0.009
CI:5% lower	0.003	0.003	0.004	0.011	0.014
CI:10% lower	0.004	0.004	0.006	0.015	0.017
CI:25% lower	0.007	0.005	0.013	0.024	0.023
CI:75% lower	0.021	0.013	0.066	0.066	0.046

‡: In this case 1% of the observed values are expected to be less than the stated value.

Table 4. Time series forecasts of age 3 survival ($\hat{s}_{smolt}$) with confidence levels for the 1997 brood year (return in 2000), for the four Strait of Georgia hatchery indicators and one wild indicator and the wVI hatchery indicator.

	Strait of Georgia indicator					wVI indicator
	Quinsam River	Big Qualicum River	Chilliwack River	Inch Creek	Black Creek (wild)	Robertson Creek
Model	LLY	LLY	RAT3	LLY	3YRA	LLY
CI:75%	0.0155	0.039	0.025	0.040	0.046	0.047
$\hat{s}_{smolt}$	**0.0096**	**0.015**	**0.014**	**0.019**	**0.033**	**0.021**
CI:25%	0.0059	0.006	0.008	0.009	0.024	0.0091
CI:10%	0.0038	0.002	0.005	0.004	0.017	0.0042
CI:5%	0.0029	0.0013	0.003	0.003	0.014	0.0026
CI:1%	0.0016	0.0004	0.0015	0.001	0.009	0.0010

Table 5. Data used for the biologically based survival forecast for Robertson Creek coho. The euphausiid biomass is the average June to August biomass of *Thysanoessa spinifera* in Barkley Sound in the smolt year (BY+2). The marine survival data are from Table 1.

return year (BY+3)	euphausiid biomass (mg dry mass/m^2)	Robertson Creek marine survival
1992	258.8	0.046
1993	65.2	0.024
1994	15.5	0.0048
1995	20.0	0.013
1996	29.0	0.016
1997	491.0	0.031
1998	92.5	0.036
1999	26.0	0.021
2000	32.0	

Table 6. Forecast of marine survival at Robertson Creek using the euphausiid model.

$a^{\dagger}$	0.192
b	0.0397
N	8
R^2	0.81
CI:99% lower	0.036
CI:95% lower	0.032
CI:90% lower	0.028
CI:75% lower	0.023
$\hat{s}_{smolt}$	0.019
CI:25% lower	0.015
CI:10% lower	0.011
CI: 5% lower	0.009
CI:1% lower	0.003

†: The fitted model was $\sin^{-1}\sqrt{R_3^{BY+3}} = a\left(1-e^{-bE}\right)$ where E is the average euphausiid biomass between June and August in BY+2.

Table 7. Forecast of p_{inside} for 2000 for Strait of Georgia hatchery indicators using the salinity model. Data used are in.

	overall (p_{inside})
$a^{\dagger}$	–28.9
b	1.002
N	23
CI:1% lower‡	0.062
CI:5% lower	0.109
CI:10% lower	0.142
CI:25% lower	0.212
$\hat{p}_{inside}$	0.314
CI:75% lower	0.437
CI:90% lower	0.557
CI:95% lower	0.631
CI:99% lower	0.759

†: The fitted model was $Logit(p_{inside}) = bS + a$ where S is the average February surface salinity at Chrome Island and the Sisters in BY+3.
‡: In this case 1% of the observed values are expected to be less than the stated value.

Table 8. Abundance estimates for the Strait of Georgia + Fraser aggregate ("Inside") and the West Coast Vancouver Island aggregate ("outside") of southern British Columbia coho.

year	"Inside" ($\times 10^6$)	"Outside" ($\times 10^5$)
1984	2.4	6.6
1985	1.5	—
1986	2.0	6.1
1987	1.8	13
1988	2.4	6.2
1989	1.3	6.0
1990	2.1	9.8
1991	1.6	5.5
1992	2.0	5.1
1993	1.9	3.2
1994	1.4	4.6
1995	1.3	5.0
1996	0.80	3.8
1997	0.36	1.8
1998	0.32	4.5
1999	0.33	2.6

Table 9. Forecast and observed abundance for west coast Vancouver Island (wVI) and Strait of Georgia + Fraser (StG-Fr) aggregates in 1999.

	StG-Fr aggregate abundance ($\times 10^5$)	wVI aggregate abundance ($\times 10^5$)
model	RAT3	LLY
A_{1999}	3.3	2.6
CI:90%	3.7	9.3
CI:75%	2.8	6.5
$\hat{A}_{1999}$	2.0	4.5
CI:25%	1.5	3.1
CI:10%	1.1	2.2
CI:5%	0.92	1.7
CI:1%	0.59	1.1

Table 10. Forecasts of abundance for StG-Fr and wVI aggregates in 2000 ($\hat{A}_{2000}$), with confidence limits. The recommended models are shaded.

	StG-Fr aggregate abundance ($\times 10^5$)				wVI aggregate abundance ($\times 10^5$)			
	LLY	3YRA	RAT1	RAT3	LLY	3YRA	RAT1	RAT3
CI:1%†	1.3	1.1	0.72	0.74	0.63	0.87	0.12	0.39
CI:5%	1.7	1.6	1.2	1.1	1.0	1.3	0.27	0.72
CI:10%	2.0	1.9	1.5	1.4	1.3	1.5	0.41	0.95
CI:25%	2.6	2.5	2.3	1.8	1.8	2.0	0.77	1.5
$\hat{A}_{2000}$	**3.3**	**3.3**	**3.4**	**2.5**	2.6	2.7	1.5	2.3
CI:75%	4.2	4.5	5.1	3.4	3.7	3.7	3.0	3.7
CI:90%	5.3	5.9	7.5	4.5	5.3	4.9	6	6
CI:95%	6.2	7.1	9.6	5.5	7	5.9	8	8
CI:99%	8.5	10.4	16.2	8.3	10	9.0	20	14

† stated % of observations will be less than tabulated value

Table 11. Streams in the interior Fraser data sets. The ‘w’ and ‘e’ indicate wild and enhanced respectively. In the Fraser – lower Thompson sub-region, the ‘wT’ and ‘eT’ indicate that the system is within the Thompson watershed. The symbol ’◆’ indicates that the stream is in the ‘average-stream’ set.

Fraser - Lower Thompson		South Thompson		North Thompson	
◆Bonaparte River	wT	◆Adams R (lwr)	w	◆Albreda R	w
◆Bridge River	w	◆Adams R (up)	w	Avola Cr	w
◆Cayoosh	wT	Anstey River	w	◆Barrierre R	w
Gates Cr	w	◆Bessette Cr	w	◆Blue R	w
Guichon Cr	w	◆Blurton Cr	w	Brookfield. Cr	w
Nahatlatch River	w	◆Bolean Cr	w	Cedar Cr	w
Nicola River (lower)	wT	◆Canoe Cr	w	◆Clearwater. R	w
Nicola River (upper)	wT	Cayenne C	w	◆Cook Cr	w
◆Portage Creek	w	◆Creighton Cr	w	Crossing Cr	w
◆Seton River	w	Danforth Creek	w	◆E. Barrierre. R	w
Stein River	w	Duteau Cr	w	◆Fennel Cr	w
Coldwater River	eT	◆Harris Cr	w	◆Finn Cr	w
Deadman River	eT	Huihill Cr	w	Goose Cr	w
Spius Creek	eT	◆Hunakwa Cr	w	Haggard Cr	w
		Ireland Cr	w	◆Lion Cr	w
		Johnson Cr	w	Mahood R	w
		◆Kingfisher Cr	w	◆Mann Cr	w
		McNomee Cr	w	◆McTag. Cr	w
		Momich Cr	w	◆N. Thompson R	w
		Noisey Cr	w	◆Raft R	w
		Onyx Cr	w	◆Reg Chris. Cr	w
		Owlhead Cr.	w	Shannon Cr	w
		◆Scotch Cr	w	◆Tumtum Cr	w
		Seymour R	w	◆Wireca. Cr	w
		◆Shuswap R (lwr)	w	Dunn Cr	e
		◆Shuswap R (mid)	w	Lemieux Cr	e
		◆Sinmax Cr	w	Louis Cr	e
		◆South Pass C	w		
		◆Tappen Cr	w		
		◆Trinity C	w		
		◆Wap Cr	w		
		Eagle R	e		
		Salmon R	e		

Table 12. Exploitation rate, escapement and total return for the North and South Thompson and Fraser – lower Thompson 'average-streams'. The exploitation rates are averages of the Thompson indicator streams and prior to 1986 is the average exploitation rate from 1986 to 1996. '*N*' is the number of streams in the 'p_{max}' index

		South Thompson				North Thompson				Fraser – lower Thompson			
year	exp. rate	*N*	p_{max}	esc.	return	*N*	p_{max}	esc.	return	*N*	p_{max}	esc.	return
1975	0.68	12	0.316	1.9E+02	5.8E+02	12	0.306	2.1E+03	6.7E+03				
1976	0.68	18	0.149	8.7E+01	2.7E+02	12	0.262	1.8E+03	5.7E+03				
1977	0.68	13	0.352	2.1E+02	6.5E+02	14	0.379	2.6E+03	8.3E+03				
1978	0.68	18	0.383	2.2E+02	7.0E+02	15	0.400	2.8E+03	8.8E+03				
1979	0.68	19	0.437	2.6E+02	8.0E+02	14	0.300	2.1E+03	6.6E+03				
1980	0.68	17	0.308	1.8E+02	5.7E+02	16	0.109	7.6E+02	2.4E+03				
1981	0.68	19	0.257	1.5E+02	4.7E+02	14	0.245	1.7E+03	5.4E+03				
1982	0.68	20	0.377	2.2E+02	6.9E+02	16	0.280	2.0E+03	6.1E+03				
1983	0.68	18	0.265	1.6E+02	4.9E+02	15	0.385	2.7E+03	8.4E+03				
1984	0.68	20	0.451	2.6E+02	8.3E+02	10	0.560	3.9E+03	1.2E+04	4	0.574	3.6E+02	1.1E+03
1985	0.68	19	0.633	3.7E+02	1.2E+03	8	0.422	2.9E+03	9.2E+03	4	0.792	5.0E+02	1.5E+03
1986	0.66	20	0.582	3.4E+02	1.0E+03	14	0.508	3.6E+03	1.0E+04	4	0.307	1.9E+02	5.6E+02
1987	0.54	18	0.551	3.2E+02	7.0E+02	12	0.469	3.3E+03	7.1E+03	5	0.380	2.4E+02	5.1E+02
1988	0.71	21	0.759	4.5E+02	1.5E+03	15	0.470	3.3E+03	1.1E+04	4	0.593	3.7E+02	1.3E+03
1989	0.65	21	0.577	3.4E+02	9.5E+02	15	0.349	2.4E+03	6.9E+03	4	0.471	2.9E+02	8.3E+02
1990	0.74	17	0.369	2.2E+02	8.2E+02	12	0.311	2.2E+03	8.3E+03	5	0.523	3.3E+02	1.2E+03
1991	0.68	13	0.226	1.3E+02	4.1E+02	7	0.140	9.8E+02	3.0E+03	5	0.258	1.6E+02	5.0E+02
1992	0.81	18	0.521	3.1E+02	1.7E+03	12	0.264	1.8E+03	1.0E+04	5	0.376	2.3E+02	1.3E+03
1993	0.88	12	0.142	8.3E+01	6.7E+02	11	0.087	6.1E+02	4.9E+03	5	0.497	3.1E+02	2.5E+03
1994	0.43	12	0.136	8.0E+01	1.4E+02	6	0.115	8.0E+02	1.4E+03	4	0.286	1.8E+02	3.2E+02
1995	0.56	17	0.201	1.2E+02	2.7E+02	10	0.191	1.3E+03	3.1E+03	1	0.244	1.5E+02	3.5E+02
1996	0.83	10	0.077	4.5E+01	2.7E+02	8	0.071	4.9E+02	3.0E+03	1	0.139	8.7E+01	5.3E+02
1997	0.40	13	0.068	4.0E+01	6.7E+01	6	0.111	7.7E+02	1.3E+03	5	0.076	4.8E+01	8.0E+01
1998	0.07	15	0.188	1.1E+02	1.2E+02	14	0.183	1.3E+03	1.4E+03	5	0.569	3.6E+02	3.8E+02
1999	0.05	16	0.088	5.2E+01	5.5E+01	14	0.181	1.3E+03	1.3E+03	5	0.172	1.1E+02	1.1E+02

Table 13. The estimated total abundance for the interior Fraser sub-regions and the whole aggregate (the interior Fraser). Underlined values in the Fraser/lower Thompson sub-region were estimated (see text).

	estimated total abundance			
year	North Thompson	South Thompson	Fraser + lower Thompson	Fraser above Hell's Gate
1975	5.82E+04	1.84E+04	<u>2.03E+04</u>	9.69E+04
1976	5.24E+04	1.23E+04	<u>1.72E+04</u>	8.18E+04
1977	1.14E+05	2.66E+04	<u>3.72E+04</u>	1.78E+05
1978	1.08E+05	2.50E+04	<u>3.54E+04</u>	1.69E+05
1979	1.37E+05	3.19E+04	<u>4.49E+04</u>	2.14E+05
1980	2.64E+04	2.20E+04	<u>1.29E+04</u>	6.13E+04
1981	5.37E+04	1.29E+04	<u>1.77E+04</u>	8.43E+04
1982	1.24E+05	1.83E+04	<u>3.77E+04</u>	1.80E+05
1983	1.07E+05	1.94E+04	<u>3.35E+04</u>	1.60E+05
1984	2.05E+05	4.82E+04	3.88E+04	2.92E+05
1985	1.32E+05	5.32E+04	1.87E+04	2.04E+05
1986	2.93E+05	4.82E+04	1.50E+04	3.56E+05
1987	1.08E+05	4.56E+04	1.65E+04	1.70E+05
1988	2.34E+05	8.48E+04	5.29E+04	3.72E+05
1989	8.01E+04	4.85E+04	4.06E+04	1.69E+05
1990	8.83E+04	3.27E+04	3.58E+04	1.57E+05
1991	3.21E+04	1.29E+04	2.48E+04	6.98E+04
1992	9.86E+04	6.41E+04	6.60E+04	2.29E+05
1993	6.21E+04	1.50E+04	1.46E+05	2.23E+05
1994	1.32E+04	7.91E+03	1.30E+04	3.41E+04
1995	4.79E+04	8.26E+03	1.09E+04	6.71E+04
1996	6.97E+04	9.00E+03	1.55E+04	9.42E+04
1997	9.87E+03	2.06E+03	9.40E+03	2.13E+04
1998	7.94E+03	5.50E+03	1.16E+04	2.51E+04
1999	7.65E+03	3.36E+03	1.00E+04	2.11E+04

Table 14. Performance of 3YRA forecasts of total return in 1999 for 'average-streams' in the interior Fraser sub-regions.

	Fraser / lower Thompson		South Thompson		North Thompson	
CI	1999 forecast	1999 observed	1999 forecast	1999 observed	1999 forecast	1999 observed
99%	2.1E+03		7.2E+02		6.1E+03	
95%	1.0E+03		4.1E+02		4.1E+03	
90%	7.1E+02		3.2E+02		3.4E+03	
75%	4.3E+02		2.1E+02		2.5E+03	
50%	**2.5E+02**	**1.1E+02**	**1.3E+02**	**5.5E+01**	**1.8E+03**	**1.3E+03**
25%	1.5E+02		8.1E+01		1.2E+03	
10%	8.9E+01		5.3E+01		9.1E+02	
5%	6.4E+01		4.0E+01		7.5E+02	
1%	3.1E+01		2.3E+01		5.0E+02	

Table 15. Forecasts of average-stream total returns to the three sub-regions of the interior Fraser for 2000 with their associated confidence intervals. All forecasts were based on the 3YRA model.

	Fraser / lower Thompson		South Thompson		North Thompson	
CI	total return	% of average total return	total return	% of average total return	total return	% of average total return
99%	1.4E+03	237%	3.7E+02	78%	5.4E+03	107%
95%	6.6E+02	112%	2.3E+02	47%	3.5E+03	69%
90%	4.6E+02	78%	1.8E+02	37%	2.8E+03	55%
75%	2.7E+02	46%	1.2E+02	25%	2.0E+03	39%
50%	**1.5E+02**	**26%**	**7.6E+01**	**16%**	**1.3E+03**	**27%**
25%	8.6E+01	15%	4.9E+01	10%	9.2E+02	18%
10%	5.0E+01	8%	3.3E+01	7%	6.4E+02	13%
5%	3.5E+01	6%	2.5E+01	5%	5.2E+02	10%
1%	1.6E+01	3%	1.5E+01	3%	3.3E+02	7%

Table 16. Performance of 1999 forecasts of total abundance for the interior Fraser sub-regions and the entire interior Fraser aggregate.

CI	Fraser / lower Thompson		South Thompson		North Thompson		interior Fraser	
	1999 forecast	1999 observed	1999 forecast	1999 observed	1999 forecast	1999 observed	1999 forecast	1999 observed
t99	1.5E+05		2.1E+04		1.2E+05		1.5E+05	
t95	5.1E+04		1.3E+04		6.6E+04		9.4E+04	
t90	3.5E+04		1.0E+04		4.8E+04		7.6E+04	
t75	1.9E+04		7.1E+03		3.0E+04		5.4E+04	
t50	**1.0E+04**	**1.0E+04**	**4.7E+03**	**3.4E+03**	**1.8E+04**	**7.7E+03**	**3.7E+04**	**2.1E+04**
t25	5.6E+03		3.1E+03		1.0E+04		2.5E+04	
t10	3.1E+03		2.1E+03		6.4E+03		1.8E+04	
t50	2.1E+03		1.7E+03		4.7E+03		1.4E+04	
t1	9.0E+02		1.0E+03		2.6E+03		9.4E+03	

Table 17. Forecasts of total abundance for the inter Fraser sub-regions and the entire interior Fraser aggregate in 2000 with their associated confidence intervals. All forecasts were based on the 3YRA model.

CI	Fraser – lower Thompson		South Thompson		North Thompson		interior Fraser	
	total return	% of average total return	total return	% of average total return	total return	% of average total return	total return	% of average total return
99%	9.7E+04	414%	1.9E+04	101%	6.9E+04	111%	1.3E+05	113%
95%	4.7E+04	203%	1.1E+04	58%	3.5E+04	57%	7.4E+04	65%
90%	3.3E+04	143%	8.4E+03	44%	2.5E+04	41%	5.6E+04	49%
75%	1.9E+04	81%	5.4E+03	28%	1.5E+04	24%	3.6E+04	32%
50%	**1.0E+04**	**44%**	**3.4E+03**	**18%**	**8.4E+03**	**14%**	**2.2E+04**	**20%**
25%	5.6E+03	24%	2.1E+03	11%	4.8E+03	8%	1.4E+04	12%
10%	3.2E+03	14%	1.4E+03	7%	2.8E+03	5%	9.0E+03	8%
5%	2.2E+03	10%	1.0E+03	5%	2.0E+03	3%	6.8E+03	6%
1%	1.1E+03	5%	5.9E+02	3%	1.0E+03	2%	3.9E+03	3%

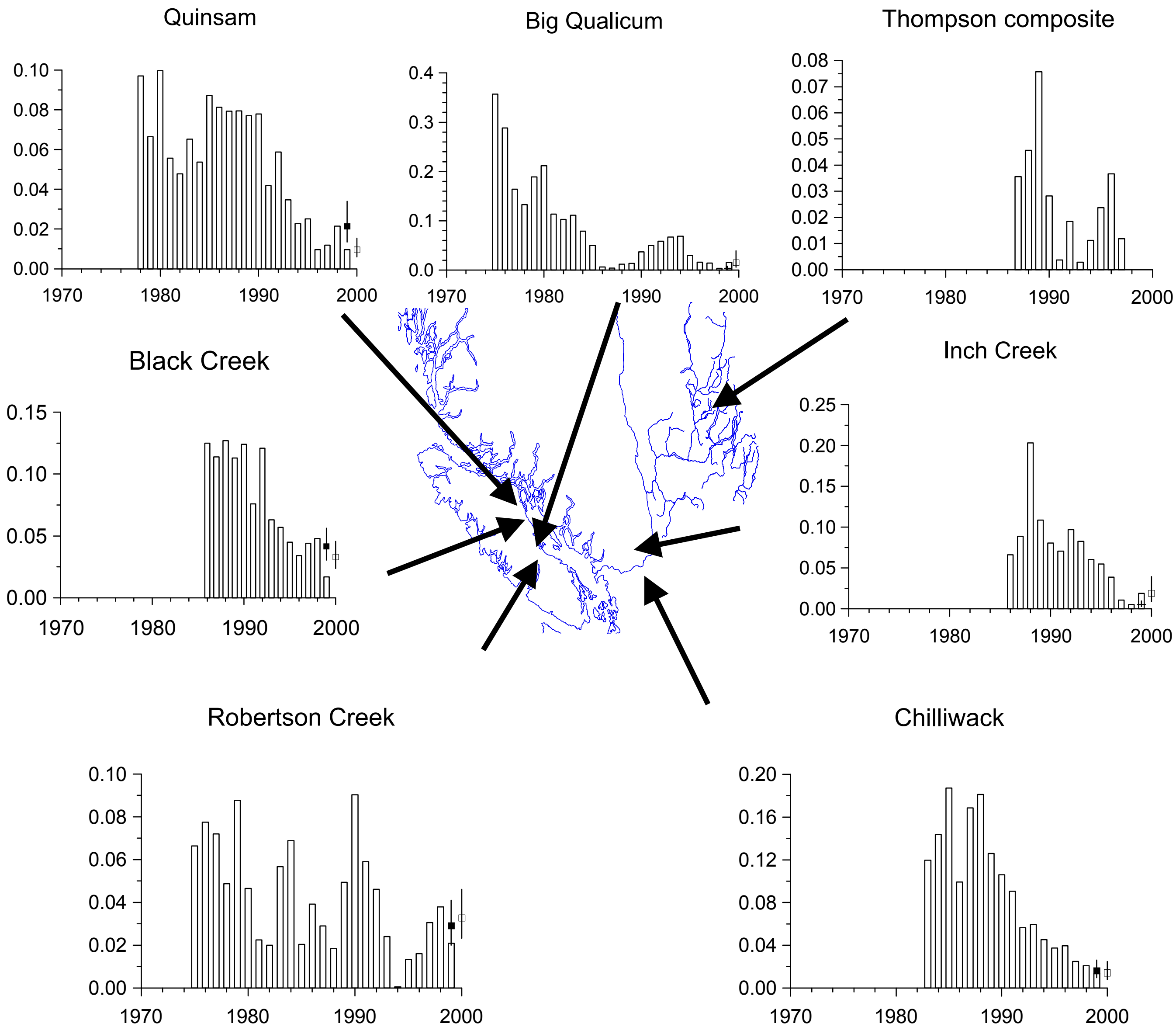

Figure 1. Marine survivals vs. return year for seven coho indicators in southern British Columbia. The forecast survivals for 1999 and 2000 are shown with associated 50% CIs. The Thompson values are a composite of all available smolt release data. Survival forecasts are not available for the interior Fraser/Thompson.

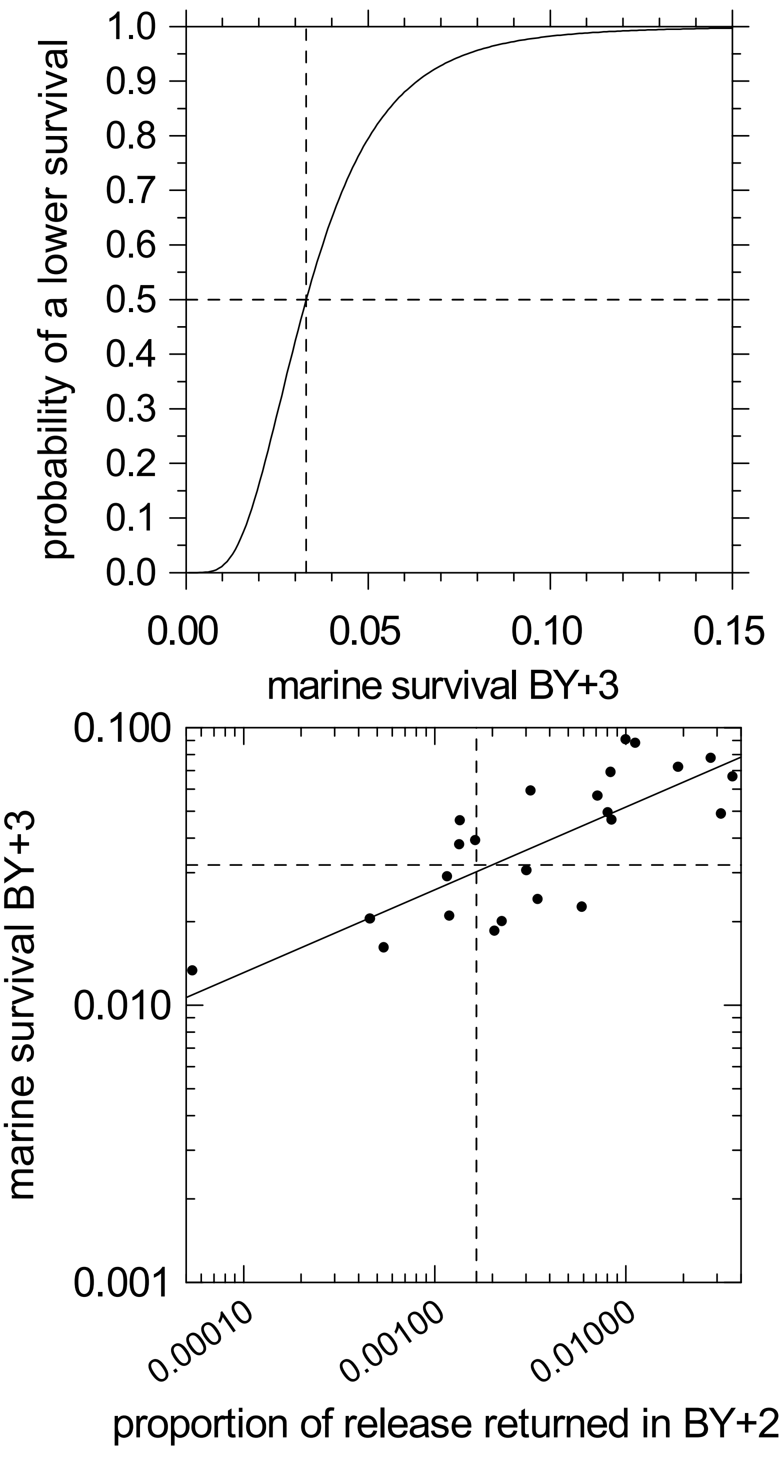

Figure 2. Return and survival forecast for Robertson Creek coho in 2000 using the sibling regression model. The lower panel is the sibling relationship. The upper panel is the probability distribution for marine survival of age-3 coho returning in BY+3.

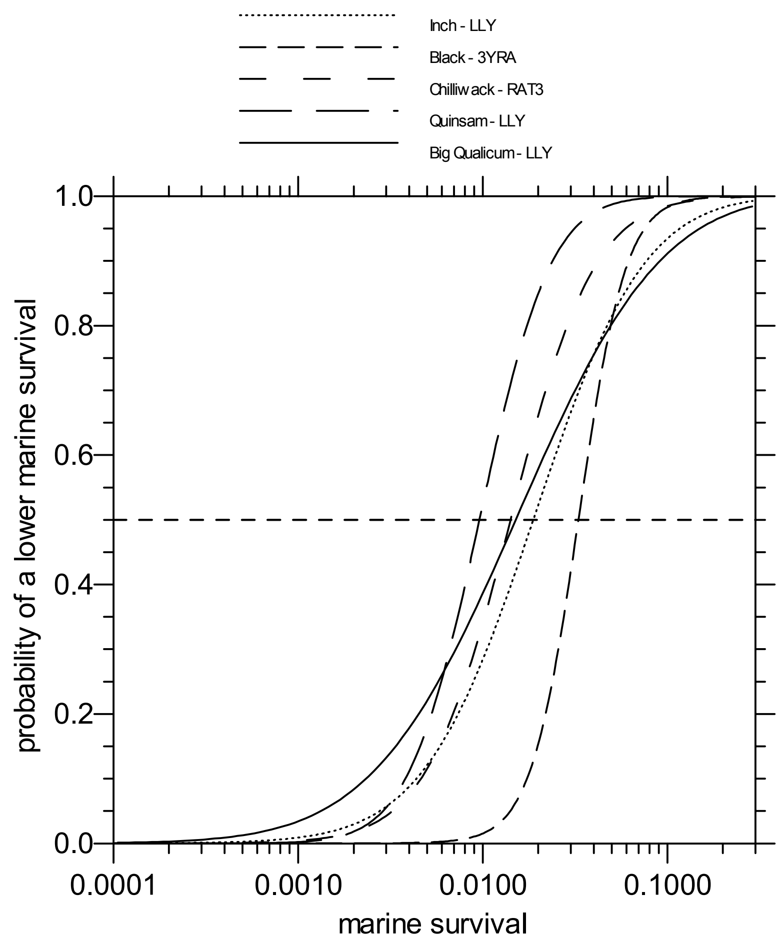

Figure 3. Confidence intervals around the time-series forecasts of marine survivals for four hatchery indicators and Black Creek.

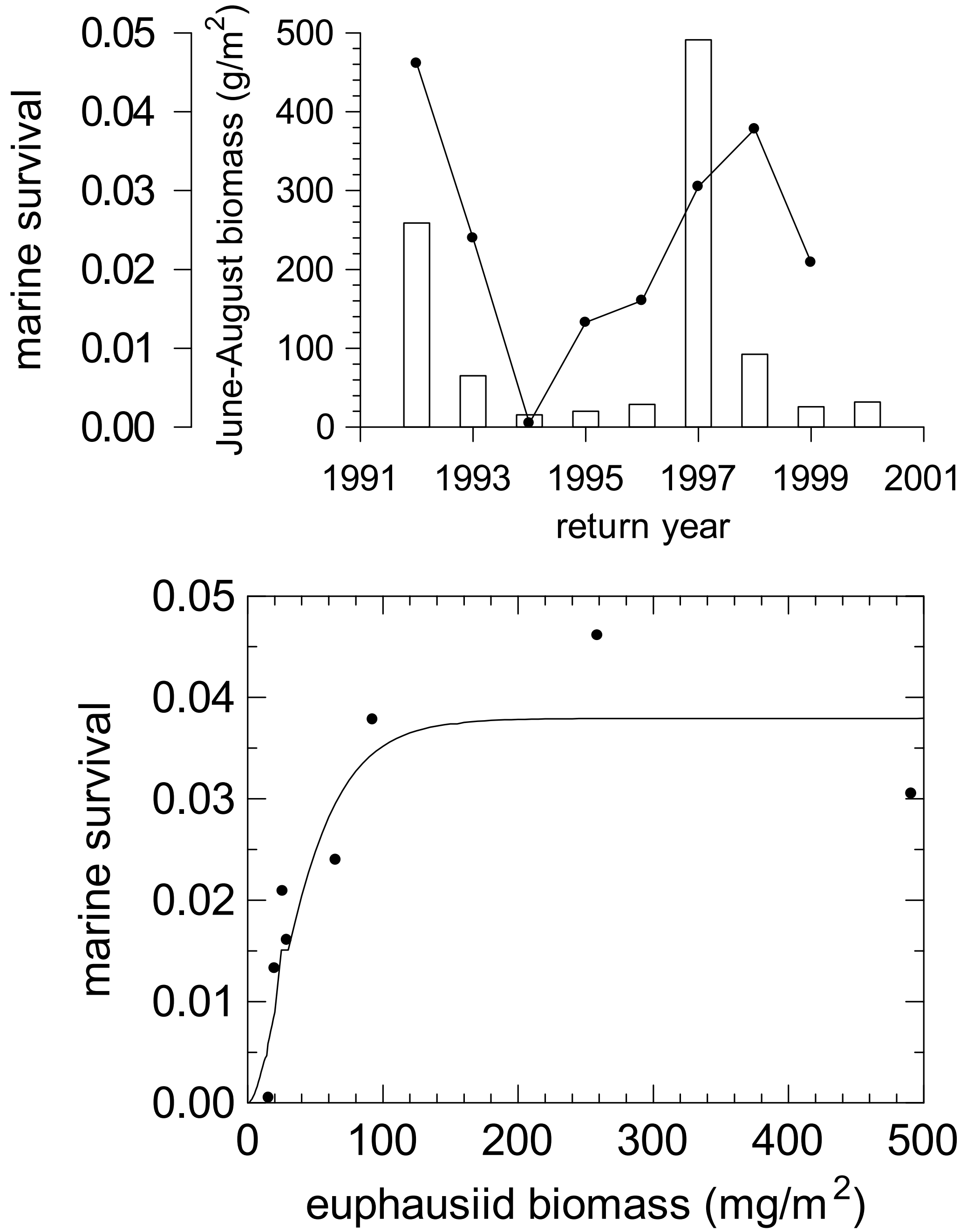

Figure 4. Marine survival at Robertson Creek and euphausiid biomass in Barkley Sound. In the top panel survival (the line) and average June to August biomass (the bars) are plotted against return year. In the bottom panel survival is plotted against euphausiid biomass.

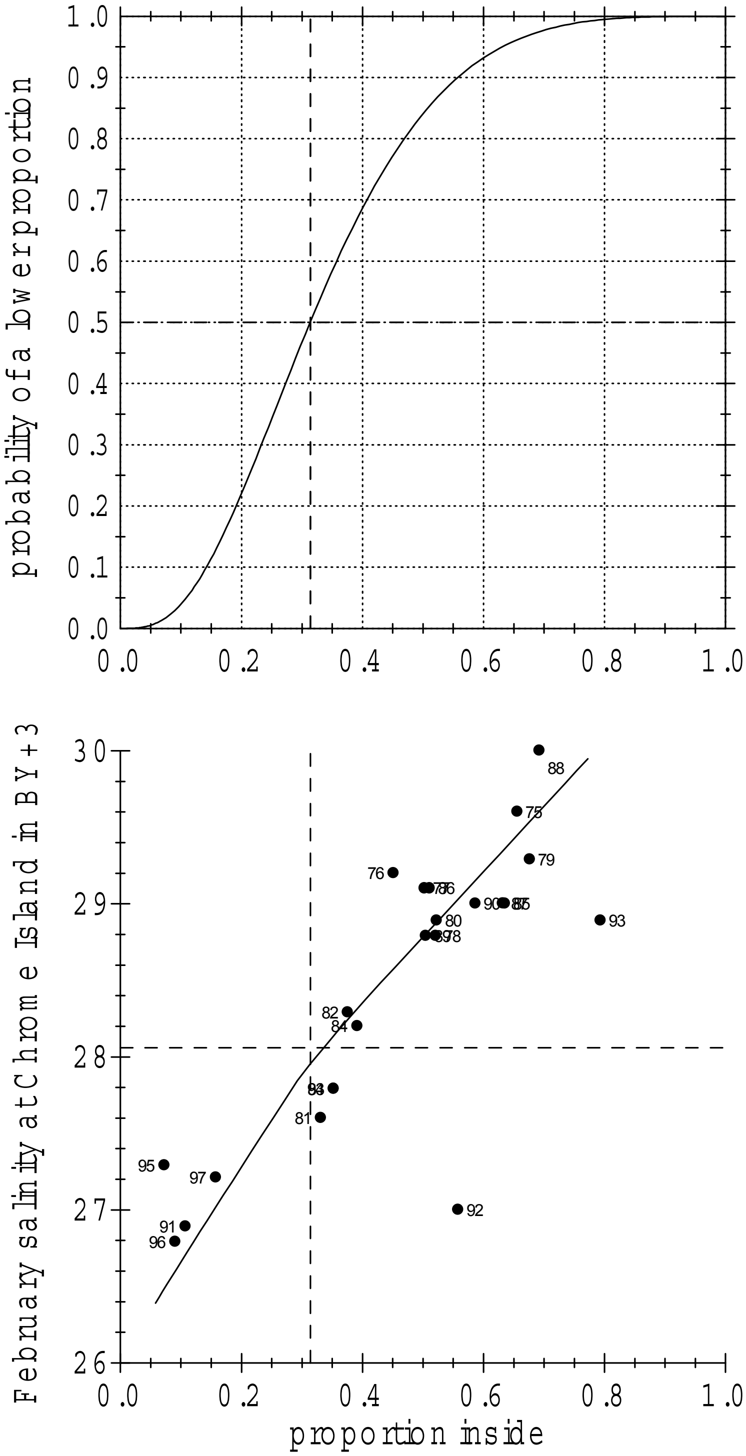

Figure 5. Predicting p_{inside} for 2000 using average Chrome Island and the Sisters February salinities. The lower panel is the predictive relationship. The upper panel is the probability distribution for the point predictions. A February salinity of 28.06 was used.

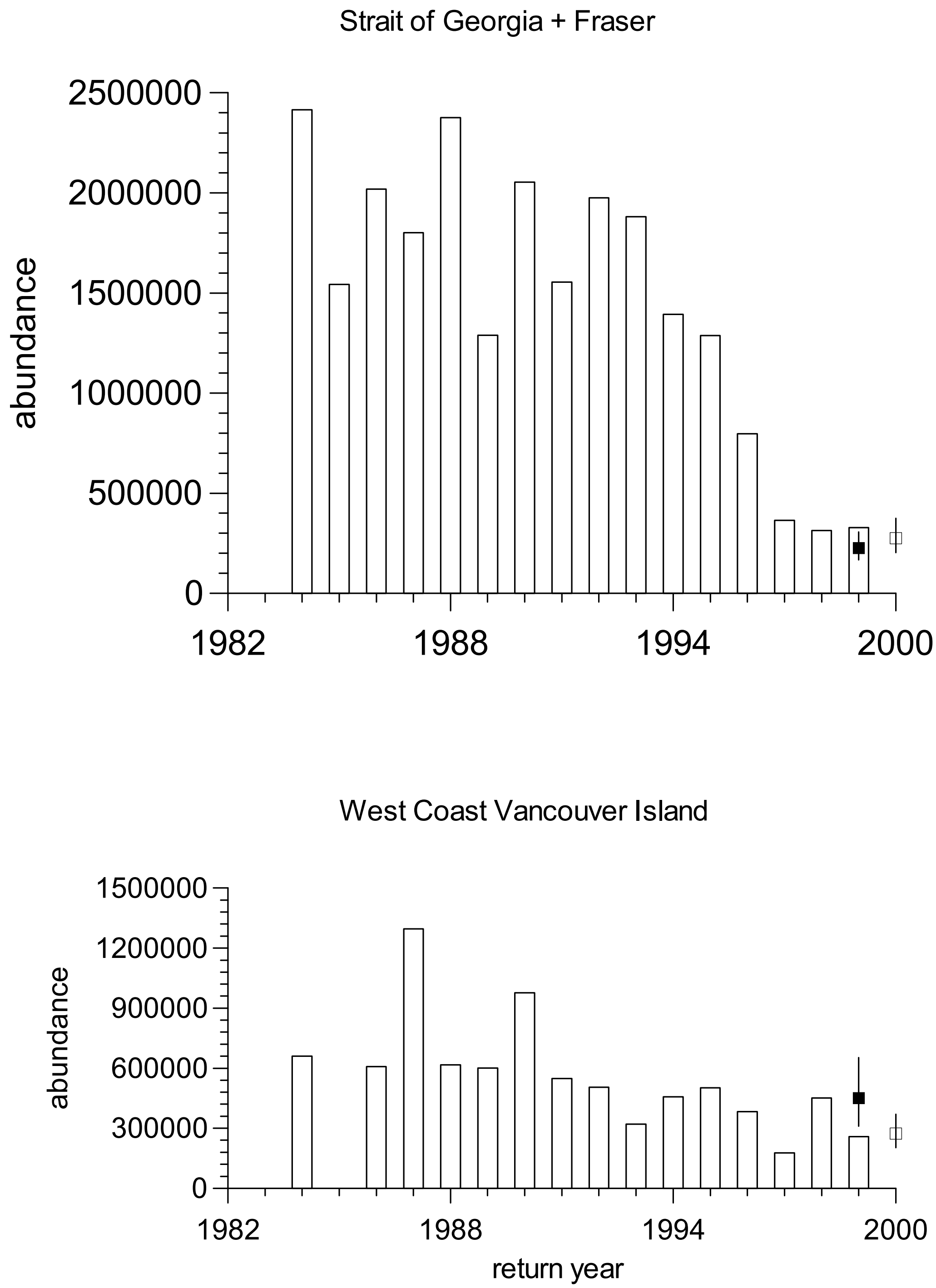

Figure 6. Abundance estimates for the Strait of Georgia+Fraser aggregate and the West Coast Vancouver Island aggregate of southern British Columbia coho. The forecast abundances for 1999 and 2000 with associated 50% CIs are shown for both aggregates.

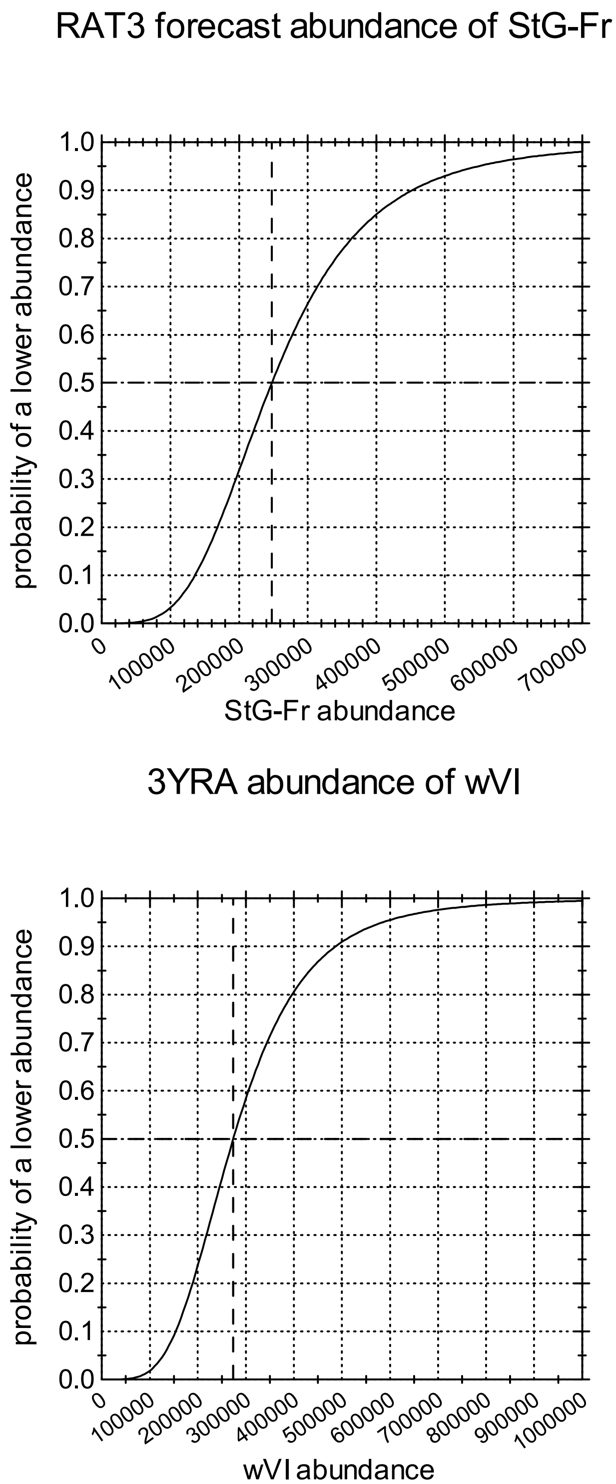

Figure 7. Probability plots for the abundance forecasts for StG-Fr and wVI aggregate abundance in 2000 using the recommended models.

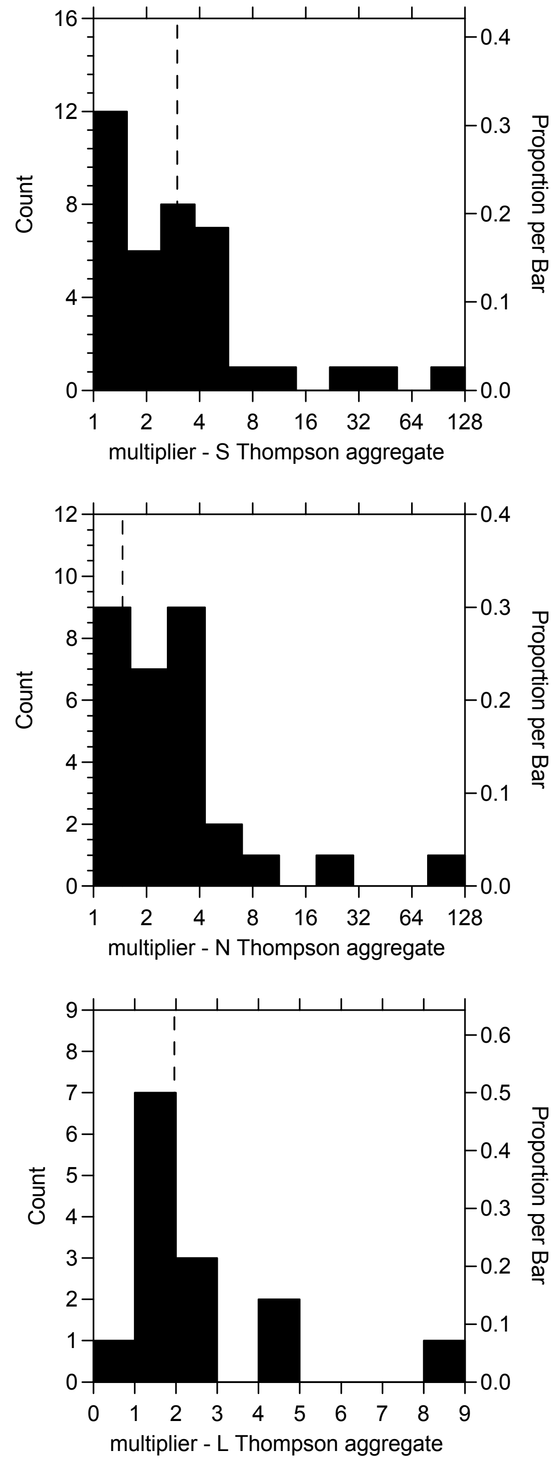

Figure 8. Observed multipliers for expansion of historical escapement estimates in the North and South Thompson sub-regions and the Fraser / lower Thompson sub-region. Systems with fences are excluded. The dashed vertical line in each plot is the geometric mean.

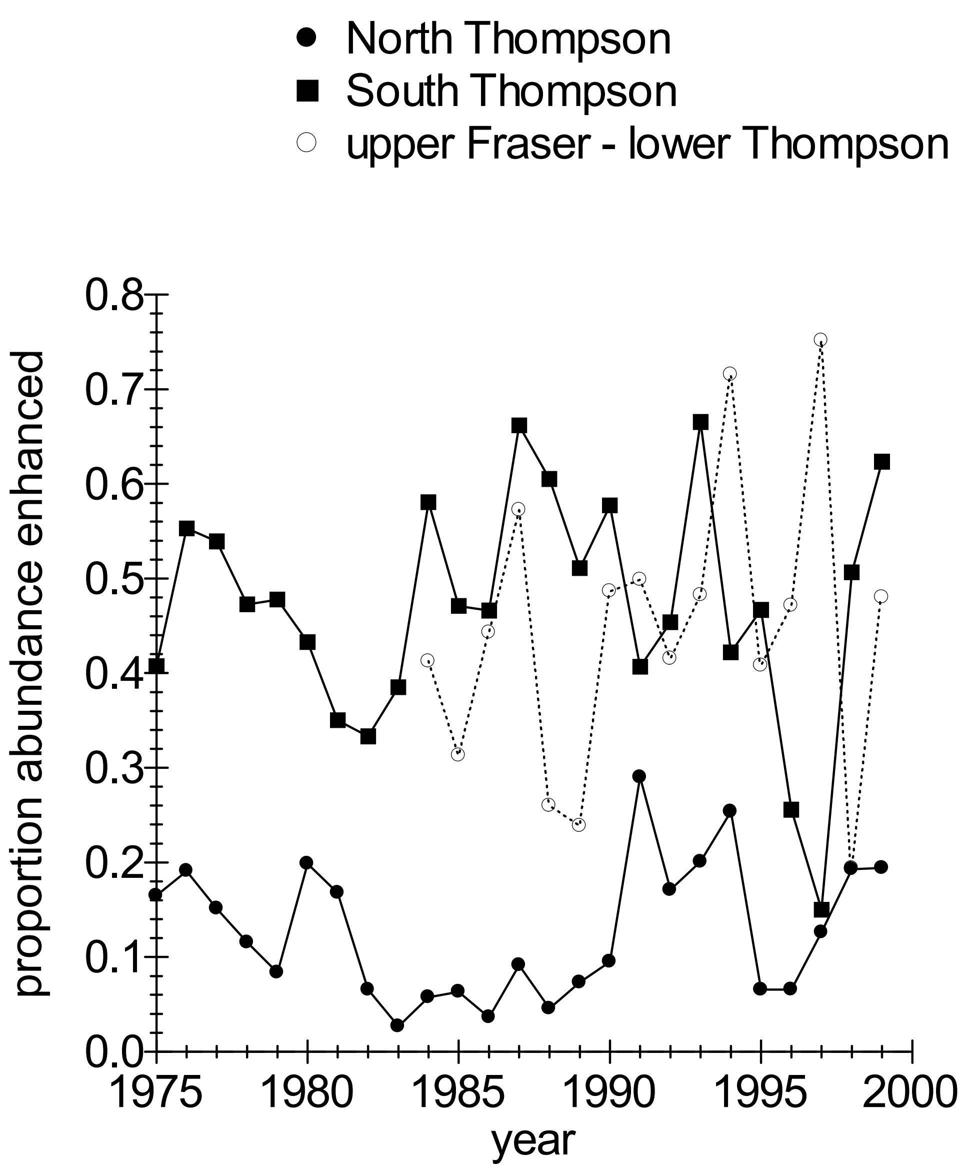

Figure 9. Approximate proportion of total estimated abundance attributable to enhanced streams. Note that the proportion of abundance in the enhanced systems that is directly attributable to enhancement is, for the most part, unknown.

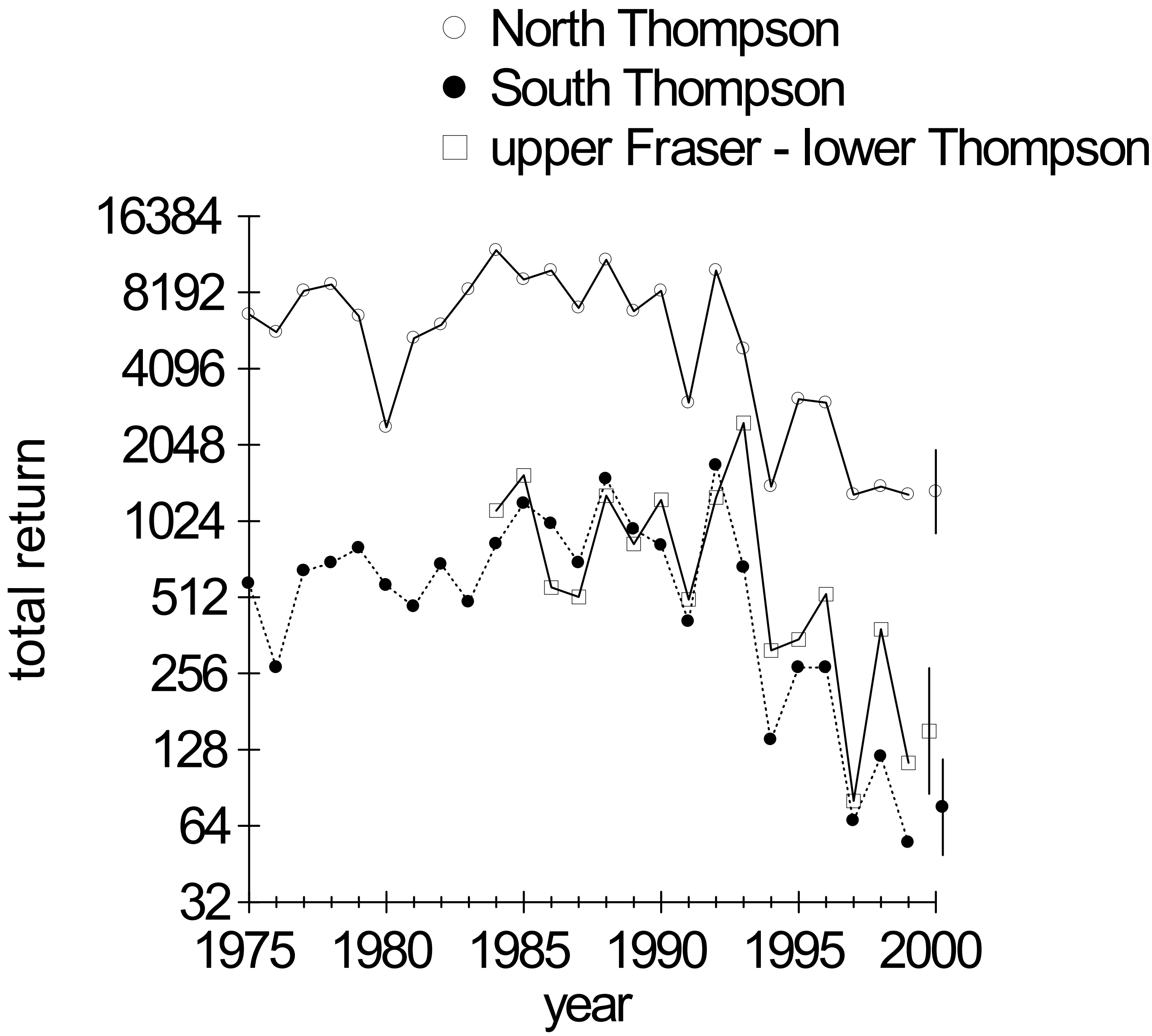

Figure 10. Total returns to the ‘average’ stream in the interior Fraser sub-regions from 1975 to 1999. The forecasts for 2000 with associated 50% CI are shown.

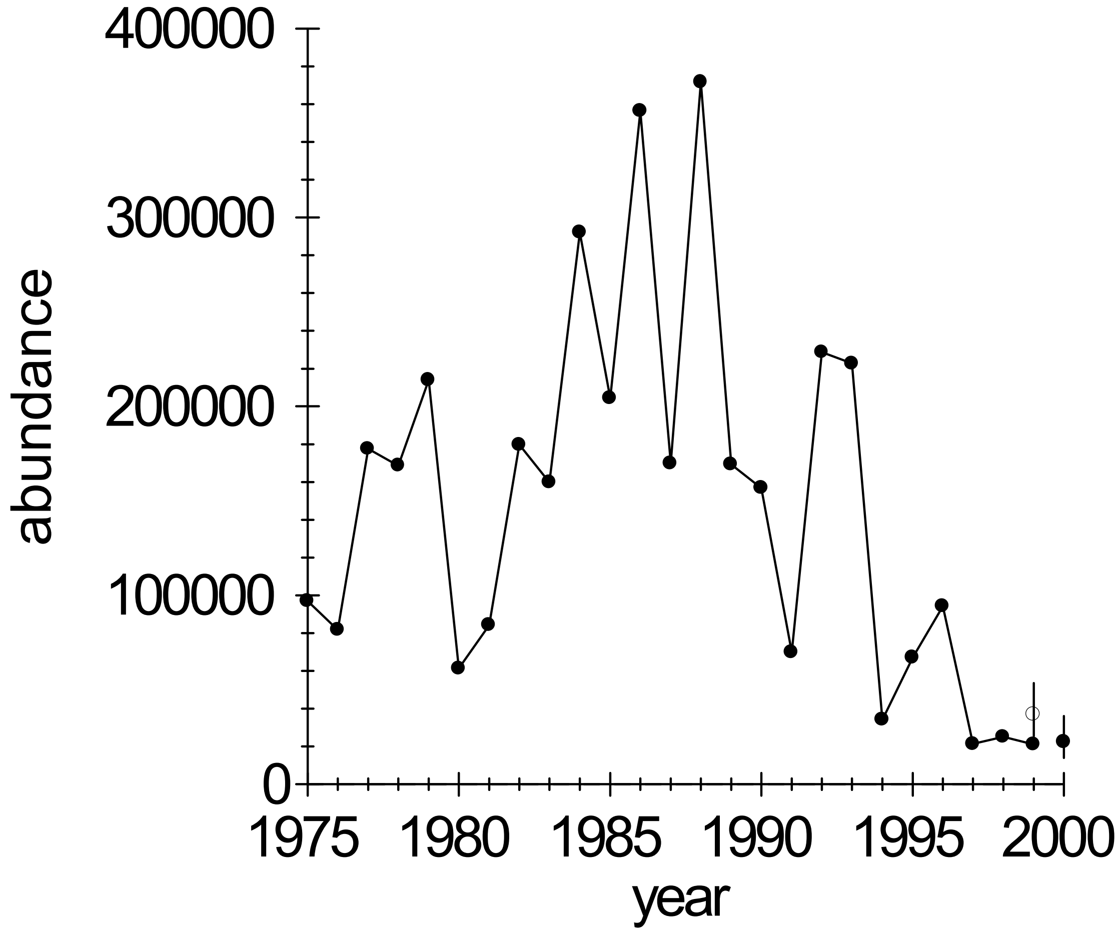

Figure 11. Estimated total abundance of the interior Fraser/Thompson River coho aggregate from 1975 to 1999. The forecasts for 2000 with associated 50% CI are shown.