Fisheries and Oceans Science
Pêches et Océans Sciences

C S A S

Canadian Science Advisory Secretariat

S C C S

Secrétariat canadien de consultation scientifique

Research Document 2001/088

Document de recherche 2001/088

Not to be cited without
permission of the authors *

Ne pas citer sans
autorisation des auteurs *

Forecast for Northern British Columbia Coho Salmon in 2001

L. B. Holtby and B. Finnegan

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

ISSN 1480-4883
Ottawa, 2001

Canadä

Abstract

This research paper documents forecasts of marine survival and abundance for the coho of selected areas of northern British Columbia including the upper Skeena conservation area.

Marine survival:

In 2001, marine survival at the three northern indicators is expected to be well above the mean for their respective periods of observation.

Indicator	model		(50% CI)	observed mean and period of observation (year of sea-entry)	
Lachmach	sibling regression	0.29	(0.23–0.35)	0.098	(1987 – 1999)
Toboggan Creek hatchery	from Lachmach	0.09	(0.05–0.14)	0.036	(1987 – 1999)
Fort Babine hatchery	from Lachmach	0.08	(0.04–0.15)	0.023	(1993 – 1999)

The period of observation is short for all three indicators. The survival rate of wild Toboggan Creek coho should be comparable to Lachmach but cannot be reliably forecast.

Abundance forecast

The forecast total return of Lachmach coho is 3.5×10^3 (50%CI: 2.8×10^3 – 4.2×10^3) which is above the mean of 2.7×10^3 observed over the period 1988 to 2000. Smolt production at Lachmach has remained modest. The estimated smolt production in 2000 was 1.4×10^4, which was well below the observed mean of 3.2×10^4 (1987 – 1999). Therefore, the above average forecast for Lachmach is due to the very high forecast survival rather than to large smolt production. In contrast, wild smolt production from Toboggan Creek in 2000 was estimated to have been 89×10^3, indicating high freshwater (FW) survival. Assuming that wild survival will be 1.7-times that of the forecast survival for hatchery coho (the same expansion observed for the 2000 return) the total return of wild Toboggan coho could be 13×10^3, which is well above the mean of 4.7×10^3 (1988 – 2000). Assuming that the exploitation rate in 2001 is unchanged from 2000 the forecast wild escapement to Toboggan is 8.1×10^3, which is well above the mean of 2.0×10^3 (1988 – 2000).

After the application of stock-recruitment and time-series models to reconstructions of abundance in the Babine Lake aggregate and the Area 6 average-stream, we conclude the following about abundance in 2001:

aggregate	proportions of observed abundance and escapement less than forecasts‡		characterization of forecast abundance
	abundance	escapement	
Area 6	0.08	0.25	well below average
Babine	0.33	0.49	average

‡ Assuming a log-normal cumulative probability distribution with mean and standard deviation calculated over the observation period 1950 (1946 for Babine) to 2000 (return years).

Caution remains warranted in the conduct of northern BC fisheries that could impact coho because Area 6 coho continues to be depressed. There are also some indications that high-interior Skeena coho, specifically the Sustut, have not recovered, as has the Babine aggregate. However, with expectations of well above average survivals at the Area 3 indicator, similarly high survivals at the two upper Skeena hatchery indicators and strong forecast returns in all areas but Area 6, we conclude that the conservation concerns of the past decade are considerably reduced.

Résumé

Le présent document de recherche présente des prévisions de la survie en mer et des effectifs du saumon coho dans certaines régions du nord de la Colombie-Britannique, y compris la zone de conservation de la haute Skeena.

Survie en mer
- On prévoit que les taux de survie en mer pour 2001, déterminés aux trois points repères du nord, seront bien supérieurs aux moyennes pour leurs périodes d'observation respectives.

Point repère	Modèle	$\hat{S}_{2001}$	(IC de 50 %)	Moyenne observée et période d'observation (année d'entrée en mer)	
Lachmach	Régression des espèces jumelles	0.29	(0.23-0.35)	0.098	(1987-1999)
Écloserie du ruisseau Toboggan	À partir de Lachmach	0.09	(0.05-0.14)	0.036	(1987-1999)
Écloserie de Fort Babine	À partir de Lachmach	0.08	(0.04-0.15)	0.023	(1993-1999)

La période d'observation est courte pour les trois points repères. Le taux de survie des cohos sauvages du ruisseau Toboggan devrait s'approcher de celui des saumons de la rivière Lachmach, mais on ne peut le prévoir de façon fiable.

Prévision des effectifs

La remonte totale prévue dans la rivière Lachmach est de $3{,}5\times10^3$ cohos (IC de 50 % : $2{,}8\text{x}10^3$ – $4{,}2\text{x}10^3$), valeur supérieure à la moyenne de $2{,}7\times10^3$ observée de 1988 à 2000. En 2000, la production de saumoneaux dans cette rivière est restée faible : elle a été estimée à $1{,}4\text{x}10^4$, bien en-dessous de la moyenne de $3{,}2\text{x}10^4$ (de 1987 à 1999). Par conséquent, la prévision d'une remonte supérieure à la moyenne dans la rivière Lachmach est attribuable au taux de survie prévu très élevé plutôt qu'à une forte production de saumoneaux. La situation est différente dans le ruisseau Toboggan, où la production de saumoneaux sauvages en 2000 a été estimée à $89\text{x}10^3$, ce qui indique un taux de survie élevé en eau douce. En supposant que le taux de survie des saumons sauvages sera 1,7 fois celui des cohos provenant de l'écloserie (le facteur observé lors de la remonte de 2000), la remonte totale de cohos sauvages du ruisseau Toboggan pourrait atteindre $13\text{x}10^3$, ce qui dépasse de beaucoup la moyenne de $4{,}7\text{x}10^3$ observée de 1988 à 2000. En supposant que le taux d'exploitation est le même en 2001 qu'en 2000, on prévoit que l'échappée des saumons sauvages du ruisseau Toboggan atteindra $8{,}1\text{x}10^3$, une valeur bien supérieure à la moyenne de $2{,}0\text{x}10^3$ observée de 1988 à 2000.

L'application de modèles stock-recrutement et de séries chronologiques pour reconstituer les effectifs du stock combiné du lac Babine et du stock du cours d'eau moyen de la zone 6 a permis d'en arriver aux conclusions suivantes concernant les effectifs pour l'année 2001 :

	Proportions de l'effectif et de l'échappée observés moins leurs prévisions respectives‡		
Stock combiné	Effectif	Échappée	Caractérisation de l'effectif prévu
Zone 6	0,08	0,25	bien en deçà de la moyenne
Babine	0,33	0,49	moyen

‡ On postule une distribution log-normale des probabilités cumulatives dont la moyenne et l'écart-type sont calculés sur la période d'observation allant de 1950 (1946 pour le stock combiné de Babine) à 2000 (années de remonte).

La prudence reste de mise en ce qui concerne les pêches dans le nord de la C.-B. qui pourraient toucher le saumon coho parce que les stocks de coho de la zone 6 continuent d'être appauvris. Il semblerait aussi que, contrairement au stock combiné du lac Babine, les stocks de coho de la haute Skeena, en particulier celui de la rivière Sustut, ne se sont pas rétablis. Toutefois, étant donné les prévisions de taux de survie bien supérieurs à la moyenne au point repère de la zone 3 et à ceux des deux écloseries de la haute Skeena ainsi que les fortes remontes prévues dans toutes les zones sauf la zone 6, nous concluons que la situation préoccupante de la dernière décennie s'est beaucoup améliorée en ce qui concerne la conservation du saumon coho.

Table of Contents page

Tables page

Figures page

1. Introduction

In this research document we detail:

1. Performance of some of the 2000 forecasts for coho aggregates in north coastal British Columbia (Holtby et al. 2000)
2. A forecast of marine survival and total return for the wild indicator stock of the Lachmach River (Area 3; Work Channel);
3. Forecasts of marine survival for the Toboggan Creek and Fort Babine hatchery indicators (Area 4; upper Skeena conservation area);
4. Forecasts of the total return and escapement of the Babine Lake (Area 4; upper Skeena conservation area) coho aggregate;
5. Forecasts of indices of total coho return to the upper Skeena (Area 4 upper) and to Kitimat (Area 6).

In past forecast papers for northern B.C. (Holtby et al. 2000, 1999a) forecasts were prepared for abundance in all Statistical Areas 1 to 10. However, this year visual escapement estimates for streams in Areas 1, 2, 3, and 5 were not available to the authors at the time of writing and visual escapement estimates for streams in Areas 4 and 7 to 10 were insufficient to conduct analysis. Consequently, no forecasts or abundance are available for those Statistical Areas.

2. Data Sources

Catches and escapement data for coded-wire tagged coho from the Lachmach River (wild indicator) and Toboggan Creek and Fort Babine hatchery indicators were obtained from an online database maintained by the Alaskan Dept. of Fish and Game[1]. CWT recovery data for 2000 are preliminary and may change as catch and escapement estimates are finalized. Escapement data for Lachmach River coho were obtained from program sources in the Stock Assessment Division. Visual escapement estimates for streams in Statistical Area 6 were obtained from Conservation and Protection staff in the Prince Rupert Office. (pers. comm. D. Wagner, DFO, Prince Rupert). Escapement data for the Babine Lake coho aggregate were obtained from a database maintained by the Stock Assessment Division in the Prince Rupert Office. (pers. comm. L. Jantz, DFO, Prince Rupert). Escapement data for Toboggan hatchery and wild coho were obtained from the Toboggan Creek Enhancement Society (pers. comm. M. O'Neill, TCES, Smithers). All data from 2000 should be considered preliminary and subject to revision as escapement estimates are finalized.

Coho could not be retained in Canadian waters in 2000 as part of the conservation measures undertaken to protect upper Skeena coho. There were some exceptions in terminal areas where surpluses were identified. Where there were fisheries, coho that were caught were released with minimal harm. Estimates of the exploitation rate in Canadian waters range between 1% and 8%.

[1] Alaska Department of Fish and Game, Commercial Fisheries: http://tagotoweb.adfg.state.ak.us

Many of the analyses presented in this research document use reconstructed time series of exploitation rate on Skeena coho. These reconstructions are derived from relationships between exploitation rate and effort stratified for gear, area and time for the period 1965 to 1987. Exploitation rate estimates of fishery-specific exploitation rate derived from coded-wire tags first became available in 1988 in northern BC. The reconstructions are part of a comprehensive assessment of coho in the northern boundary area and will be summarized elsewhere (unpubl. data, Northern Boundary Technical Committee of the Pacific Salmon Commission, Vancouver, BC.; Holtby et al. 1999b)

3. Forecasting Models and Retrospective Analysis of Predictive Power.

3.1 Forecasting models

We use three approaches to forecasting in the research document. Where there are time-series longer than about 15 years we use four quasi time-series models. In each model the variable being forecast (*v*) is first transformed so that

$$Z = \Im(v) \tag{1}$$

where $\Im$ is the transformation and *Z* is the transformed value of *v*. The Log transformation was used for abundance. The Logit transformation[2] was applied to proportions such as survival (*s*). The four models can then be described as follows where Z_{t+1} is the forecast value for time t+1:

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

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 the purpose of 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	years used in prediction: 3 (≈ 1 cycle)
project trends?	NO	LLY	3YRA
	YES	RAT1	RAT3

For Lachmach River coho the marine survival rate was predicted using a "sibling-regression" model, where the total return of age-n.1[3] fish ($A_{t,n.1}$) is predicted from the observed age-n.0 escapement of males ($E_{t-1,n.0}$, 'jacks'):

$$\log_e A_{t,n.1} = b \log_e E_{t-1,n.0} + a + \varepsilon_t \qquad (6)$$

Survival (s_{smolt}) was then calculated by dividing the age-n.1 return in year t by the number of smolts counted out of the system in year t-1 (N_{smolt}).

All of the approximately 25 coho populations spawning above the Babine River counting fish have been combined into the Babine Lake aggregate. For these coho we have estimates of total escapement from 1946 to 2000. The fence was not operated in 1964. The 1964 escapement in that year was estimated from the Skeena test-fishery index using an iterative contingency-table algorithm (Brown 1974) implemented in Excel®[4] (pers. comm. J. Blick, ADFG, Juneau, AK). Estimates of age composition of returning adults exist for 15 years in the 1970's and 1980's. Age composition in the escapement is significantly related to spawner numbers in the brood year. We used that relationship to estimate age composition in years for which there were no data. Using the reconstructed exploitation rate time-series we then estimated total recruitment and did a standard Ricker stock-recruitment analysis (Hilborn and Walters 1992). Recruitment for the 1997 brood year is not yet complete because a significant proportion of the returning adults is age 2.1. To estimate recruitment of age 2.1 fish in the next year we used the number of age-1.1 fish ($N_{1.1}$) and the estimated age composition ($p_{1.1}$) for the current year.

---

[2] $Z_t = \log_e {v_t}/{1-v_t}$

[3] The age designation follows the European convention, which is "number of FW winters **.** number of ocean winters". In most northern coho escapement and catch is made up of a mixture of age 1.1 and age 2.1 adults with some age 3.1 animals.

[4] Registered trade-mark of Microsoft Corp., Redmond, WA. Mention of this product does not constitute endorsement.

Estimates of escapement to individual streams throughout BC have been made since at least 1950. These estimates are mostly based on visual inspections of the streams. The methods used to inspect the streams, and convert the counts to estimates of escapement, the frequency of surveys, etc., are largely undocumented. These methods are known to differ between systems and to have changed over time. The records are also fragmentary. Nevertheless, we think that the time series do contain information about escapement trends in each area.

To extract that information we first coded the various designators for "no-data" to a common missing value indicator. We then scaled the escapement (E) in each stream i to the maximum escapement recorded in that stream across all years t:

$$p_{i,t} = \frac{E_{i,t}}{\max(E_i)} \tag{7}$$

Then the $p_{i,t}$ were averaged across all streams i within each year t to give a time series (p_{max}) for the area as a whole. The "average-stream" or index escapement was constructed by multiplying p_{max} by the average across the i streams of $\max(E_i)$. This procedure was carried out for the streams of Area 6 only.

To construct an index of total abundance we then made some assumptions about the time series of historical exploitation rates. We know from CWT recoveries in ocean fisheries between 1987 and 1994 that coho from the entire North and Central Coast areas have very similar ocean distributions (Anon. 1994). Most coded-wire tags have been recovered in troll fisheries both in Alaska and northern B.C. This lead us to assume that the levels and the temporal patterns in ocean exploitation rates are likely similar between all of the sites in the North and Central Coast. We also know from patterns of CWT recoveries that fish from the lower and middle Skeena are more similar to coho from the more southerly Areas, while fish from the Babine have similar distributions to Area 3 coho. We therefore assumed that the exploitation rate time series developed for Toboggan Creek was applicable to Area 6. In using the exploitation rate time series for Skeena populations, the FW components of those exploitation time series were removed before application to the other areas.

Forecasts for the Babine Lake and the Area 6 aggregate were made in two ways. First, total returns to the "average stream" within each aggregate were forecast using the four time-series models. Second, the time series of escapement and returns were used as inputs to Ricker stock-recruitment analyses, which were then used to forecast recruitment and returns in 2001 using observed spawner indices in 1998.

The 'average-stream' indices may be effective descriptors of status of coho within a geographical area. The areas covered by the aggregates used in this analysis are smaller than those recently proposed (Anon. 1999). Some regrouping might be advisable to combine streams of similar physiography. However, the utility of the average-stream index in describing trends within an area have not been thoroughly explored and no diagnostics have been developed for recognizing situations where the index is unsuitable.

To give the reader a feel for the approximate likelihood of forecast values, the forecasts have been expressed in terms of *Z*-scores:

$$Z = \frac{x - \overline{x}}{SD} \qquad (8)$$

Tabulated values of *Z* and their associated cumulative probability values can be found in most statistical texts but for convenience we have graphed the cumulative probability values for $Z \pm 3$ (Figure 1).

3.2 Retrospective analyses

There was not sufficient time to complete retrospective analyses of alternative forecasts. The relative performance of the models has not varied during previous retrospective analyses (Holtby et al. 1999a, 2000) and consequently those models selected as having the smallest Root Mean Square Error (*RMSE*):

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

and Mean Absolute Deviation (*MAD*):

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

in the 2000 forecast (Holtby et al. 2000) were used for the 2001 forecasts.

4. Marine Survival Estimates

4.1 2000 Forecasts compared to marine survivals observed in 2000

Holtby et al. (2000) forecast marine survival rates for the Lachmach wild indicator and for the Toboggan Creek and Fort Babine hatchery indicators. Those forecasts and the observed marine survivals are given in the following Table. The time series of survival and total stock sizes can be found in Table 1. For Lachmach wild coho marine survival was as forecast. Survivals were lower than predicted for the two Skeena hatcheries and slightly higher than forecast for the Toboggan wild coho.

indicator	forecasting model	forecast survival ($\hat{s}_{2000}$)	50% CI	observed survival (s_{2000})
Lachmach River	sibling regression	0.14	0.114 – 0.172	0.14
Toboggan Creek	regression on Lachmach survival	0.05	0.03 – 0.08	0.044
Toboggan Creek (wild)	observed scalar from hatchery survival	0.06	none given	0.074
Fort Babine	regression on Lachmach survival	0.03	0.02 – 0.06	0.018

4.2 Marine Survival Rate Forecast

The forecast for the total return of Lachmach coho was made with the following sibling regression:

$$\log_e(A\ \text{n.1}) = 5.8904 + 0.3907\log_e(E\ \text{n.0})$$
$$(N = 12;\ \text{adj. } r^2 = 0.55;\ P < 0.005)$$

The estimated jack escapement ($E_{\text{n.0}}$) in 2000 to Lachmach was 397, which leads to a forecast total return of 3.5×10^3, which is above the mean of 2.7×10^3 (Table 1; 1989 to 2000 returns, Z-score = 0.65). The 2000 smolt run at Lachmach was estimated to be 14×10^3 leading to a marine survival forecast of 0.29, which would be well above the mean of 0.098 (Table 1; 1987 to 1999 sea-entry; Z-score = 4.1). The confidence intervals for the Lachmach survival and abundance forecasts are detailed in Table 2 and in Figure 2.

Very few or no jacks return to interior sites so sibling regression is not possible for either Babine or Toboggan Creek. However, the temporal patterns in marine survival are similar for the three northern indicators (Figure 3), allowing us to use the Lachmach forecast to forecast survivals in the Skeena indicators. The relationship between Lachmach and Toboggan survivals:

$$\text{logit}\left(s_{Toboggan}\right) = 0.860\,\text{logit}\left(s_{Lachmach}\right) - 1.516$$
$$(N = 13;\ \text{adj. } r^2 = 0.37;\ P < 0.02),$$

gives a forecast survival at Toboggan of 0.088 (50%CI: 0.053 – 0.14; Table 2; Figure 3). That survival is well above 0.036, the mean of the time series (1987 to 1999 sea-entry; Z-score = 2.0). Note that the uncertainty is a minimal estimate because the uncertainty in the forecast of Lachmach survival is not taken in to account.

The wild smolt output from Toboggan Creek in 2000 was estimated to have been 89×10^3. The variability of the ratio between observed hatchery and estimated wild survival (see Table below) is too large to allow a useful forecast of wild survival or returns. If the scalar is the same as in 2000 (1999 sea-entry), wild survival estimated from the predicted survival of Toboggan hatchery coho would be 15% and the total wild return would be 13×10^3. Assuming an exploitation rate of 38% (i.e., same as 2000), the wild escapement to Toboggan would be 8.1×10^3.

smolt year	estimated wild smolt number ($\times10^3$)	ratio of wild to hatchery marine survival	estimated wild survival
1995	38	3.895	0.097
1996	35	3.97	0.020
1997	42	3.61	0.067
1998	67	1.15	0.12
1999	44	1.66	0.074
2000	89	assumed: 1.66	forecast: 0.15

The relationship between survival of Lachmach and Fort Babine hatchery coho is weaker largely because of the smaller time series and lower than expected survival for the 1995 brood year (Table 1) but is improving as the time series lengthens. The predictive relationship is

$$\text{logit}\left(s_{Babine}\right) = 1.286\,\text{logit}\left(s_{Lachmach}\right) - 1.26$$

(N = 7; adj. r^2 = 0.49; $P < 0.05$)

The forecast survival for Babine coho is 0.08, which is considerably higher than recent values (Table 2; Figure 3). Again note that the uncertainty is a minimal estimate because the uncertainty in the forecast of Lachmach survival is not taken in to account.

5. Forecasts of abundance and escapement

5.1 Performance of the 2000 forecasts of abundance

Forecasts of abundance in 2000 were provided for Lachmach, Toboggan wild, the Babine aggregate, and the average-stream indices in Statistical Areas 3, 4-lower, 4-upper, 5, 6, 7 and 8. Performance of the forecasts can be determined only for the Babine aggregate (Table 5), Lachmach (Table 6),and the average-stream indices in Statistical Area 6 (Table 7). Realized abundance was between the 95th and 99th percentiles of the forecasts in Statistical Area 6 (3YRA model) but was less than the 1st percentile for the Babine Lake aggregate (S-R model). The poor performance of the forecast at Babine was likely due to the below forecast marine survival (Section 4.1). The observed abundance at Lachmach was between the 25th and 50th percentiles.

5.2 2001 Abundance forecasts

Forecasts of abundance for the Lachmach wild indicator were presented in an earlier section (Table 2). Forecasts for the Babine Lake aggregate and for the Kitimat region (Statistical Area 6) were made following the same procedures, and are considered together in this section. The following Table summarizes the organization of data and forecast Tables and Figures. The Figures show the time series of total returns (Babine) or total return index (Area 6) with S-R and 3YRA forecasts for 2000. The Figures also show both the S-R and 3YRA forecasts for 2001 for both of the aggregates.

aggregate	data Table	forecast summary Table	relevant Figures
Babine Lake aggregate	Table 3	Table 9	Figure 5
Kitimat (Area 6)	Table 4	Table 10	Figure 6

Table 8 summarizes the results of the Ricker stock-recruitment model fits for the 2 coho aggregates. The time series for each aggregate are long and have at least an eight-fold range in *S*. However, the properties of these indices of aggregate abundance and their use in stock and recruitment analyses have not been explored. Although the forecast is believed to be conservative, considerable caution must be used in interpreting the Area 6 forecast.

Table 9 summarizes the forecasts of abundance and escapement for the Babine Lake aggregate. Abundance is forecast to be 1.4×10^4 (50%CI: $1.0\times10^4 - 2.1\times10^4$) using the preferred S-R model. This return is above the mean of the time series (1946 to 2000; Z-score = 0.43). Assuming an exploitation rate of 0.54, escapement would be 6.3×10^3, which is approximately 50% of the provisional escapement target for the aggregate (1.2×10^4; Holtby et al. 1999b).

Table 10 summarizes the forecasts of abundance and escapement for the Area 6 ‘average-stream’. Abundance is forecast to be 8.4×10^2 (50%CI: $6.0\times10^2 - 1.2\times10^3$; Z-score = –1.12) using the preferred 3YRA time-series model. Although abundance appears to be recovering slowly the forecast return remains well below the mean of the time series. Assuming an exploitation rate of 0.37, escapement is forecast to be 5.3×10^2 (50%CI: $3.8\times10^2 - 7.4\times10^2$; Z-score = –0.63) or approximately 25% of a proposed escapement target (Holtby et al. 2000).

Forecasts of escapement are dependent not only on forecast abundance but also on exploitation rate. Exploitation rates ranged between 37% and 54% on Skeena CWT groups in 2000 and were largely unchanged from immediate past years. Alaskan exploitation rates are likely to remain the same in 2000. Therefore, between 50% and 70% of forecast abundance would be available for escapement in the absence of Canadian fisheries.

6. Conclusions

6.1 Marine survival

In 2001, marine survival at the three northern indicators is expected to be well above the means over their respective periods of observation.

indicator	model	$\hat{s}_{2001}$	(50% CI)	observed mean and period of observation (year of sea-entry)
Lachmach	sibling regression	0.29	(0.23–0.35)	0.098 (1987 – 1999)
Toboggan Creek hatchery	from Lachmach	0.09	(0.05–0.14)	0.036 (1987 – 1999)
Fort Babine hatchery	from Lachmach	0.08	(0.04–0.15)	0.023 (1993 – 1999)

The period of observation is short for all three indicators. The survival rate of wild Toboggan Creek coho should be comparable to Lachmach but cannot be reliably forecast.

6.2 Abundance forecast

The forecast total return of Lachmach coho is 3.5×10^3 (50%CI: 2.8×10^3 – 4.2×10^3) which is above the mean of 2.7×10^3 observed over the period 1988 to 2000. Smolt production at Lachmach has remained modest. Estimated smolt production in 2000 was 1.4×10^4 was well below the observed mean of 3.2×10^4 (1987 – 1999). Therefore, the above average forecast for Lachmach is due to the very high forecast survival rather than to large smolt production. In contrast, wild smolt production from Toboggan Creek in 2000 was estimated to have been 89×10^3, indicating high FW survival. Assuming that wild survival will be 1.7-times that of the forecast survival for hatchery coho (the same expansion observed for the 2000 return) the total return of wild Toboggan coho could be 13×10^3, which is well above the mean of 4.7×10^3 (1988 – 2000; *Z*-score $= 3.3$). Assuming that the exploitation rate in 2001 is unchanged from 2000 the forecast wild escapement to Toboggan is 8.1×10^3, which is well above the mean of 2.0×10^3 (1988 – 2000; *Z*-score $= 4.3$).

After the application of stock-recruitment and time-series models to reconstructions of abundance in the Babine Lake aggregate and the Area 6 average-stream, we conclude the following about abundance in 2001:

aggregate	proportions of observed abundance and escapement less than forecasts‡: abundance	escapement	characterization of forecast abundance
Area 6	0.08	0.25	well below average
Babine	0.33	0.49	average

‡ Assuming a log-normal cumulative probability distribution with mean and standard deviation calculated over the observation period 1950 (1946 for Babine) to 2000 (return years).

Caution remains warranted in the conduct of northern BC coho fisheries because Area 6 coho continues to be depressed. There are also some indications that high-interior Skeena coho, specifically the Sustut, have not recovered, as has the Babine aggregate. However, with expectations of well above average survivals at the Area 3 indicator and similarly high survivals at the two upper Skeena hatchery indicators and strong forecast returns we conclude that the conservation concerns of the past decade are considerably reduced.

7. References

ANON. 1994. Interim estimates of coho stock composition for 1984-1991 southern panel area fisheries and for 1987-1991 northern panel area fisheries. Pac. Salmon Comm. Coho Tech. Cmte. (94)-1: 25p.

BROWN, M. B. 1974. Identification of sources of significance in two-way contingency tables. Appl. Statist. 23: 405-413.

HILBORN, R., AND C. J. WALTERS. 1992. Quantitative Fisheries Stock Assessment: choice, dynamics and uncertainty. Chapman & Hall, Inc., New York, NY. 570 p.

HOLTBY, B., B. FINNEGAN AND B. SPILSTED. 2000. Forecast for northern British Columbia coho salmon in 2000. Can. Stock Assessment Sec. Res. Doc. 2000/128: 74p.

HOLTBY, L. B., B. FINNEGAN AND B. SPILSTED. 1999a. Forecast for northern British Columbia coho salmon in 1999. Can. Stock Assessment Sec. Res. Doc. 99/186: 47p.

HOLTBY, L. B., B. FINNEGAN, D. CHEN AND D. PEACOCK. 1999b. Biological Assessment of Skeena River coho salmon. Can. Stock Assessment Sec. Res. Doc. 99/140: 47p.

Table 1. Marine survival rate estimates at three northern BC coho indicators. Toboggan and Fort Babine are hatchery indicators. Lachmach is a wild indicator. The stock size for Toboggan Creek is the wild component only.

	marine survival rates			total stock size	
return year	Lachmach	Toboggan	Fort Babine	Lachmach	Toboggan
1988	0.030	0.021		2,146	1,689
1989	0.044	0.027		1,590	5,498
1990	0.113	0.041		4,116	8,842
1991	0.121	0.060		4,194	8,125
1992	0.088	0.017		1,679	5,897
1993	0.061	0.028		2,065	3,638
1994	0.174	0.060	0.040	4,570	5,779
1995	0.082	0.018	0.010	3,223	2,736
1996	0.072	0.025	0.031	3,925	3,708
1997	0.055	0.005	0.006	1,728	691
1998	0.096	0.018	0.007	2,025	2,823
1999	0.125	0.104	0.051	2,437	7,872
2000	0.144	0.044	0.018	1,960	3,479

Table 2. Forecasts of 2000 sea-entry (2001 return) marine survival for three northern BC coho indicators and abundance for the Lachmach River, with associated confidence intervals. '*A*' is total abundance while '*s*' is marine survival.

	Lachmach		Toboggan	Fort Babine
probability of smaller return or survival	$\hat{A}_{2001}$	$\hat{s}_{2001}$	$\hat{s}_{2001}$	$\hat{s}_{2001}$
99%	7.7×10^3	0.64	0.45	0.65
95%	5.9×10^3	0.48	0.28	0.35
90%	5.2×10^3	0.43	0.22	0.25
75%	4.2×10^3	0.35	0.14	0.15
50%	$\mathbf{3.5\times10^3}$	**0.29**	**0.09**	**0.08**
25%	2.8×10^3	0.23	0.05	0.04
10%	2.3×10^3	0.19	0.03	0.02
5%	2.0×10^3	0.17	0.02	0.01
1%	1.5×10^3	0.13	0.01	0.004

Table 3. Stock-recruit data for the Babine coho aggregate.

brood year	total escapement	exploitation rate	proportion age 3	R/S
1946	13411	0.55	0.65	1.895
1947	10815	0.55	0.65	3.441
1948	13734	0.55	0.65	2.473
1949	12961	0.55	0.52	1.521
1950	11654	0.55	0.59	0.950
1951	2276	0.55	0.51	6.400
1952	10554	0.55	0.53	1.887
1953	7655	0.55	0.57	2.199
1954	3359	0.55	0.80	4.366
1955	9714	0.55	0.60	2.236
1956	9857	0.55	0.67	2.096
1957	4421	0.55	0.78	5.480
1958	8438	0.55	0.62	4.218
1959	12004	0.55	0.62	1.989
1960	7942	0.55	0.75	3.117
1961	14416	0.55	0.65	2.602
1962	15183	0.55	0.56	2.084
1963	7737	0.50	0.67	4.064
1964	10689	0.63	0.49	3.465
1965	22985	0.48	0.47	0.649
1966	13377	0.59	0.67	1.343
1967	12487	0.47	0.59	1.915
1968	13054	0.59	0.27	1.296
1969	6702	0.50	0.52	3.039
1970	10404	0.57	0.55	2.243
1971	9909	0.57	0.53	2.602
1972	5381	0.66	0.70	1.631
1973	11606	0.51	0.60	1.608
1974	13661	0.56	0.71	1.462
1975	4913	0.46	0.60	6.468
1976	4499	0.46	0.60	2.668
1977	10474	0.59	0.46	1.894
1978	11861	0.69	0.78	0.339
1979	2909	0.71	0.77	3.296
1980	5046	0.74	0.78	3.599
1981	2486	0.67	0.36	3.006
1982	2673	0.58	0.79	4.229
1983	3402	0.81	0.74	5.193
1984	3241	0.72	0.54	2.128
1985	2129	0.75	0.85	4.999
1986	3671	0.83	0.81	4.483
1987	2101	0.64	0.90	10.37
1988	3225	0.63	0.81	5.609
1989	5228	0.67	0.77	1.222
1990	5619	0.74	0.81	2.355
1991	4941	0.77	0.78	5.021
1992	1714	0.70	0.73	9.495
1993	2186	0.72	0.72	3.084
1994	4053	0.86	0.74	0.717
1995	2345	0.87	0.81	6.080
1996	2669	0.67	0.80	8.469
1997	453	0.55	0.76	14.15
1998	4291	0.60	0.80	

brood year	total escapement	exploitation rate	proportion age 3	R/S
1999	14908	0.46	0.79	
2000	2225	0.57	0.84	

Table 4. For the Kitimat aggregate (Area 6), indices of escapement and total return derived from visual stream counts.

year	exploitation rate	records	pmax	escapement N	escapement Z-score	total return N	total return Z-score	R/S
1950	0.527	81	0.221	9.92E+02	0.26	2.10E+03	0.08	3.113
1951	0.527	85	0.464	2.09E+03	2.36	4.41E+03	2.29	1.458
1952	0.527	9	0.362	1.63E+03	1.48	3.44E+03	1.36	2.000
1953	0.527	84	0.306	1.38E+03	1.00	2.91E+03	0.85	3.108
1954	0.527	83	0.355	1.60E+03	1.42	3.37E+03	1.30	2.066
1955	0.527	85	0.266	1.20E+03	0.65	2.53E+03	0.49	1.641
1956	0.527	85	0.464	2.09E+03	2.36	4.41E+03	2.29	0.895
1957	0.527	61	0.428	1.92E+03	2.05	4.07E+03	1.96	1.064
1958	0.527	66	0.220	9.88E+02	0.25	2.09E+03	0.07	2.465
1959	0.527	74	0.185	8.33E+02	-0.05	1.76E+03	-0.24	3.776
1960	0.527	66	0.214	9.64E+02	0.20	2.04E+03	0.02	3.356
1961	0.527	71	0.217	9.75E+02	0.23	2.06E+03	0.04	3.395
1962	0.527	74	0.319	1.43E+03	1.10	3.03E+03	0.97	2.262
1963	0.478	73	0.387	1.74E+03	1.70	3.34E+03	1.26	1.252
1964	0.606	70	0.270	1.21E+03	0.68	3.08E+03	1.01	2.006
1965	0.462	56	0.441	1.98E+03	2.16	3.68E+03	1.59	1.386
1966	0.569	34	0.244	1.10E+03	0.46	2.55E+03	0.51	1.205
1967	0.451	57	0.196	8.82E+02	0.05	1.61E+03	-0.39	1.919
1968	0.565	58	0.362	1.63E+03	1.47	3.74E+03	1.64	1.412
1969	0.484	42	0.136	6.12E+02	-0.47	1.18E+03	-0.80	3.588
1970	0.547	50	0.155	6.96E+02	-0.31	1.54E+03	-0.46	1.813
1971	0.550	49	0.194	8.72E+02	0.03	1.94E+03	-0.08	1.717
1972	0.636	55	0.232	1.04E+03	0.35	2.86E+03	0.81	1.415
1973	0.490	46	0.129	5.82E+02	-0.53	1.14E+03	-0.84	2.273
1974	0.541	49	0.148	6.66E+02	-0.37	1.45E+03	-0.54	2.215
1975	0.440	41	0.196	8.79E+02	0.04	1.57E+03	-0.43	2.217
1976	0.436	50	0.166	7.48E+02	-0.21	1.33E+03	-0.66	2.889
1977	0.566	55	0.127	5.71E+02	-0.55	1.32E+03	-0.67	3.043
1978	0.666	53	0.128	5.76E+02	-0.54	1.72E+03	-0.28	2.424
1979	0.690	58	0.159	7.16E+02	-0.27	2.31E+03	0.28	2.020
1980	0.718	53	0.121	5.43E+02	-0.61	1.93E+03	-0.09	3.324
1981	0.646	59	0.114	5.11E+02	-0.67	1.44E+03	-0.55	3.824
1982	0.559	68	0.130	5.84E+02	-0.53	1.32E+03	-0.66	4.651
1983	0.785	56	0.086	3.87E+02	-0.91	1.80E+03	-0.21	6.818
1984	0.697	66	0.122	5.48E+02	-0.60	1.81E+03	-0.20	1.890
1985	0.732	82	0.130	5.84E+02	-0.53	2.18E+03	0.16	1.558
1986	0.806	79	0.154	6.91E+02	-0.32	3.56E+03	1.48	2.034
1987	0.617	76	0.101	4.53E+02	-0.78	1.18E+03	-0.80	3.839
1988	0.608	48	0.070	3.15E+02	-1.04	8.03E+02	-1.16	4.385
1989	0.652	45	0.083	3.75E+02	-0.93	1.08E+03	-0.90	3.231
1990	0.716	30	0.121	5.44E+02	-0.60	1.92E+03	-0.09	1.983
1991	0.747	47	0.082	3.68E+02	-0.94	1.45E+03	-0.54	2.012
1992	0.681	45	0.090	4.03E+02	-0.88	1.26E+03	-0.72	1.555
1993	0.703	36	0.075	3.37E+02	-1.00	1.13E+03	-0.85	2.199
1994	0.665	37	0.074	3.32E+02	-1.01	9.92E+02	-0.98	1.863
1995	0.558	33	0.034	1.52E+02	-1.36	3.44E+02	-1.60	6.065
1996	0.636	30	0.087	3.89E+02	-0.90	1.07E+03	-0.90	1.386
1997	0.419	37	0.028	1.28E+02	-1.40	2.21E+02	-1.72	11.324

year	exploitation rate	records	pmax	escapement		total return		R/S
				N	Z-score	N	Z-score	
1998	0.564	55	0.121	5.44E+02	-0.60	1.25E+03	-0.74	
1999	0.190	29	0.060	2.68E+02	-1.13	4.11E+02	-1.54	
2000	0.348	35	0.163	7.33E+02	-0.24	1.16E+03	-0.82	

Table 5. Performance of the 2000 forecast total return for the Babine Lake coho aggregate. Stock-recruitment and time series models were used to forecast in 2000. The preferred model is underlined.

probability of a lower value	total return		
	observed	2000 forecast	
		S-R	3YRA
99%		1.4E+04	4.2E+04
95%		1.1E+04	2.4E+04
90%		9.5E+03	1.8E+04
75%		8.3E+03	1.1E+04
50%	**5.1E+03**	**7.4E+03**	6.7E+03
25%		6.8E+03	4.0E+03
10%		6.4E+03	2.5E+03
5%		6.2E+03	1.9E+03
1%		5.9E+03	1.1E+03

Table 6. Performance of the 2000 forecast total return and marine survival for the Lachmach River wild indicator. The forecasts are based on a sibling regression model.

probability of a lower value	total return		marine survival	
	observed	2000 forecast	observed	2000 forecast
99%		5242		0.323
95%		3906		0.241
90%		3417		0.211
75%		2792		0.172
50%	**1960**	**2267**	**0.144**	**0.140**
25%		1842		0.114
10%		1505		0.093
5%		1316		0.081
1%		981		0.061

Table 7. Performance of the 2000 forecast total return for the Area 6 aggregate. Stock-recruitment and time series models were used to forecast in 2000. The preferred model is underlined.

	total return		
	observed	2000 forecast	
probability of a lower value		S-R	3YRA
99%		8.5E+02	1.5E+03
95%		6.4E+02	1.0E+03
90%		5.7E+02	8.6E+02
75%		4.7E+02	6.3E+02
50%	**1.2E+03**	**3.9E+02**	**4.6E+02**
25%		3.3E+02	3.3E+02
10%		2.8E+02	2.4E+02
5%		2.6E+02	2.0E+02
1%		2.2E+02	1.4E+02

Table 8. Summary of the Ricker stock-recruitment analyses on reconstructed time series for the Babine Lake and Area 6 aggregates.

	Ricker stock-recruitment analysis						
aggregate	N	adj. r^2	a'	b'	S_{MSY}	S_{MAX}[§]	u_{MSY}
Babine Lake	52	0.44	1.931	19248	7022	9968	0.71
Kitimat (Area 6)	48	0.33	1.425	2562	1026	1798	0.57

[§] The carrying capacity, or the spawner number producing on average the maximum recruitment..

Table 9. For the Babine Lake aggregate, forecasts and associated confidence intervals for total return, escapement and proportion of S_{max} from the Stock-Recruitment (S-R) and time series (3YRA) models. *Z*-scores for the forecasts of total return and escapement are also given. An exploitation rate of 0.54 was assumed. The S-R model is preferred model.

$P^{§}$	forecast total return				forecast escapement				proportion of Smax	
	S-R	z-score	3YRA	z-score	S-R	z-score	3YRA	z-score	S-R	3YRA
99%	5.8E+04	7.65	1.4E+05	20.58	2.5E+04	2.23	5.9E+04	7.84	212%	497%
95%	3.6E+04	4.06	6.4E+04	8.59	1.6E+04	0.66	2.8E+04	2.63	132%	232%
90%	2.9E+04	2.88	4.3E+04	5.18	1.3E+04	0.15	1.9E+04	1.15	106%	157%
75%	2.1E+04	1.46	2.3E+04	1.81	9.0E+03	-0.47	9.9E+03	-0.31	75%	83%
50%	**1.4E+04**	**0.43**	**1.1E+04**	**-0.08**	**6.3E+03**	**-0.91**	**4.9E+03**	**-1.13**	**52%**	**41%**
25%	1.0E+04	-0.26	5.6E+03	-1.02	4.4E+03	-1.21	2.4E+03	-1.54	37%	20%
10%	7.4E+03	-0.72	3.0E+03	-1.46	3.2E+03	-1.41	1.3E+03	-1.73	27%	11%
5%	6.1E+03	-0.94	2.0E+03	-1.61	2.7E+03	-1.51	8.7E+02	-1.80	22%	7%
1%	4.2E+03	-1.26	9.4E+02	-1.79	1.8E+03	-1.65	4.1E+02	-1.88	15%	3%

§probability of a lower value

Table 10. For the Area 6 aggregate (Kitimat), forecasts and associated confidence intervals for total return, escapement and proportion of S_{max} from the Stock-Recruitment (S-R) and time series (3YRA) models. *Z*-scores for the forecasts of total return and escapement are also given. An exploitation rate of 0.37 was assumed. The 3YRA is the preferred model.

$P^{§}$	forecast total return				forecast escapement				proportion of Smax	
	S-R	z-score	3YRA	z-score	S-R	z-score	3YRA	z-score	S-R	3YRA
99%	3.2E+03	1.17	2.8E+03	0.74	2.0E+03	2.29	1.8E+03	1.74	95%	82%
95%	2.4E+03	0.36	1.9E+03	-0.08	1.5E+03	1.26	1.2E+03	0.70	70%	57%
90%	2.1E+03	0.07	1.6E+03	-0.40	1.3E+03	0.89	1.0E+03	0.30	61%	47%
75%	1.7E+03	-0.30	1.2E+03	-0.80	1.1E+03	0.42	7.4E+02	-0.22	50%	35%
50%	**1.4E+03**	**-0.60**	**8.4E+02**	**-1.12**	**8.8E+02**	**0.04**	**5.3E+02**	**-0.63**	**41%**	**25%**
25%	1.2E+03	-0.82	6.0E+02	-1.35	7.3E+02	-0.24	3.8E+02	-0.92	34%	18%
10%	9.9E+02	-0.98	4.4E+02	-1.51	6.3E+02	-0.45	2.8E+02	-1.11	29%	13%
5%	9.0E+02	-1.06	3.7E+02	-1.58	5.7E+02	-0.55	2.3E+02	-1.21	27%	11%
1%	7.7E+02	-1.20	2.5E+02	-1.69	4.9E+02	-0.72	1.6E+02	-1.34	22%	7%

§probability of a lower value

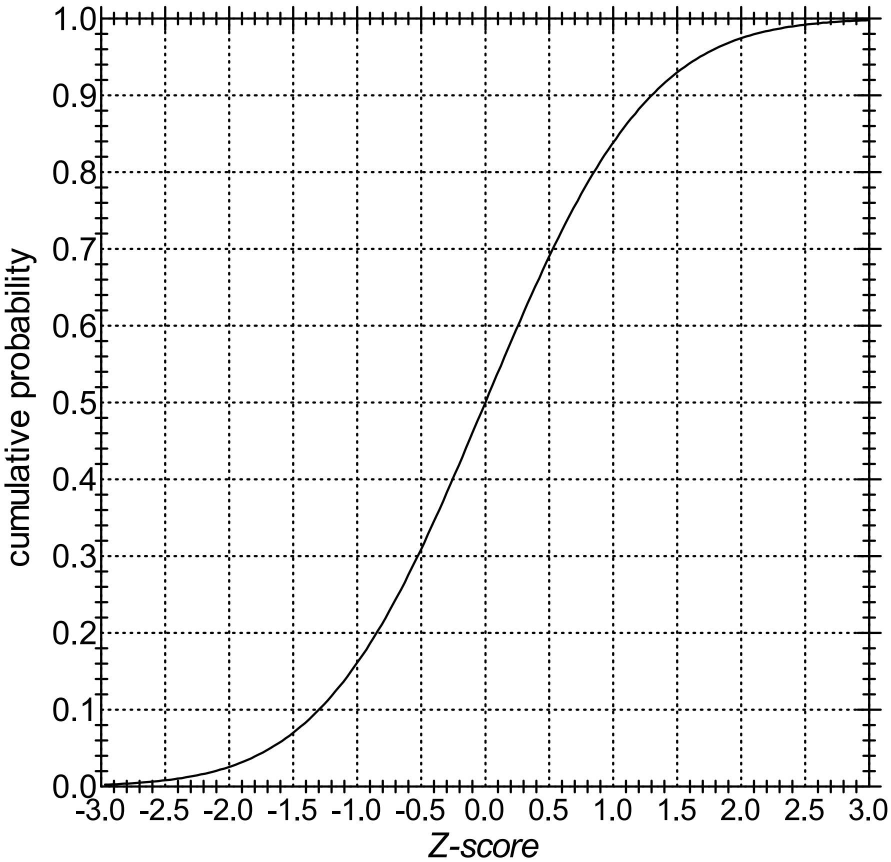

Figure 1. Cumulative probabilities for *Z*-scores applicable to the time series of Babine Lake coho and the average-stream indices from the Statistical Areas. This plot can be used to convert *Z-scores* to probabilities.

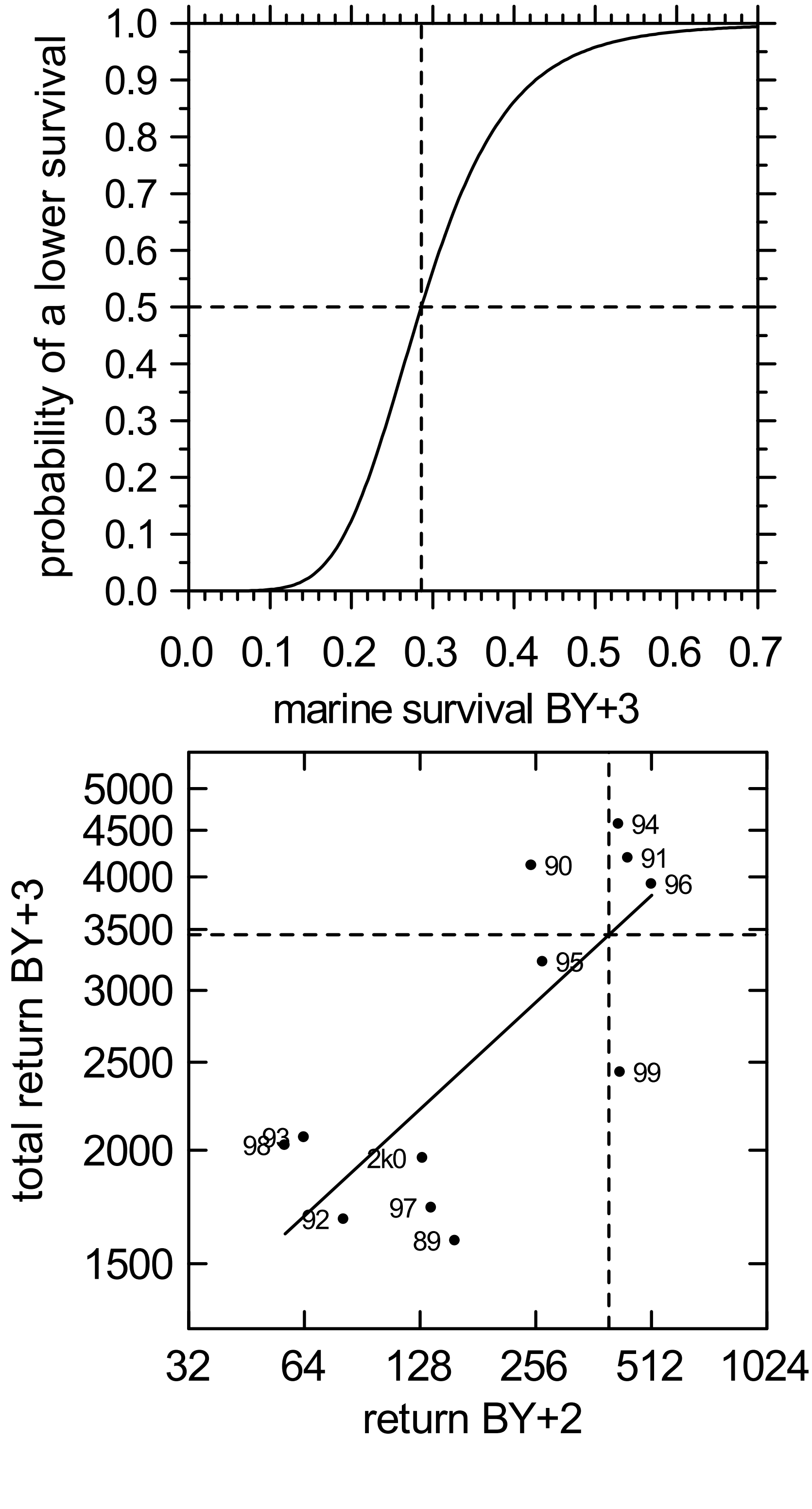

Figure 2. Return and survival forecast for Lachmach River coho in 2001 using the sibling regression model. The lower panel is the sibling relationship. The upper panel is the probability distribution for the predicted age 3+4 return.

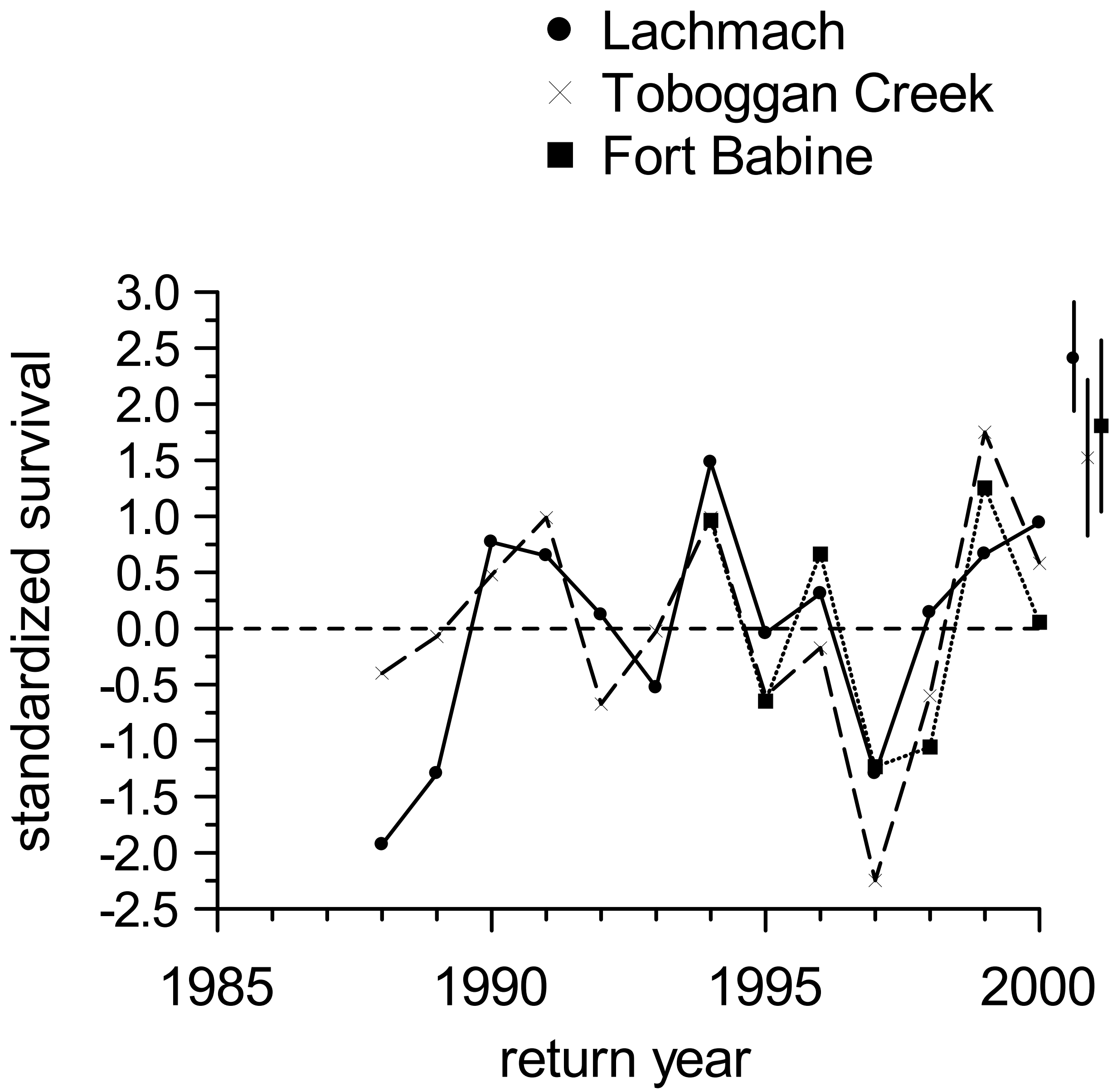

Figure 3. Time series of standardized survivals for three northern BC coho indicators. Forecast survivals for 2001 are shown with 50% confidence intervals to the right of the plot.

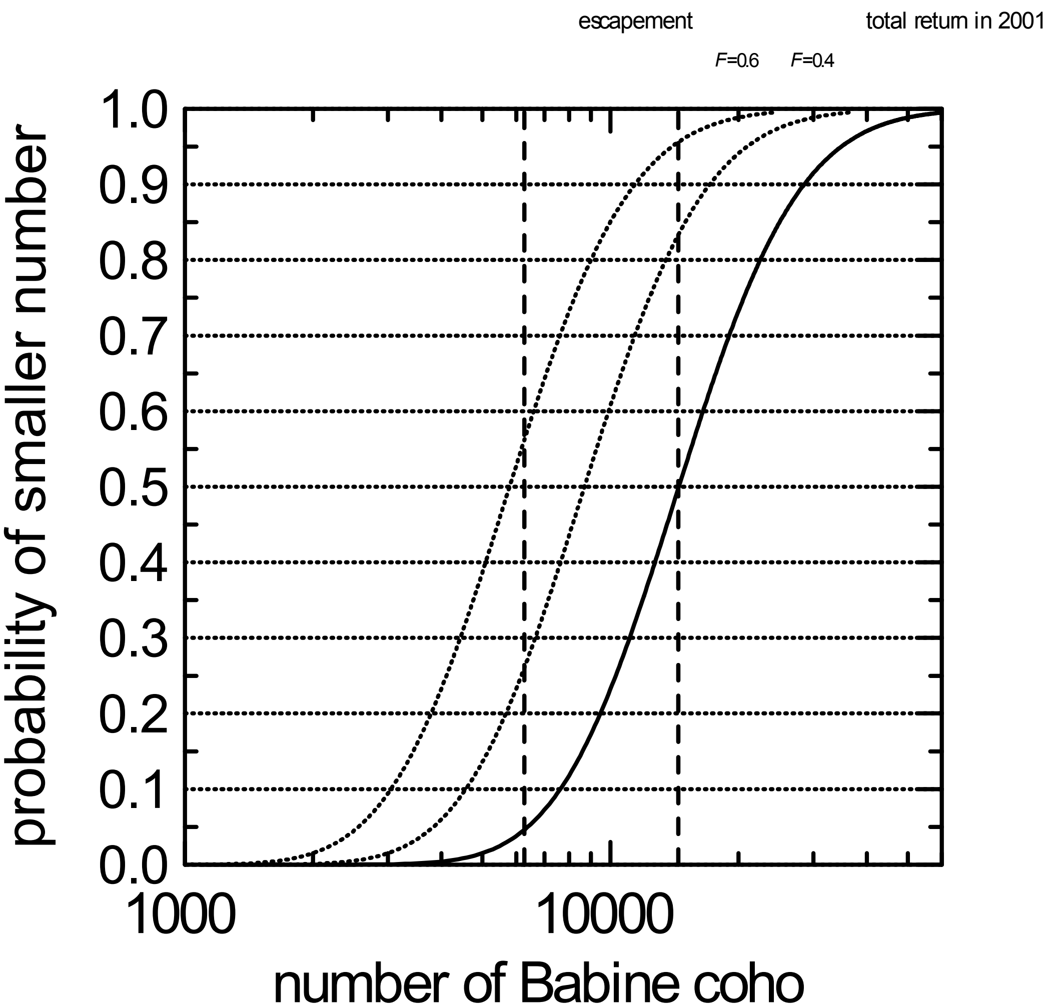

Figure 4. Stock-recruitment forecast for Babine coho aggregate in 2001. Escapement (dotted lines) is forecast for two exploitation rates (0.4 and 0.6). The solid line is the forecast for the total return in 2001. The two vertical dashed lines indicate the point forecasts for total return on the right and after fishing at the rate observed in 2000 of 57%.

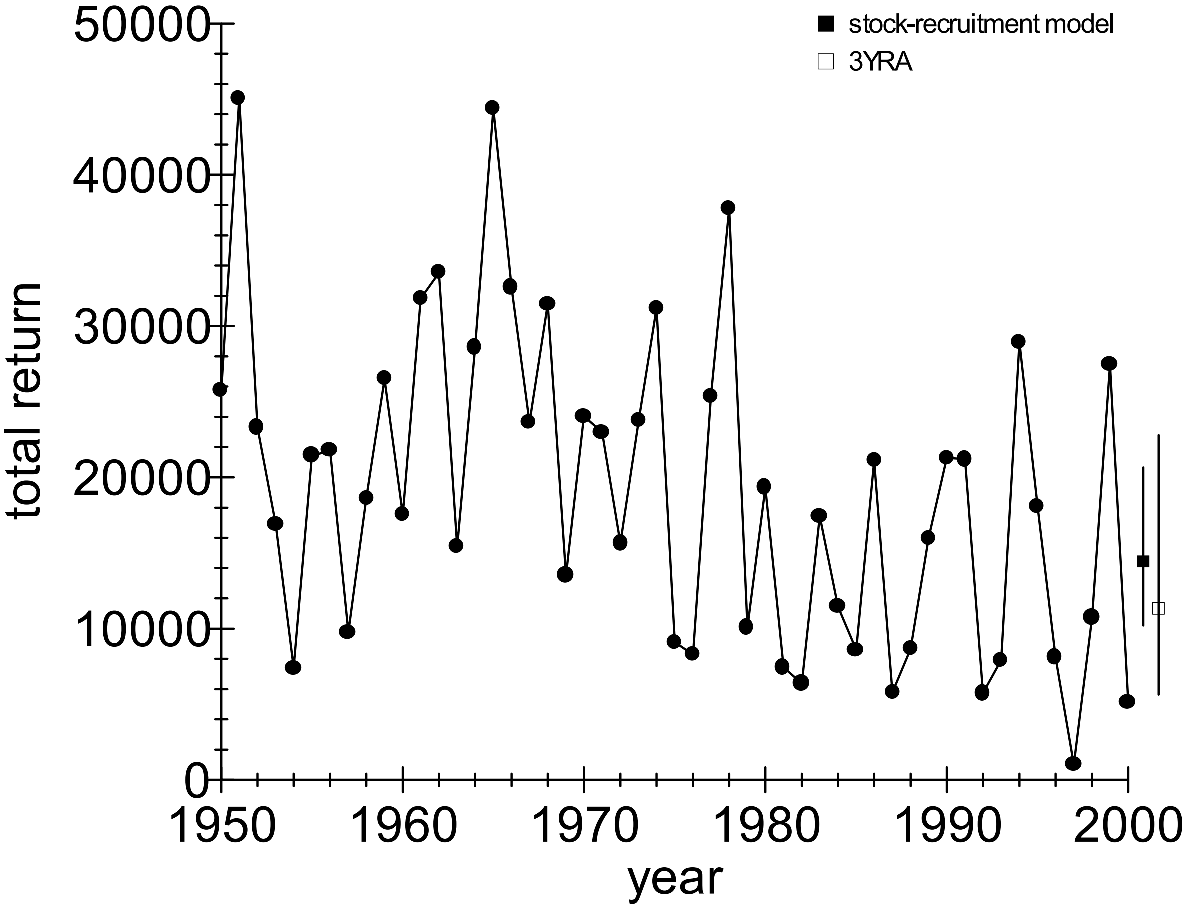

Figure 5. Forecast of total return of the Babine Lake coho aggregate in 2001. The S-R and 3YRA forecasts with 50% CI are shown to the right of the graph. The S-R model is the preferred model.

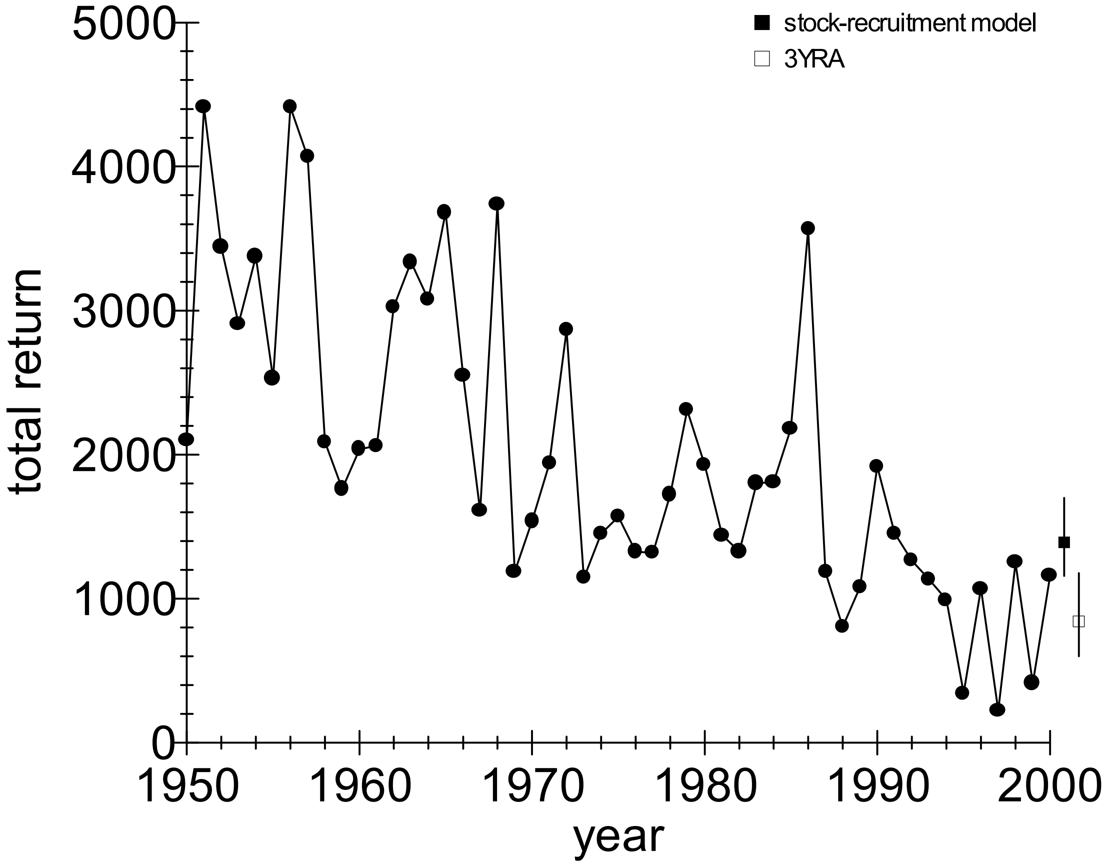

Figure 6. Total return to the average stream in Area 6. The S-R and 3YRA forecasts for 2001 with associated 50% CI are shown to the right of the graph. The 3YRA model is the preferred model.