PACIFIC SALMON COMMISSION
NORTHERN BOUNDARY TECHNICAL COMMITTEE REPORT

STATUS OF COHO SALMON STOCKS AND FISHERIES IN THE NORTHERN BOUNDARY AREA

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Appendix 2

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Stock status of Northern Boundary coho

Canadian Report

Blair Holtby[1]

Stock Assessment Division, Science Branch

[1]Pacific Biological Station, Nanaimo, B.C. V9R 5K6

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Table of Contents page

Tables page

Figures page

1 Introduction

This document presents an assessment of the status of coho salmon (*Oncorhynchus kisutch*) in the Canadian northern boundary areas with emphasis on the Skeena River. The content of this assessment has largely been drawn from published assessments (Holtby et al, 1999a; Holtby et al, 1999b; Holtby and Kadowaki, 1998; Holtby and Finnegan, 1997).

Biological assessment of coho across such a vast area is highly problematic. First, quantitative data are sparse and, in most of the area, assessment relies on escapement indices derived from visual escapement counts of uncertain quality from a highly variable stream set. Second, measures of exploitation and marine survival are of short duration and have been made in only a few streams. Third, there are only two measures of FW production (smolt output) in the area and they are of short duration and come from populations that may be of higher productivity than the norm for the area. Fourth, there has been significant sockeye enhancement in Babine Lake, one of the major systems of concern, but the impacts of that assessment on the limnology of the lake and on other species are largely unknown. Fifth, the biology of coho in interior systems has been little studied compared to the extent of study in southern coastal systems, which makes interpretation of what observations are available uncertain.

This section of the report has three sections. The first deals with information derived from exploitation rate-survival indicator populations. The second summarizes data from a variety of abundance indicators and presents an area wide synopsis of status. The third presents some comparative analyses of stock productivity and discusses a hypothesis to explain the pattern of status across the area.

2 Indicator populations

Three wild and two hatchery exploitation rate-survival indicators in the study area are considered in this report. The hatchery indicators are the Toboggan CDP project on Toboggan Creek, a lower tributary of the Bulkley River and the Fort Babine CDP project on Nilkitkwa Lake, part of the Babine Lake system. The wild indicators are Zolzap Creek, a lower tributary of the Nass River, the Lachmach River at the head of Work Channel and the wild population at Toboggan Creek[1]. There are no indicator streams in Areas 5 to 10, which includes the Central Coast. There is insufficient data from indicator streams on the Queen Charlotte Islands to warrant their inclusion.

Canadian catch data up to and including 1997 were obtained from the commercial catch database maintained by StAD at PBS, Nanaimo. Data on CWT recoveries in fisheries were obtained from the MRP database maintained at the Pacific Biological Station using the standard processing routines (Kuhn et al. 1988). There were known problems with the reporting of CWT recoveries in Area 3 and 4 gill-net fisheries during 1997, with the result that only 1 CWT was reported recovered. To estimate actual net exploitation rates in 1997 Holtby and Finnegan (1997) used the sockeye run-reconstruction model developed for Skeena-Nass fisheries (pers. comm. S. Cox-Rogers, DFO, Prince Rupert, Cox-Rogers 1994; Gazey and English 1996) to estimate the probable coho encounters during the 1994 through 1997 fisheries. The number of encounters was

[1] We will leave to others the philosophical question of whether or not the component of the Toboggan run that arises from naturally spawning and rearing fish is “wild”. The parents of hatchery stock have always been unmarked individuals that are almost exclusively naturally spawned and reared. Since the proportion of the hatchery reared component of the run is not increasing and natural smolt production from the system appears to be stable and substantial we presume that the naturally spawning and rearing population segment could be self-sustaining and, consequently, treat it as a wild population.

used to estimate exploitation rates in the 1997 fisheries. In 1998 coho retention was not permitted in any fisheries affecting Skeena coho. We used the same approach used in 1997 to estimate exploitation rates in each of the fisheries that affected Skeena coho and extended the models to fresh water fisheries by First Nations.

Adult counting fences are operated on all of the indicator streams. At all three locations all coho are processed[2] at a fence located in the lower river and either all or a systematic proportion of the fish processed are given an external tag. In the event that either fence topped during fall freshets, visual estimates of tagged and untagged fish were made by swimmers (Lachmach) or stream-side observers (Toboggan and Zolzap). The counts were then used to estimate the number of fish in the stream using either a Petersen mark-recapture procedure or Bayesian estimator described by Lane et al. (1994b). The fences operate for the entire duration of the run (Lane and Finnegan 1991; Lane et al. 1994a, b, unpubl. data B. Finnegan, StAD, PBS). Data for the Toboggan Creek and Houston fence operations were obtained from the annual reports of the Toboggan Creek CDP hatchery[3]. The Babine River salmon counting fence was constructed in 1946 with the intent of enumerating the large runs of sockeye salmon that spawn in the tributaries of Babine Lake. During operation of the fence visual counts are made of other species, but in recent years most coho have been dip-netted and examined for adipose clips. Fence operations have ended on various dates, but no earlier than September 13th. The enhanced component appears to be part of the early return to the lake and the fence has consistently operated late enough to capture that entire component. Data summaries were obtained from a database maintained by StAD in Prince Rupert (M. Jakubowski, B. Spilsted, pers. comm.)

Smolts are enumerated at Lachmach River, where they are trapped on their seaward migration, either at a weir or in a variety of rotary and fyke traps. Mark-recapture estimates of total run size were made when traps were in use. All smolts captured were tagged with coded-wire tags and adipose-clipped (Finnegan et al. 1990; Finnegan 1991; Davies et al. 1992; Baillie 1994; Lane and Baillie 1994; unpubl. data B. Finnegan, StAD, PBS).

Varying proportions of the adults enumerated at the Lachmach fence did not have an adipose clip and presumably did not have a coded-wire tag. Exploitation and survival rates, which are calculated from the coded-wire tagged releases, were used to estimate the actual smolt production. The expansion factor has ranged between 1.26 and 1.89 with a mean of 1.581 (SD = 0.234; N = 9).

Beginning in 1995, the number of wild smolts leaving Toboggan Creek was estimated by trapping both wild and hatchery smolts near the outlet of the stream. All Toboggan Creek hatchery smolts are CWT'd and there is volitional release. Four years of trapping (Saimoto 1995; SKR Consultants Ltd. 1996; B. Finnegan, StAD, PBS, unpubl. data) have indicated that the out-migration timing of wild and hatchery smolts is very similar. Consequently a simple ratiometric procedure is used to estimate the number of wild smolts (N_w) using the observed numbers of wild and hatchery smolts (n_w, n_h) and the known number of hatchery smolts released (N_h):

$$N_w = {}^{N_h n_w}\!\big/_{n_h} \qquad (1)$$

Smolts are not enumerated at the Babine and no other smolt data are available from the Skeena drainage.

[2] sexed, FL measured, weight taken (Lachmach), scales taken for aging, presence/absence of adipose clip recorded.
[3] obtainable from M. O'Neill, Manager, Toboggan Creek Salmon and Steelhead Enhancement Society, RR#1, Smithers BC, V0J 2N0

2.1 Smolt survival

Smolt survival has varied with a high degree of synchrony over the Canadian indicators in the northern boundary area (Figure 1) and simple correlations between the indicators are, with one exception, statistically significant (following Table).

indicator	average smolt survival[1] (CV)	correlations between survival time series (number of pairs; approximate probability levels for H_0: no correlation)			
		SE Alaskan index	Lachmach	Zolzap	Babine
SE Alaskan index	0.187 (0.26)	–			
Lachmach	0.096 (0.38)	0.84 (10; P < 0.01)	–		
Zolzap	0.043 (0.63)	0.89 (5; P < 0.05)	0.81 (6; P<0.06)	–	–
Babine	0.019 (0.83)	0.95 (4; P = 0.05)	0.69 (5; NS)	0.99 (5; P<0.01)	–
Toboggan	0.030 (0.64)	0.60 (10; P <0.1)	0.75 (11; P<0.01)	0.83 (6; P<0.05)	0.88 (5; P<0.05)

[1]average over the period 1990 to 1998 return year inclusive, where data were available.

On average, smolt survival in Canadian indicators was highest at Lachmach, lowest at the two hatchery indicators and intermediate at Zolzap. In general, marine survivals in Canadian northern boundary indicators are considerably less than in American streams to the immediate north (Shaul 1998). The difference in average survivals between the Canadian and Alaskan indicators is of great significance in explaining differences in status in respective northern boundary areas.

The levels of inter-annual variability in smolt survivals also differ between the indicators. The least variability, as measured with the Coefficient of Variation (CV), was observed in the Alaskan indicators, followed closely by Lachmach. Smolt survival is more variable at Zolzap and Toboggan, which had similar levels, and was highest at Babine.

Although there appears to be a downward trend in survival for the three Skeena populations (Figure 1), none of the trends are significant. Preliminary indications of survival for the 1998 sea-entry year suggest that it has been above average for all indicators, which would effectively remove any apparent trends in survival. Survivals of hatchery smolts in the north appears to be as dismal as in Strait of Georgia facilities (Holtby et al. 1999c), which is cause for concern even if there is no conclusive evidence of a downward trend.

The severity of the survival reduction observed for the 1996 entry year also differed considerably among the indicators. Modest reductions were observed in the Alaskan index (to 60% of average) and at Lachmach (to 54% of average). A slightly larger decline was observed at Zolzap (to 44% of average). Severe declines were observed at Toboggan (to 14% of average) and the Babine (to 22% of average). Coho escapement was severely reduced in Statistical Areas 6 and 7 but not in Areas 5 or 2E (east coast of the Queen Charlottes). The cause of the 1996 event is unknown but clearly whatever the cause its effects were rapidly attenuated immediately to the north of the Skeena River.

2.2 Exploitation rates

Average exploitation rates (1990 to 1997, where data available, in following Table) ranged from 0.63 on the Toboggan population (excluding terminal sport) to 0.72 on the Babine population. The share of the exploitation rate between Canadian and Alaskan fisheries is dependent on geographical proximity to the border and to fish behavior. For Toboggan, Lachmach and Zolzap coho the Alaskan exploitation rate increases and the Canadian rate decreases in that stream order reflecting proximity to the border. The shift in exploitation rate is, on average, symmetrical, meaning that as the Alaskan rate increases the Canadian rate falls, with the result that the total exploitation rate is nearly the same for all three populations. The exception to the geographical pattern is the Babine. Babine coho are exploited more heavily in Alaskan fisheries than their geographical origin would suggest, which is probably the result of a more northerly ocean distribution. Babine coho are also subject to in-river fisheries, with the result that average exploitation rate is highest for this population.

	average exploitation rates, all years excluding 1998			average proportion of exploitation in Alaskan fisheries
indicator	total	Canadian fisheries	Alaskan fisheries	(excluding 1998)
Toboggan	0.63	0.23	0.39	0.362
Babine	0.72	0.39	0.35	0.536
Lachmach	0.68	0.40	0.29	0.592
Zolzap	0.66	0.51	0.15	0.775

Total exploitation rates in 1998 fell relative to 1997 levels at three of the four indicator sites as a direct result of Canadian management actions, but otherwise, there are no trends in the total exploitation rates (Figure 2). In 1998 the exploitation rate actually increased on the Fort Babine hatchery population. Directed Canadian fisheries were not permitted in 1998 and so all of the very modest exploitation in Canadian fisheries was due to incidental catch or to release mortality. Exploitation in Alaska in 1998 remained at recent levels for the Zolzap, Lachmach and Toboggan indicators but increased for the Fort Babine indicator (Table 3). There were no counting problems at the Babine fence and 71 CWTs were observed in ocean fisheries, so we think it likely that the exploitation rate estimate is correct. It is likely that this anomaly was due to fish distribution, which seems to be more variable for Babine coho than for the other indicators.

Table 1. CWT release and recovery data for the Lachmach River wild coho indicator.

		observed CWTs	estimated CWTs by sector					exploitation rates				survival rate
return year	CWTs released	all ocean fisheries	Canadian commercial	Canadian sport	Alaska	escapement	total	ocean sport	Canadian commercial	Alaska	total	smolt
1988	1169	5	12	0	11	12	35	0.005	0.341	0.313	0.659	0.030
1989	9481	68	98	2	153	153	406	0.005	0.241	0.377	0.623	0.044
1990	17210	418	895	11	833	537	2276	0.005	0.393	0.366	0.764	0.113
1991	24408	635	1166	23	1019	825	3033	0.008	0.384	0.336	0.728	0.121
1992	13186	268	383	12	539	301	1235	0.010	0.310	0.436	0.756	0.088
1993	19921	255	353	20	481	457	1311	0.015	0.269	0.367	0.651	0.061
1994	14055	502	635	53	1192	761	2641	0.020	0.240	0.451	0.712	0.174
1995	6276	102	118	11	247	163	539	0.020	0.219	0.458	0.697	0.082
1996	3629	91	118	8	146	106	378	0.020	0.313	0.387	0.719	0.072
1997	5234	41	4	4	117	98	223	0.020	0.018	0.524	0.561	0.055
1998	7645	108	0	5	333	391	729	0.007	0.000	0.457	0.464	0.096

Table 2. CWT release and recovery data for the Toboggan hatchery coho indicator. The fresh water (FW) exploitation rate can be obtained by subtraction.

		observed CWTs	estimated CWTs by sector						exploitation rates				survival rate
return year	CWTs released	all ocean fisheries	Canadian commercial	Canadian sport	FW	Alaska	escapement & terminal sport	total	ocean sport	Canadian commercial	Alaska	total	smolt
1988	31794	37	87	3	139	41	397	668	0.005	0.130	0.061	0.406	0.021
1989	30354	129	286	4	98	159	278	825	0.005	0.347	0.193	0.663	0.027
1990	31300	213	483	6	136	272	387	1284	0.005	0.376	0.220	0.727	0.041
1991	30954	309	514	14	226	465	642	1861	0.008	0.276	0.254	0.665	0.060
1992	31290	86	144	5	57	157	162	525	0.010	0.274	0.299	0.692	0.017
1993	30926	75	361	13	101	110	287	872	0.015	0.414	0.129	0.687	0.028
1994	32600	323	440	39	226	611	642	1958	0.020	0.225	0.320	0.690	0.060
1995	33533	64	81	12	91	93	323	600	0.020	0.135	0.158	0.470	0.018
1996	33609	195	316	17	43	238	227	841	0.020	0.376	0.287	0.740	0.025
1997	32368	26	19	3	7	55	77	161	0.020	0.120	0.350	0.535	0.005
1998	33255	57	2	4	4	162	440	613	0.007	0.003	0.264	0.282	0.018

Table 3. CWT release and recovery data for the Fort Babine hatchery coho indicator. The fresh water (FW) exploitation rate can be obtained by subtraction.

		observed CWTs	estimated CWTs by sector						exploitation rates				survival rate
return year	CWTs released	all ocean fisheries	Canadian commercial	Canadian sport	FW	Alaska	escapement & terminal sport	total	ocean sport	Canadian commercial	Alaska	total	smolt
1994	30753	270	720	25	31	283	173	1231	0.020	0.585	0.230	0.859	0.040
1995	32934	79	72	7	7	211	44	340	0.020	0.212	0.620	0.871	0.010
1996	29255	168	231	18	34	333	303	919	0.020	0.251	0.362	0.670	0.031
1997	29694	21	27	3	4	56	74	164	0.020	0.163	0.342	0.548	0.006
1998	59891	71	2	3	2	229	156	391	0.007	0.005	0.585	0.601	0.007

Table 4. CWT release and recovery data for the Zolzap wild coho indicator. The fresh water (FW) exploitation rate can be obtained by subtraction.

		observed CWTs	estimated CWTs by sector						exploitation rates				survival rate
return year	CWTs released	all ocean fisheries	Canadian commercial	Canadian sport	FW	Alaska	escapement & terminal sport	total	ocean sport	Canadian commercial	Alaska	total	smolt
1993	33923	138	98	10	0	330	255	693	0.015	0.141	0.476	0.632	0.020
1994	22986	394	382	41	0	1106	524	2053	0.020	0.186	0.539	0.745	0.089
1995	29615	190	85	21	0	612	309	1027	0.020	0.083	0.596	0.699	0.035
1996	10166	130	116	13	0	308	220	657	0.020	0.177	0.469	0.665	0.065
1997	20525	83	32	9	0	217	204	462	0.020	0.069	0.469	0.559	0.023
1998	13566	58	0	3	0	182	212	397	0.007	0.000	0.459	0.466	0.029

Table 5. Estimates of wild smolt production and wild smolt survival for the non-hatchery population at Toboggan Creek.

smolt year	observed number of wild smolts	apparent wild survival	ratio of wild to hatchery survival	estimated number of wild smolts	estimated wild survival
1987				21106	0.08
1988				52961	0.10
1989				56355	0.15
1990				35374	0.23
1991				91950	0.06
1992				33768	0.11
1993				25179	0.23
1994				39990	0.07
1995	38137	0.10	3.8855		
1996	34989	0.02	3.9663		
1997	42429	0.07	3.6110		
1998	66565				

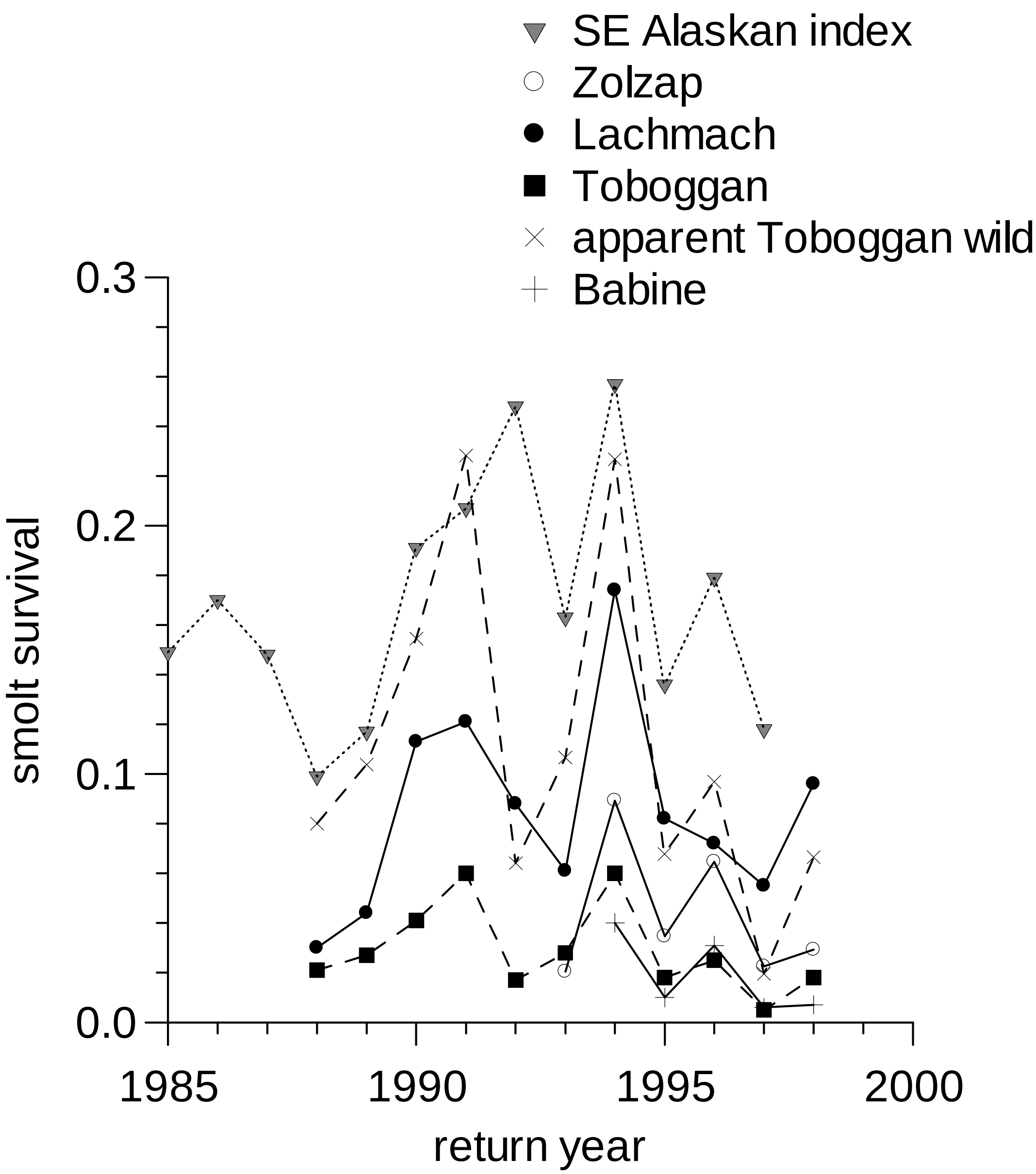

Figure 1. Time series of smolt survivals for the indicator streams and for the SE Alaska survival index.

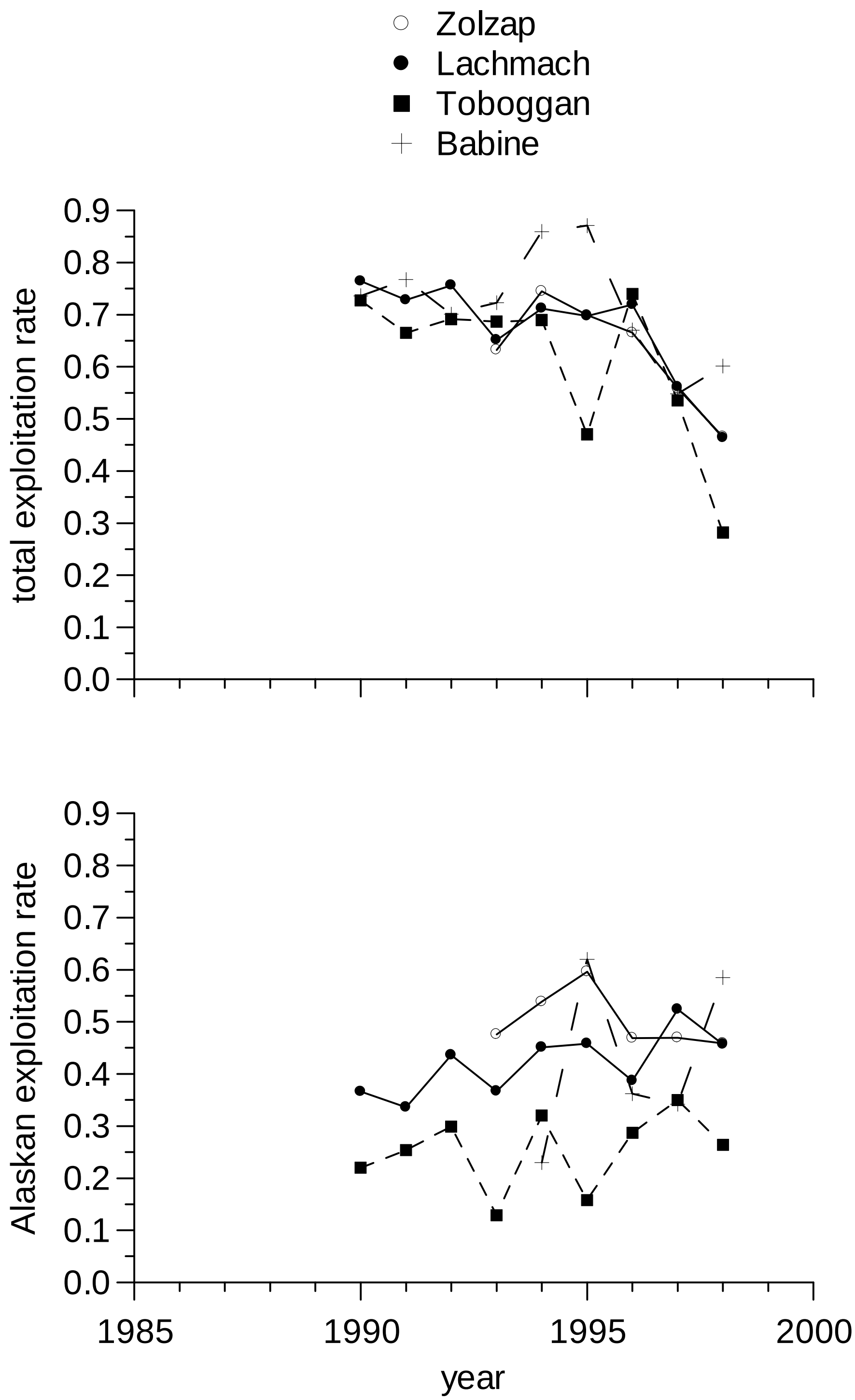

Figure 2. Total exploitation rate and Alaskan exploitation rate on the four coho indicator populations.

3 Indices of abundance

The only indices of abundance available for all areas within the northern boundary area are visual escapement counts. These are presented for Statistical Areas 1 & 2 (Queen Charlotte Islands), 3 (Portland and Nass), 4 (Skeena), 5 (Principe & Grenville) and 6 (Kitimat). In addition to the visual counts there is one fishway count in the Nass River. Within the Skeena there are three fence counts, time series of juvenile densities in late fall, and a test-fishery index.

3.1 Visual escapement counts

Visual escapement estimates by stream and year were obtained from the escapement database maintained in the Prince Rupert office of DFO (pers. comm., B. Spilsted,). For comparative purposes escapement time series for coho streams in Statistical Areas 3 (Nass River; Portland Canal) and Area 6 (Kitimat) were obtained in addition to those in Area 4 (Skeena River and approaches) The data series begin in 1950 and extend to 1998. Escapement estimates have been made in a variety of ways, most of which are not adequately documented. In situations where the method was known to have changed from a visual count to a fence at some point in the record, the fence counts were not included in the series (e.g. Area 4: Toboggan Creek, upper Bulkley River; Area 3: Lachmach River; Zolzap Creek). The Babine fence count was excluded from Area 4 series but independently surveyed Babine tributaries were included. The estimates have no associated measures of uncertainty. In SE Alaska escapement records for a set of index streams begin in 1987. A variety of catch and CPUE indices track escapement to their indicator streams quite well (Shaul 1998). To extend the escapement (abundance) index for SE Alaska back to 1950 we selected the catch per hook in the SE Alaska troll with estimated hatchery contributions removed and standardized it using the procedure described below.

The time series of visual counts in Canadian streams are highly discontinuous, meaning that there are very few complete or nearly complete time series. It is not appropriate to total the escapements within an area and treat the sum as a measure of escapement. To recover information about trends in escapement by Area we first selected streams in which there were at least 10 observations. In years where no numeric estimate was recorded entries were ignored unless 'N/O' or none observed, in which case the estimate was set to zero. Then by stream we divided the escapement in each year where it was recorded by the maximum escapement observed in that stream across all years on record. We then calculated the average proportion by year ($p_{\max}$) by averaging across streams within years. Thus, where $n_i \geq 10$:

$$p_{\max,ij} = E_{ij} \big/ \max E_i \qquad (2)$$

and

$$p_{\max,j} = \sum_i p_{\max,ij} \big/ n_j \qquad (3)$$

where

i : stream;
j : year;
E_{ij} : observed escapement to the i^{th} stream in the j^{th} year;
n_i : number of escapement records for the i^{th} stream;
$p_{max,ij}$: escapement to the i^{th} stream in the j^{th} year as a proportion of the maximum escapement to the i^{th} stream.

An escapement time series for the Area (E_A) was also computed by multiplying p_{max} by the average maximum escapement observed in all streams in the Area:

$$E_{A,j} = p_{\max,j}\overline{E}_{\max} \tag{4}$$

These values were used in the productivity analyses (see Section 4). Sample sizes by Statistical Area and fill-in procedures used to estimate missing data in Area 5 are described in Holtby et al. (1999a).

The escapement indices in all areas but Area 5 increased in 1998 over 1997 values (Table 6; Figure 3). The largest proportional increases were in the upper and lower Skeena (13.9× and 4.4×, respectively) and in Area 6 (4.3×). The increases in the Alaskan CPUE index and in Area 3 were more modest (1.5× and 1.9×, respectively). The magnitude of the increase in the escapement index to the upper Skeena is surprising since it indicates near-average escapement to the area. Only six streams met the criteria for inclusion in 1998,which is inadequate even though only two streams met the criteria in 1997 and but one in 1996. The recorded count in the Telkwa in 1998 was the highest on record. However, counting conditions this year were ideal and an intensive aerial count began sooner than usual because of concerns that significant numbers of fish had been missed in previous counts. The count in the Morrison River (a Babine Lake tributary) was at least partially a fence count and Station Creek (lower tributary of the Bulkley) is partially enhanced. Two other Babine tributaries were enumerated. The $P_{\max}$ in Fulton River was high (0.58) compared to Pinkut River (0.015) and both were quite different from the $P_{\max}$ derived from the fence count (0.19). The remaining stream, Gosnell Creek, an upper tributary of the Morice River, had an index value of 0.08. Such a wide range of index values is unusual but there are insufficient data to correct what we think is an anomaly. Increased escapement enumeration in the upper Skeena is clearly warranted.

There appear to be three distinct temporal patterns in abundance (Figure 3). To explore these patterns we did a Principal Component Analysis on the $P_{\max}$ values in which three components were extracted from the correlation matrix and VARIMAX rotated. The analysis (following Table) confirmed the visual impression of the temporal patterns.

	loading on VARIMAX rotated component			
escapement index	1	2	3	4
SE Alaska	0.029	0.061	–0.952	0.048
Area 3	–0.055	0.937	–0.047	0.005
lower Skeena	0.403	0.758	0.096	–0.061
upper Skeena	0.661	–0.069	0.316	–0.092
WQCI	0.791	0.129	–0.144	–0.004
NQCI	0.054	–0.040	–0.030	0.985
EQCI	0.506	0.209	0.620	0.053
Area 5	0.770	0.254	0.195	0.217
Area 6	0.879	0.068	0.053	0.041
% variance explained	32%	18%	16%	12%

The upper Skeena, Areas 5 and 6 and WQCI (Area 2W) and to a limited extent EQCI (Area 2E) share the same pattern of prolonged depression and all load on the first component. There is no discernable temporal trend in Area 3 and the lower Skeena indices and both load on the second component. The SE Alaskan CPUE index is low in the early 1970's and has shown a prolonged increase since, the opposite pattern to EQCI and both load on the third component in opposite directions. The pattern in NQCI (Area 1) is superficially similar to Area 3 and to SEAK but a low period in the late 1960's give this area a distinctive pattern and it and loads by itself on the fourth component.

Finite rates of change were calculated for all of the indices for the period 1970 to 1996 and are shown in the following Table. Abundance of coho in SE Alaska is clearly trending in the opposite direction to abundance in the upper Skeena, EQCI and Area 6. Trends in the other areas, which are geographically intermediate, are not statistically significant from zero but the direction and magnitude of their trends strongly suggest that there is a geographical pattern in this particular measure of stock status.

				finite rate of change	
area	slope	*r*	*P*†	year	generation ‡
SE Alaska	0.028	0.81	<<0.001	+3%	+9%
Area 3	0.012	0.26	NS	+1%	+4%
lower Skeena	-0.011	0.24	NS	-1%	-4%
upper Skeena	-0.050	0.60	0.001	-5%	-18%
WQCI	0.013	0.17	NS	+1%	+4%
NQCI	-0.017	0.23	NS	-2%	-5%
EQCI	-0.051	0.79	<<0.001	-5%	-16%
Area 5	-0.022	0.32	0.1	-2%	-7%
Area 6	-0.042	0.80	<<0.001	-4%	-15%

† H_0: slope=0

‡ generation time assumed to be 3.3 years

Table 6. The P_{max} escapement index for five Statistical Area aggregates in Canada. The values for SE Alaska are similarly standardized wild catch per hook in the SE Alaska troll fishery.

year	P_{max}					
	SE Alaska	Area 3	lower Skeena	Area 5	Area 6	upper Skeena
1950	0.443	0.094	0.191	0.254	0.223	0.391
1951	0.893	0.172	0.243	0.303	0.458	0.284
1952	0.425	0.104	0.256	0.346	0.362	0.449
1953	0.244	0.089	0.179	0.331	0.298	0.402
1954	0.524	0.129	0.230	0.359	0.353	0.422
1955	0.368	0.270	0.243	0.443	0.267	0.474
1956	0.105	0.136	0.253	0.472	0.458	0.504
1957	0.341	0.129	0.299	0.450	0.428	0.242
1958	0.199	0.255	0.468	0.307	0.222	0.484
1959	0.239	0.181	0.264	0.421	0.185	0.463
1960	0.223	0.200	0.246	0.335	0.214	0.383
1961	0.147	0.389	0.223	0.544	0.217	0.403
1962	0.365	0.233	0.196	0.324	0.319	0.521
1963	0.362	0.489	0.183	0.454	0.387	0.481
1964	0.342	0.438	0.395	0.568	0.270	0.385
1965	0.286	0.649	0.509	0.669	0.445	0.361
1966	0.217	0.585	0.436	0.574	0.244	0.281
1967	0.172	0.398	0.176	0.304	0.196	0.260
1968	0.287	0.544	0.632	0.486	0.362	0.269
1969	0.136	0.259	0.257	0.157	0.136	0.308
1970	0.088	0.388	0.304	0.076	0.155	0.351
1971	0.147	0.457	0.320	0.097	0.194	0.365
1972	0.262	0.257	0.297	0.141	0.232	0.480
1973	0.161	0.223	0.205	0.163	0.129	0.404
1974	0.231	0.193	0.212	0.217	0.148	0.351
1975	0.072	0.218	0.174	0.307	0.196	0.106
1976	0.172	0.233	0.216	0.186	0.166	0.154
1977	0.139	0.247	0.184	0.244	0.127	0.413
1978	0.240	0.265	0.233	0.232	0.128	0.509
1979	0.222	0.130	0.142	0.139	0.159	0.055
1980	0.183	0.148	0.196	0.113	0.104	0.407
1981	0.267	0.244	0.151	0.207	0.113	0.245
1982	0.390	0.207	0.187	0.041	0.131	0.274
1983	0.389	0.280	0.179	0.088	0.086	0.267
1984	0.350	0.390	0.277	0.094	0.122	0.206
1985	0.464	0.478	0.151	0.120	0.130	0.275
1986	0.565	0.333	0.411	0.224	0.149	0.260
1987	0.310	0.335	0.276	0.154	0.100	0.128
1988	0.156	0.180	0.067	0.206	0.070	0.073
1989	0.420	0.286	0.222	0.067	0.083	0.099
1990	0.470	0.413	0.326	0.073	0.121	0.139
1991	0.375	0.239	0.233	0.047	0.082	0.152
1992	0.429	0.347	0.196	0.063	0.087	0.087

year	P_{max}					
	SE Alaska	Area 3	lower Skeena	Area 5	Area 6	upper Skeena
1993	0.630	0.244	0.115	0.058	0.075	0.095
1994	1.000	0.592	0.258	0.187	0.065	0.277
1995	0.461	0.294	0.207	0.138	0.032	0.066
1996	0.762	0.306	0.132	0.126	0.087	0.125
1997	0.340	0.126	0.060	0.333	0.028	0.028
1998	0.518	0.241	0.264	0.205	0.122	0.388

Table 7. Escapement indices for the three Statistical Areas on the Queen Charlotte Islands. The p_{max} values can be converted to average-stream escapements with the following average maximum escapements: Area 1, 14,433; Area 2W, 5376; and Area 2E, 3407.

	Area 1 – QCI north		Area 2W – QCI west		Area 2E – QCI east	
year	records	p_{max}	records	p_{max}	records	p_{max}
1950	8	0.350	40	0.159	32	0.112
1951	9	0.318	40	0.287	31	0.278
1952	7	0.190	50	0.375	43	0.405
1953	4	0.187	39	0.183	35	0.183
1954	7	0.352	39	0.262	32	0.242
1955	5	0.204	26	0.162	21	0.152
1956	6	0.121	30	0.186	24	0.202
1957	8	0.241	35	0.246	27	0.247
1958	7	0.146	33	0.237	26	0.261
1959	10	0.326	37	0.320	27	0.317
1960	13	0.127	43	0.231	30	0.276
1961	12	0.326	37	0.355	25	0.369
1962	11	0.429	42	0.383	31	0.367
1963	10	0.114	36	0.286	26	0.353
1964	13	0.458	48	0.444	35	0.439
1965	13	0.574	38	0.361	25	0.250
1966	10	0.151	50	0.501	40	0.588
1967	13	0.174	57	0.315	44	0.357
1968	11	0.135	53	0.217	42	0.239
1969	8	0.072	53	0.441	45	0.507
1970	13	0.266	40	0.432	27	0.511
1971	15	0.072	28	0.130	13	0.198
1972	15	0.235	31	0.283	16	0.328
1973	15	0.245	35	0.311	20	0.360
1974	15	0.517	31	0.309	16	0.115
1975	15	0.376	62	0.377	47	0.377
1976	15	0.656	57	0.405	42	0.316
1977	15	0.338	60	0.285	45	0.267
1978	15	0.436	57	0.310	42	0.265
1979	15	0.324	54	0.219	39	0.178
1980	13	0.126	49	0.135	36	0.138

	Area 1 – QCI north		Area 2W – QCI west		Area 2E – QCI east	
year	records	p_{max}	records	p_{max}	records	p_{max}
1981	15	0.171	62	0.152	47	0.145
1982	15	0.290	65	0.148	50	0.106
1983	14	0.242	70	0.153	56	0.131
1984	15	0.274	60	0.159	45	0.121
1985	15	0.221	51	0.150	36	0.121
1986	15	0.285	67	0.196	52	0.170
1987	15	0.293	75	0.171	60	0.140
1988	15	0.179	71	0.174	56	0.173
1989	11	0.137	69	0.146	58	0.148
1990	6	0.139	60	0.122	54	0.121
1991	7	0.151	63	0.127	56	0.124
1992	6	0.128	57	0.111	51	0.109
1993	2	0.411	58	0.117	56	0.107
1994	0	–	33	0.056	33	0.056
1995	0	–	37	0.108	37	0.108
1996	0	–	37	0.087	37	0.087
1997	0	–	34	0.099	34	0.099
1998	12	0.247	58	0.210	46	0.200

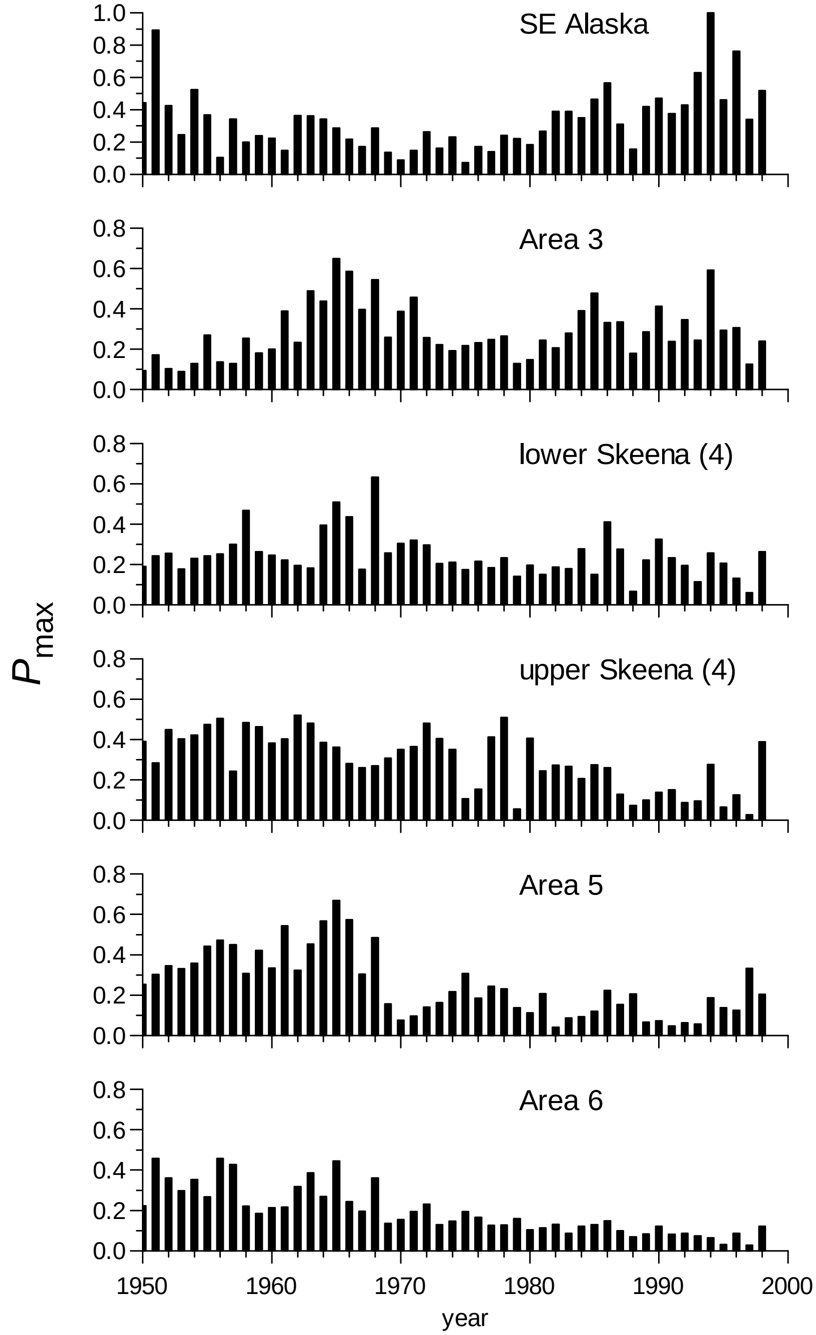

Figure 3. Time series of standardized average escapements to Canadian streams grouped by Statistical Area as indicated. For SE Alaska the standardized catch per hook of wild coho in the SE troll is plotted.

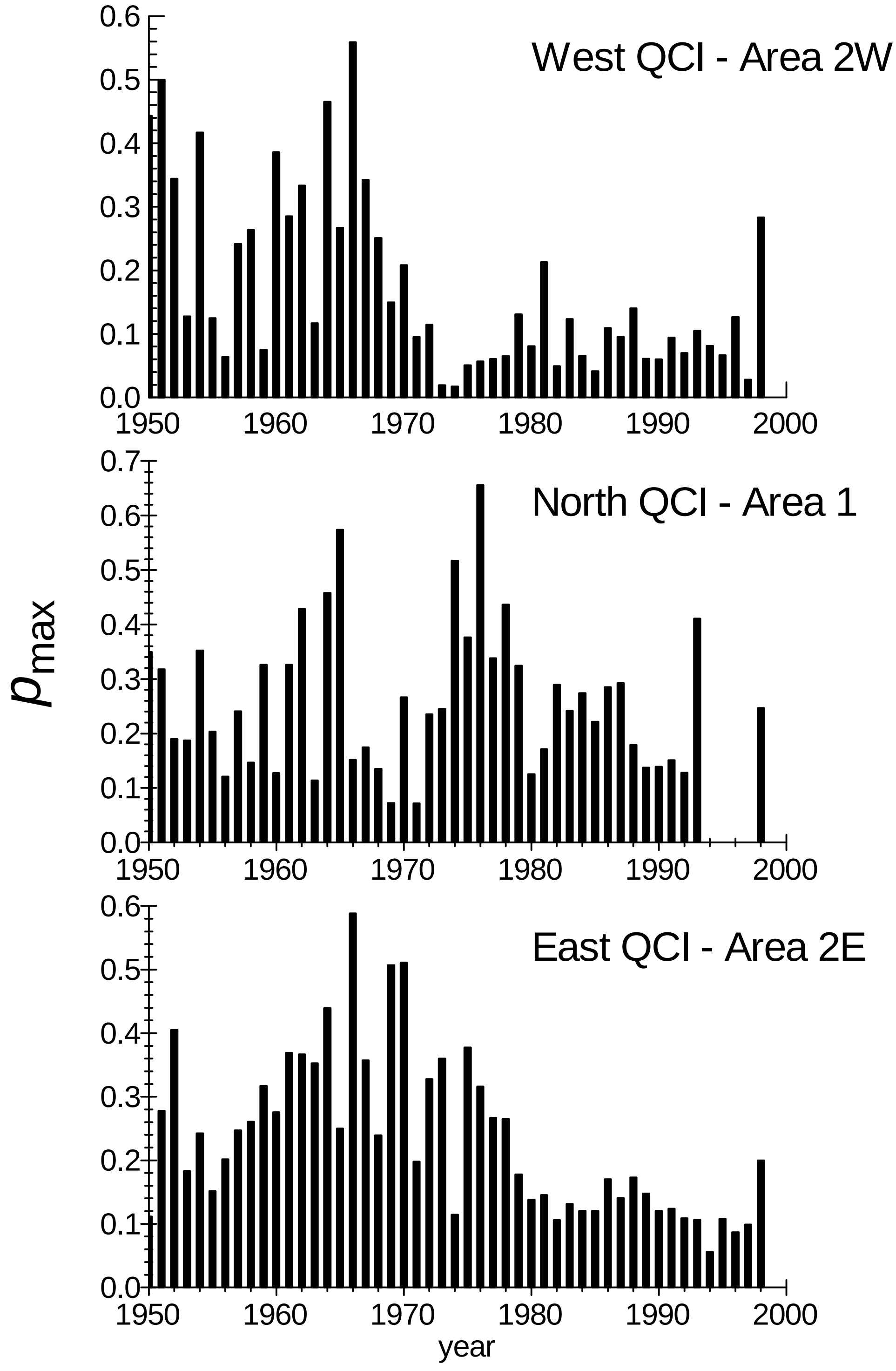

Figure 4. Standarized escapement indices for the three coho aggregates of the Queen Charlotte Islands. There is insufficient data to enable reconstructions of total abundance.

3.2 Juveniles – indices of 1997 escapement and status indicators

The methods used to determine juvenile densities and various aspects of the history of this program have been described extensively elsewhere (Holtby and Kadowaki 1996; Kadowaki et al. 1996; Holtby and Finnegan 1997; Simpson et al. 1997). Data for the Skeena in 1998 were obtained from Taylor (1998), Williamson (1998) and from unpublished summaries (B. Finnegan, DFO, Nanaimo, pers. comm.).

The marked differences in juvenile densities seen in previous years between the seven Skeena areas have persisted (Table 8; Figure 5). In the 1998 surveys the highest juvenile densities were found in the Lachmach River and in the coastal Skeena tributaries. Densities were intermediate in the streams around Terrace, in the Kispiox and in the main-stem Bulkley/Morice. Densities were lowest in streams of the high interior, in Babine tributaries and in the upper Bulkley River (above Houston). No juvenile coho were found in the upper Bulkley (Figure 5). Juvenile densities in the low-flow period at the end of summer of between 0.75 and 2 fish/m^2 generally indicate fully seeded streams. The juvenile densities observed in the upper Skeena, which have averaged less than 0.25 fish/m^2 are consistent with the sparse and often-qualitative escapement indices from these areas.

Juvenile densities in five of eight areas fell in 1998 compared to 1997. Aside from the upper Bulkley, which had no juveniles, the largest decrease was seen in the upper Skeena (0.12×). Decreases in the Kispiox, Terrace and Bulkley/Morice areas ranged from 0.59× to 0.68×. Juvenile densities in the remaining three areas increased in 1998 relative to 1997. The increases were largest in the Lachmach (1.7×) and the coastal Skeena streams (1.8×). Surprisingly and inexplicably, coho densities increased in the Babine by a factor of 1.29×. Despite this anomaly densities in the Babine remain low, although not as low as they were in the high interior or in the upper Bulkley.

Escapement and juvenile densities in the following fall would be strongly correlated only if egg to juvenile mortality is invariant. If it weren't then juvenile densities would not be a particularly useful index of escapement. Of course, if FW survival was highly variable and often poor one might also conclude that escapement is not a particularly useful index of status. To examine temporal patterns in juvenile densities and escapement we did a Principal Component Analysis on the juvenile densities over the period 1994 to 1998 combined with six indices of escapement over the period 1993 to 1997 (Table 9). Derivation of the upper and lower Skeena average escapement indices can be found in Holtby et al. 1999a. Four components were extracted from the correlation matrix and VARIMAX rotated.

Four temporal patterns were identified. The first accounted for 46% of the explained variance after rotation and involved all of the escapement indices and to some extent all of the juvenile indices except in the high interior (Table 9). This association reflects the widespread effects of low escapement in 1997. The increased juvenile densities seen in coastal streams and in the Babine in 1998 are reflected by their negative loadings on the first component. The second component, which accounts for 29% of the explained variance after rotation identifies the association between four of the remaining six juvenile indices. The remaining two juvenile indices (the High Interior and the Babine) dominate the third and fourth component respectively (Table 9).

There are several reasons why escapement and subsequent juvenile density indices might be poorly related. First, the escapement indices might be poor indices of adult numbers. This explanation is plausible where the index is based on visual counts in a set of streams which is changing from year to year and where the methods are poorly standardized. Even where there are fence counts, there are always suspicions that some coho arrive before or after the fence operation. However, all of the escapement indices have high loadings with the same sign on the first component, which indicates that escapements were varying together over the entire basin. We think it unlikely that the visual indices, the test-fishery and three fence counts would be consistently biased.

Second, there are several reasons why the juvenile density measures could be misleading. Extended periods of poor weather can play havoc with juvenile censuses. Wet summers can make counting juveniles in large streams very difficult especially in streams with moderate gradients draining higher elevations. The summer of 1995 was very wet with numerous fall storms, which might account for the relatively low densities recorded in many areas that year. Although the index sites are often more than 30 m in length and always include multiple habitat features it is possible that many more sites than the 7 to 18 per area that we have available are required to adequately index juvenile abundance. Most of the sites were chosen because of easy access with some consideration about the feasibility of enumeration. The best coho habitat in most of these streams is either pond or lake margin or deep pools in larger streams–habitats that are not easily enumerated within a single day. Consequently, most of the sites in our surveys would not be considered the best habitat available[4]. Furthermore the constraints of access and sampling have acted to make the site characteristics uniform across the entire basin. Aside from the logistics and statistical characteristics of the sampling there is no compelling reason to expect other than a weak relationship between egg numbers and juvenile numbers a year afterward. Egg-to-fry survival can be highly variable (Scrivener and Brownlee 1989) and FW population processes in coho tend to damp variation in smolt production and subsequent escapement (e.g. Scrivener and Andersen 1984). Juvenile coho can be highly mobile within large FW systems. Juvenile coho might migrate into or out of the index sites before the end-of-summer sampling period. The few studies that have been done on coho movements in systems subjected to continental winters do indicate that a lot of seasonal movement does occur (Cederholm and Scarlett 1981; Swales et al. 1986; Swales and Levings 1989; Radtke et al. 1996). Many of the movements documented are autumnal shifts from mainstem habitats to ponds, which often have warmer winter temperatures (Swales and Levings 1989). Spring or summer movements might be a particular problem in the Babine where most of the coho rearing is thought to occur in Nilkitkwa and Morrison Lakes (Bustard 1990). Habitat use and seasonal migration patterns should be more thoroughly investigated in these interior systems.

The observed changes in coho densities may be distributional shifts resulting from displacement by chinook. Since the signing of the Pacific Salmon Treaty exploitation rates on chinook have fallen and escapements have generally increased (Figure 6). Chinook juveniles are found in many of the sites sampled for coho. A behavioral interaction between the species, which resulted in the displacement of coho from the best habitat, could result in low apparent juvenile densities if we were not sampling in marginal habitats. To examine this possibility we examined the relationship between coho and chinook densities in sites where they occurred together. If an interaction was occurring of sufficient magnitude to bias our measured densities we would expect to see a negative relationship between coho and chinook densities.

In the 48 samples in the upper Skeena where either coho, chinook or both species were found we found the following association:

Where the two species co-occurred their densities were positively related (Figure 7), although not significantly so (P~0.15). The habitats that are sampled are those where experienced field biologists would expect to find coho. Extensive searches in areas such as the upper Sustut River (pers. comm. D. Atagi, BCMELP, Smithers, BC), the Kluatantan and the Onerka Rivers (unpubl.

[4] The sites in the Lachmach are exceptions to this generality. The L3300, L3800 and L5000 sites are all in pond or pond-like areas of a type not sampled anywhere else in the Skeena basin. However, the other sites are not exceptional.

data B. Finnegan, CDFO, Nanaimo) have revealed no coho in marginal habitats. Coho and chinook seem to cohabit the Morice River side-channels but studies of micro-habitat use suggest that consistent differences between the species allow co-existence (Lister and Genoe 1970; Murphy et al. 1989; Shirvell 1994). Regardless, if there have been extensive interactions between coho and chinook that have resulted in the displacement of coho from their preferred habitats, then the consequence would have been to lower the productivity of the coho populations and in consequence their ability to sustain harvest.

species	number of samples
coho & chinook:	23
coho only:	22
chinook only:	3

Table 8. Juvenile coho densities in Skeena Basin streams and the Lachmach River measured in the fall of 1998. The streams are grouped into the same areas graphed in Figure 5.

region	system	density (n/m^2)
high interior		
	Johanson Creek #1	0
	Johanson Creek #2	0
	Kluatantan River	2.4E-02
	Moosevale Creek	0
	Motase SC	2.8E-01
	Salix Creek	3.0E-02
	Sicintine River	1.4E-01
	Sustut River	0
	Sustut River @ lake	0
Babine		
	Boucher Creek (upper)	8.0E-02
	Lamprey Creek	5.0E-01
	Morrison River	7.0E-02
	Nichyeskwa River	4.0E-02
	Nine Mile Creek #1	2.9E-01
	Nine Mile Creek #2	6.0E-02
	Tachek Creek #1	3.9E-01
	Tachek Creek #2	2.7E-01
upper Bulkley		
	Ailport Creek	0
	Buck Creek	0
	Bulkley River @ Byman	0
	Bulkley River @ Houston Fence	1.0E-03
	Bulkley River @ McQuarrie	0
	Byman Creek #1, #2	0
Bulkley/Morice		
	Elliot Creek (lower)	7.4E-01
	Elliot Creek (upper)	5.0E-02
	Gosnell Creek	5.5E-01
	McBride Creek (lower #1)	3.0E-02
	Morice SC @km 44.5	5.0E-01
	Morice SC @km33	2.1E-02
	Morice SC @km38.5	8.5E-01
	Owen Creek (lower)	1.5E-01
	Owen Creek (upper)	3.7E-01
	Shea Creek (lower)	2.2E-01
	Shea Creek (upper)	2.5E-01
	Toboggan Creek	2.1E-01
	Toboggan Creek (lower)	5.4E-01
	Toboggan Creek tributary	7.0E-02
Kispiox		

region	system	density (n/m^2)
	Clifford Creek #1	1.0E-02
	Clifford Creek #2	1.6E-01
	Cullon Creek #1	4.6E-01
	Cullon Creek #2	2.2E+00
	Cullon Creek #3	1.3E-01
	Kispiox River SC	1.5E-01
	Moonlit Creek	2.0E-01
	Nangeese Creek	3.9E-01
Terrace		
	Clear Creek	2.8E-01
	Clearwater Creek	2.0E-02
	Coldwater Creek #3	1.6E-01
	Coldwater Creek (lower)	8.9E-01
	Coldwater Creek (upper)	1.4E+00
	Copper River #1	8.7E-01
	Copper River #2	7.2E-01
	Deep Creek #1	2.4E-01
	Deep Creek #2	2.3E-01
	Hadenschild Creek	3.7E-01
	Hankin Creek (lower)	0
	Hankin Creek (middle)	0
	Kitwanga Creek	1.7E-01
	Schulbuckhand Creek	5.3E-01
	Singlehurst Creek #1	1.8E-01
	Singlehurst Creek #2	1.7E-01
	Sockeye Creek (lower)	1.2E+00
	Sockeye Creek (upper)	7.7E-01
coastal		
	Ecstall River	2.0E+00
	Ecstall River tributary #1	2.2E-01
	Ecstall River tributary #2	3.5E-01
	Green River (lower)	3.3E-01
	Green River (upper)	8.8E-01
	Hayes Creek	2.3E+00
	Kideen Creek	3.0E-02
Lachmach		
	L0500	6.1E-01
	L2000	1.7E+00
	L2600	7.7E-01
	L3390	3.0E-01
	L3820	4.6E+00
	L4500	1.7E+00
	L5000	8.0E-02
	L6300	1.5E+00
	L7000	1.2E+00

Table 9. Results of a Principal Components Analysis of the juvenile density and escapement indices and measures for the Skeena Basin. Escapement data are for 1993 to 1997 while the juvenile data are for the period 1994 to 1998. A VARIMAX rotation has been applied. The shading of factor scores highlights variables with more than 50% of their variance explained on a particular rotated component.

	factor loadings after VARIMAX rotation			
variable	1	2	3	4
Upper Skeena average escapement	0.971	–0.010	0.225	–0.084
Babine escapement	0.934	0.215	0.116	0.261
Toboggan escapement	0.810	0.558	–0.048	0.171
Tyee test-fishery Aug. 25	0.766	0.386	0.369	0.357
Lower Skeena average escapement	0.751	0.614	0.228	0.081
Lachmach escapement	0.745	0.163	0.628	0.155
JUV: Lachmach	–0.222	0.846	0.466	–0.135
JUV: Coastal	–0.714	–0.494	–0.428	–0.253
JUV: Terrace	0.956	0.141	0.190	–0.172
JUV: Kispiox	0.558	0.796	0.235	–0.013
JUV: Bulkley/Morice	0.236	0.955	0.031	0.177
JUV: upper Bulkley	0.603	0.719	0.335	–0.081
JUV: Babine	–0.350	–0.326	–0.875	0.080
JUV: high interior	0.050	0.017	–0.027	0.998
Percent of Total Variance Explained	46%	29%	14%	10%

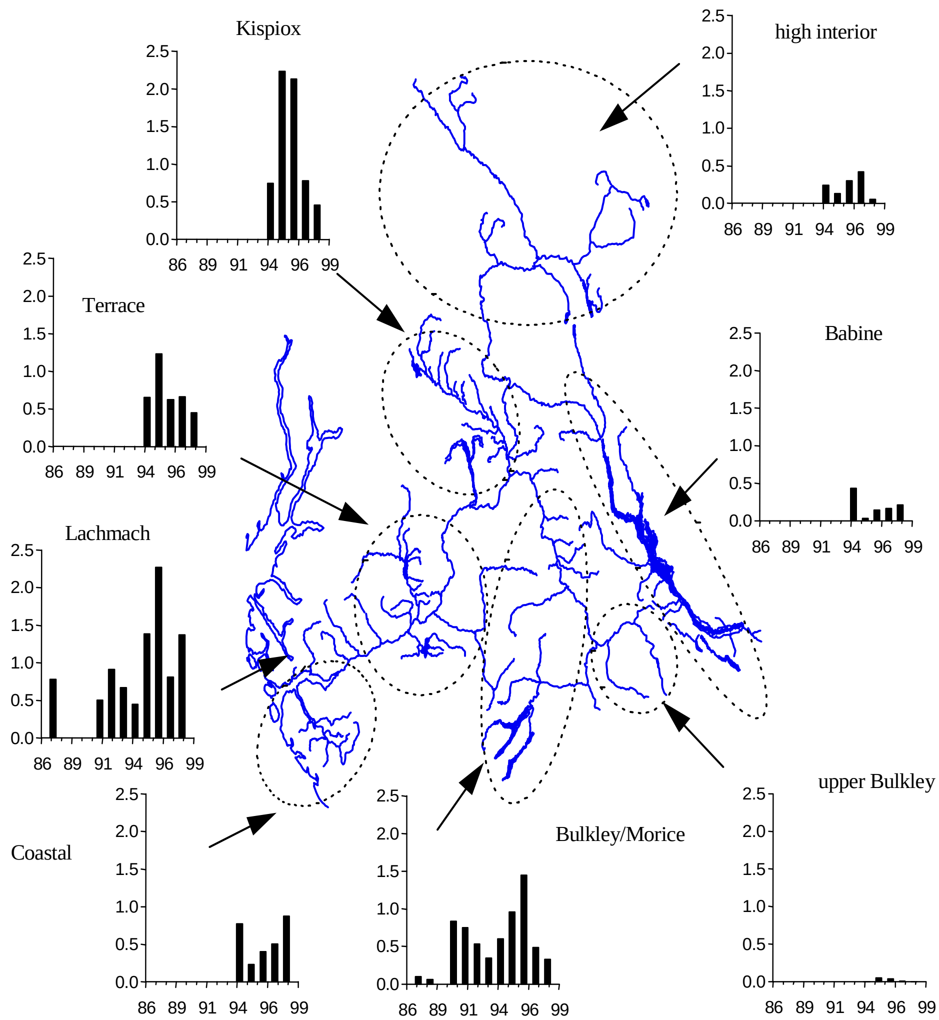

Figure 5. Time series of juvenile coho densities in late summer within the geographic assessments units of the Skeena basin including the Lachmach River. The bars in all graphs show number of juvenile coho per m^2.

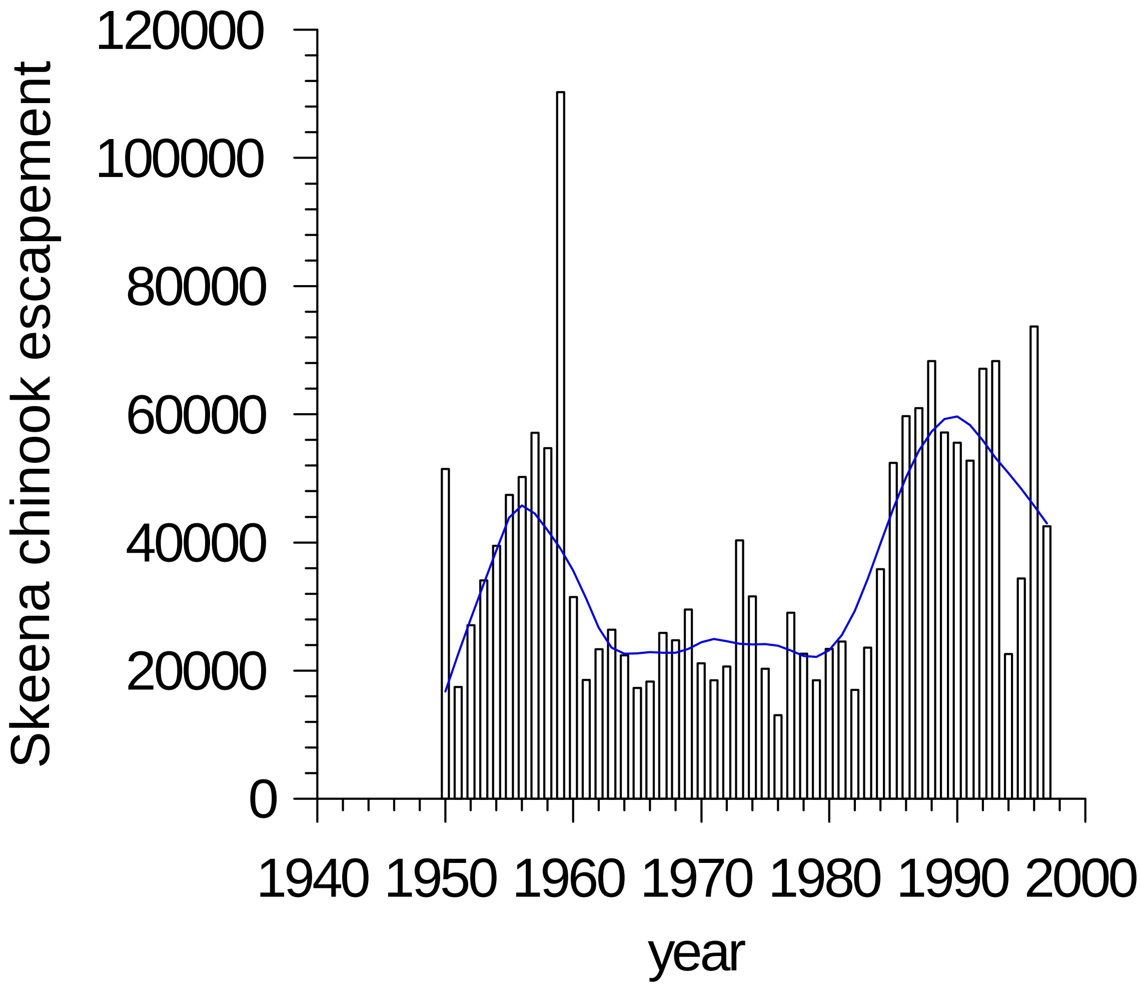

Figure 6. Total chinook escapement to the Skeena River (Area 4) from 1950 to 1997. The line is a LOWESS smooth. Chinook densities increased dramatically after the signing of the Pacific Salmon Treaty.

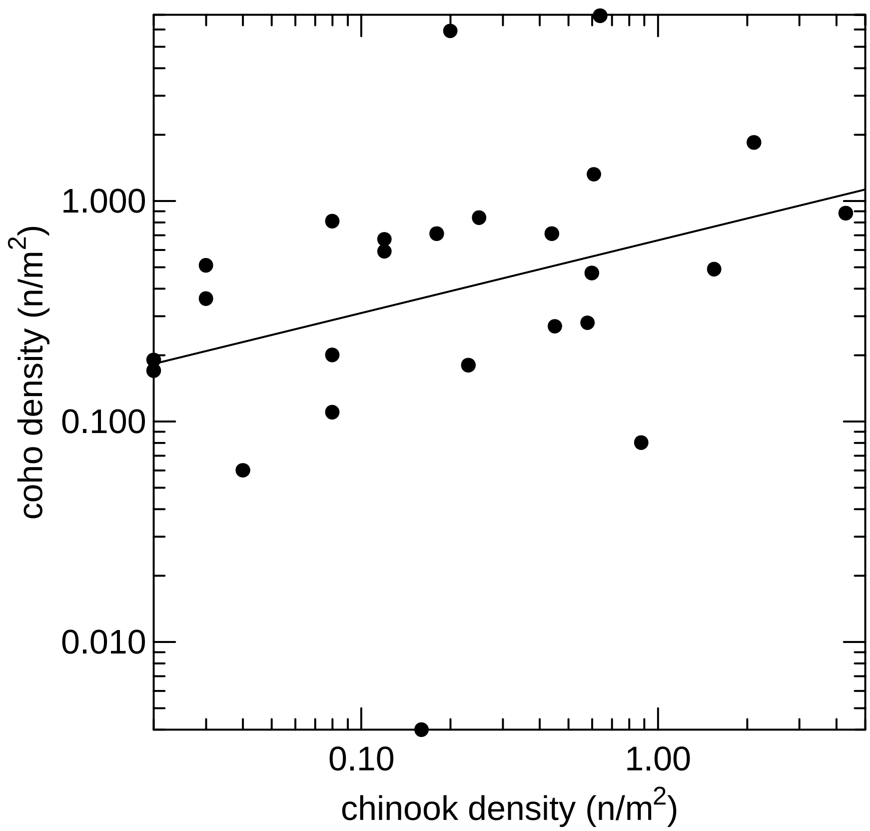

Figure 7. Relationships between the densities of juvenile coho and chinook salmon in the sites where they were found to co-occur in the Skeena Basin.

3.3 Tyee (Skeena) Test Fishery

The Tyee test fishery is described in detail by Kadowaki (1988) and by Cox-Rogers and Jantz (1993). The Tyee test-fishery is primarily intended for in-season management of the Skeena sockeye fisheries but because coho, chinook, steelhead and pink are also caught it has been routinely used as an abundance index for all salmon species in Area 4. The number of all species captured in the Tyee test-fishery has been recorded daily for the period July 1st to August 25th since 1956. The unadjusted test-fishery index is the cumulative catch per 1000 fathom·minutes from mid-June to a fixed termination date, which has typically been August 25th, the earliest date of fishery closure. The 'adjusted' test-fishery index has been 'corrected' for annual variations in sockeye catchability. The test-fishery has operated in the same place with the same gear since 1956. Test-fishery data were obtained from a database maintained by Fisheries Management staff in the DFO Prince Rupert office (pers. comm. L. Jantz).

The test-fishery index is simply the cumulative daily capture between these two dates. Assuming that a constant proportion of the run is caught, the catchability of sockeye (q_{so}) is determined with the expression:

$$q_{so} = T_{so} / E_{so} \qquad (5)$$

where:

T_{so} : sockeye test fishery index, and

E_{so} : estimated sockeye escapement indexed by the test fishery.

Escapements can be estimated using eqn. (5) given values of catchability and the test-fishery index. The escapement of the coho population aggregate indexed by the test fishery is not known with any precision. The summed visual escapement estimates for populations upstream of Terrace in the 1960's and 1970's suggested that a value of 1/543 was reasonable. However, provided that catchability remains constant over time, the value used is largely irrelevant to the use of the test-fishery as an index.

However, the value of q_{so} has been decreasing since the mid-1970's (Figure 8) and it is reasonable to assume that the catchability of coho has been changing as well, although the reasons for the change in q_{so} are unknown. A radio-tagging study in the Skeena in 1994 provided an estimated escapement to the Skeena above Terrace of 3.81×10^4. The test-fishery index in 1994 was 37.17. Applying eq. 2 gives a value for coho catchability in 1994 $\left(q_{co,1994}\right)$ of 0.000977. Sockeye catchability in the same year was 0.000621. Coho catchability adjusted for the changing efficiency of the test-fishery can then be expressed as:

$$q'_{co} = q_{so} q_{co,1994} / q_{so,1994} \qquad (6)$$

and an adjusted test-fishery index can be calculated with:

$$T'_{co} = q_{so,1994} T_{co} / q_{so} \qquad (7)$$

In many years the test-fishery was run beyond August 25th. The utility of running the test-fishery beyond the end of August has not been demonstrated. Without definitive stock composition estimates from the test fishery we can't determine what proportion of the coho captured in the test-fishery are bound for the upper Skeena. However, based on the 1994 radio-tagging study and run timing at Lachmach (Lane et al. 1994a) we currently think that middle and coastal Skeena coho are beginning to show by the middle of August and dominate the run by the second week of

September. In years when pink abundance was low the test-fishers reported that seal predation on caught fish led to an under-estimate of abundance. For this report the index was extrapolated to September 4th in a fashion similar to that used to extrapolate the Babine fence counts.

In 16 years the test-fishery was run until at least September 4th. For each of those years, for every day past August 25th the cumulative test-fishery index was divided by the total for that year to September 4th. Then for every day past August 25th the average proportion of the total run across the 16 base-years was calculated. For the years when the test-fishery stopped before September 4th the index value to that date was estimated by dividing the index on the last day observed by the average proportion of the total index to that date calculated with the base years. The index was also tabulated for August 10th, which is roughly the average date of the peak when bimodality is evident in the daily index values.

Because of the temporal pattern of the catchability correction, its application to the coho index values has a marked effect on the temporal pattern of the index (compare Figure 11 with Figure 12). Although there is considerable variability in each, the unadjusted index values decrease with a “saw-tooth” pattern since the mid-1960’s (Figure 11). In contrast, the adjusted test-fishery index decreases abruptly in 1972 and remains relatively constant between that year and 1996 (Figure 12).

We don’t understand why the sockeye catchability varies and so can’t definitively determine which index is best. One recent suggestion is that sockeye catchability is varying directly with average sockeye size. The sockeye catchability coefficient (q_{so}) is positively correlated with average sockeye length in the test-fishery over the period 1969 to 1998 (adj. $r^2 = 0.18$, $P<0.02$, $N = 29$; Figure 10). Coho are larger than sockeye so their catchability may not have varied over time. However, q_{so} is more strongly correlated with sockeye escapement to the Babine (adj. $r^2 = 0.44$, $P<<0.001$, $N = 29$), suggesting that catchability was affected by the magnitude of the run. However, if coho catchability is varying then it is difficult to explain why the Babine fence index and total escapement are so much better correlated with the unadjusted test-fishery index when the period 1970 to 1998 is considered (Table 11). If the starting year of the period is varied from 1956 to 1992 then the unadjusted index is better correlated with the total Babine fence count overall and in all periods beginning prior to 1978. Thereafter the correlation between the indices and the Babine escapement are nearly the same except for four periods that began in 1981 to 1984 (Figure 13). Since the Babine Lake aggregate is presumed to be a major component of the larger upper Skeena aggregate indexed by the test-fishery index the use of the unadjusted test-fishery index is the most suitable choice.

Index values in 1998 were considerably higher than in 1997 (Table 10; Figure 11; Figure 12). The value of the (preferred) unadjusted index was about the 29th percentile (Figure 14), which was significantly lower than the median value of the index. In contrast the value of the adjusted index was approximately the 45th percentile. The difference in the two percentiles is a direct result of the correction in depressing index values during the 1970’s. The index date has considerable effect on the index as a measure of relative status. In 1998 the index value on August 10th was approximately the 18th percentile while on September 4th the index value stood at approximately the 40th percentile (Figure 15).

A log-linear plot of the unadjusted test-fishery index to September 4th vs. year is linear between the mid-1960’s and the end of the time-series (Figure 16). The slope of the line fitted to the period 1965 to 1996 is –0.051. This corresponds to a finite rate of decrease of 0.0497 $\left(1-e^{-0.051}\right)$. With an average age of 3.3 years the generational rate of decrease is 15.5% and the decrease over three generations of 39.6%. These are similar rates to those observed for Babine escapement and total stock size and for the upper Skeena average escapement.

Table 10. Cumulative Tyee test fishing index to three termination dates. CDFO uses the index to August 25th. See the text for details on adjustments made to the index values for varying sockeye catchability.

	Cumulative index values				Cumulative index values adjusted for sockeye catchability (q_{so})		
year	August 10th	August 25th	Sept. 4th	q_{so}	August 10th	August 25th	Sept. 4th
1956	46.0	91.4	127.3	0.002148	13.3	26.4	36.8
1957	48.7	97.1	115.1	0.001517	19.9	39.8	47.2
1958	90.5	156.0	208.3	0.001348	41.7	71.9	96.0
1959	58.5	76.2	90.9	0.001359	26.8	34.8	41.6
1960	44.6	71.5	77.5	0.001484	18.7	29.9	32.4
1961	35.1	56.2	92.9	0.001214	18.0	28.7	47.5
1962	55.1	119.3	131.4	0.001318	25.9	56.2	62.0
1963	64.0	90.2	102.4	0.001326	30.0	42.3	48.0
1964	55.0	119.6	144.7	0.001372	24.9	54.1	65.5
1965	123.1	175.5	272.3	0.001109	68.9	98.3	152.5
1966	127.2	168.5	182.3	0.002081	38.0	50.3	54.4
1967	83.0	163.3	208.8	0.001714	30.1	59.2	75.7
1968	41.6	77.4	112.3	0.001536	16.8	31.3	45.4
1969	37.8	146.5	185.6	0.001574	14.9	57.8	73.3
1970	63.5	136.9	159.1	0.001427	27.7	59.6	69.3
1971	78.4	168.3	191.1	0.001417	34.4	73.8	83.8
1972	36.0	75.9	95.6	0.001533	14.6	30.8	38.8
1973	39.4	91.4	121.0	0.002077	11.8	27.3	36.2
1974	18.7	47.7	68.6	0.001984	5.9	14.9	21.5
1975	43.8	63.5	88.6	0.001684	16.2	23.4	32.7
1976	15.1	68.0	78.2	0.001721	5.4	24.6	28.2
1977	25.1	103.5	134.5	0.001553	10.0	41.4	53.8
1978	44.6	111.6	149.8	0.00207	13.4	33.5	45.0
1979	15.5	28.2	37.2	0.001362	7.1	12.8	17.0
1980	39.3	73.5	103.0	0.002259	10.8	20.2	28.3
1981	40.0	57.8	79.0	0.001184	21.0	30.3	41.4
1982	38.2	63.6	86.2	0.001475	16.1	26.8	36.3
1983	36.4	64.3	87.2	0.001252	18.1	31.9	43.3
1984	35.1	74.8	103.4	0.001089	20.0	42.7	59.0
1985	19.9	48.1	57.6	0.001106	11.2	27.0	32.4
1986	25.5	52.5	56.8	0.001313	12.1	24.8	26.9
1987	20.0	30.6	59.8	0.000781	15.9	24.4	47.6
1988	12.6	23.7	36.1	0.00108	7.3	13.7	20.9
1989	31.3	81.3	109.0	0.000997	19.5	50.7	67.9
1990	39.9	77.8	104.1	0.000994	24.9	48.6	65.1
1991	22.2	59.4	92.3	0.000903	15.3	40.9	63.5
1992	8.7	12.1	24.4	0.000632	8.6	11.9	23.9
1993	6.8	14.2	20.1	0.000665	6.4	13.3	18.7
1994	14.8	37.2	51.9	0.00061	15.1	37.9	52.9
1995	12.1	27.9	42.6	0.000898	8.4	19.3	29.4
1996	12.5	27.4	39.4	0.000792	9.8	21.5	30.9
1997	3.1	5.2	5.2	0.000941	2.0	3.4	3.4
1998	15.9	52.3	85.2	0.00193	8.9	29.1	47.5

Table 11. Correlation between estimated Babine escapement and raw and adjusted test fishing indices for the period 1970 to 1998. *P < 0.05; ** P < 0.01; *** P < 0.001. Number of observations = 28.

Test fishery index	Escapement to Sept. 13th	Estimated total escapement
August 15th	0.641***	0.537**
August 15th (adj.)	0.348	0.266
August 25th	0.788***	0.715***
August 25th (adj.)	0.492**	0.449*
September 4th	0.798***	0.729***
September 4th (adj.)	0.410*	0.381*

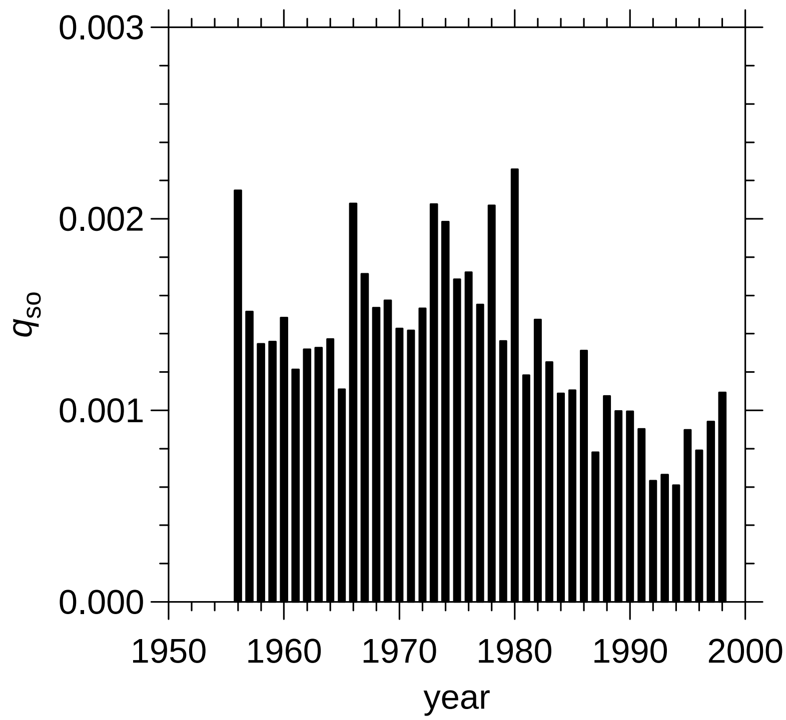

Figure 8. Time series of sockeye catchability (qso) with a LOWESS smooth trend line.

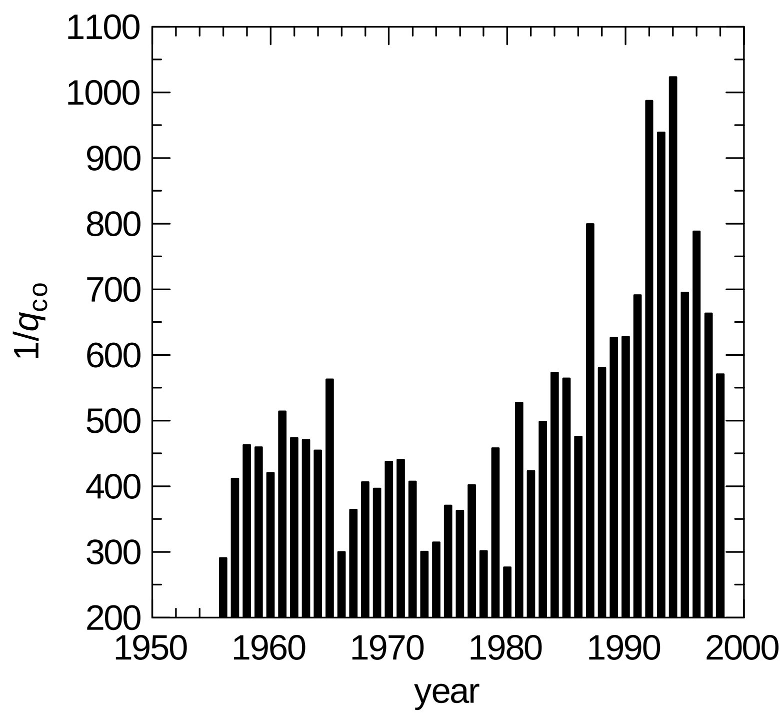

Figure 9. Time series of $1/q_{co}$.

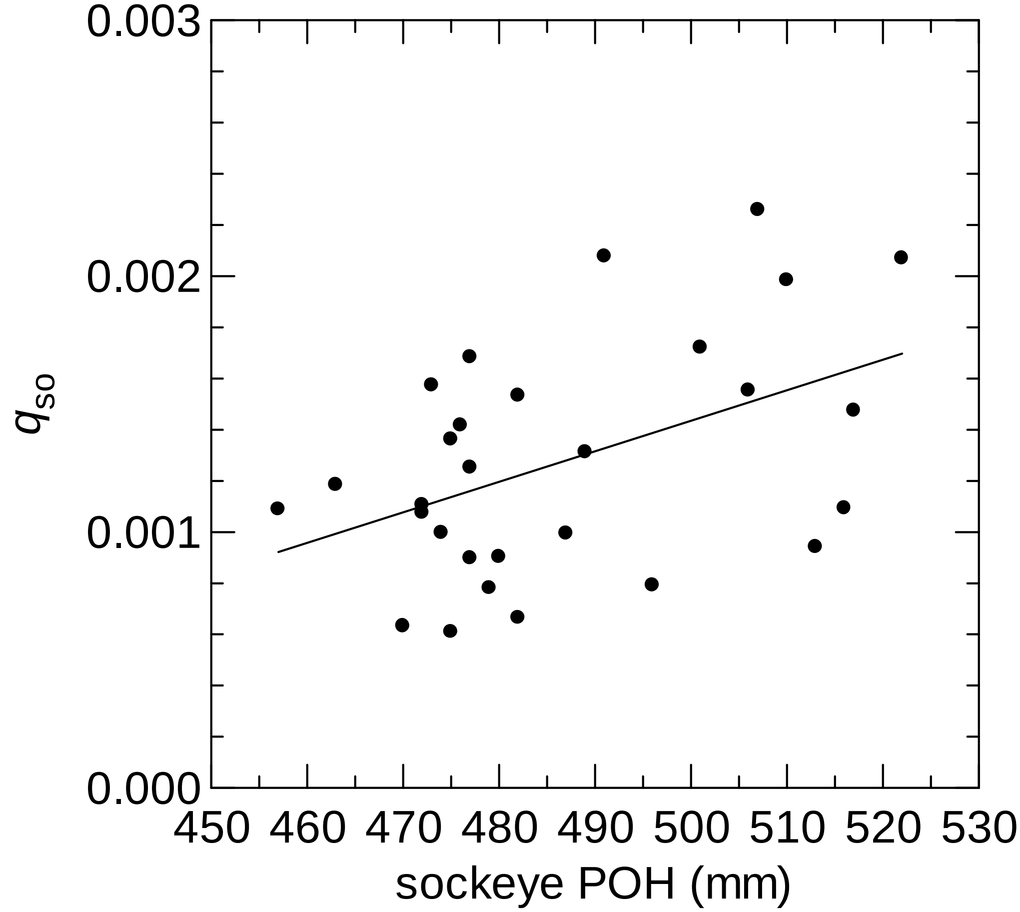

Figure 10. Linear relationship of estimated coho catchability coefficient for Tyee test-fishery and sockeye post-orbital hypural (POH) length in the test-fishery.

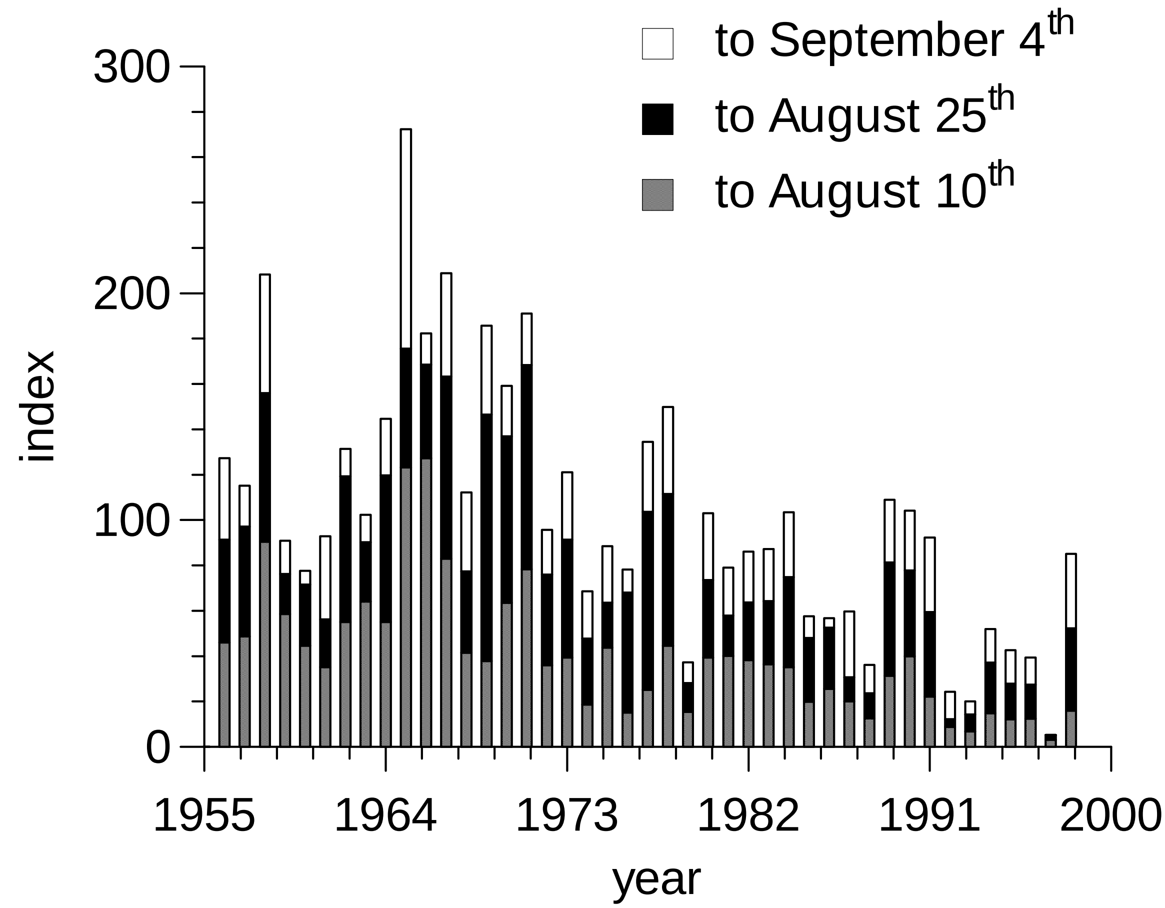

Figure 11. Tyee test fishing index summed to three fixed termination dates: August 15th, August 25th (the usual termination date), and September 4th. Index values have not been adjusted for varying sockeye catchability.

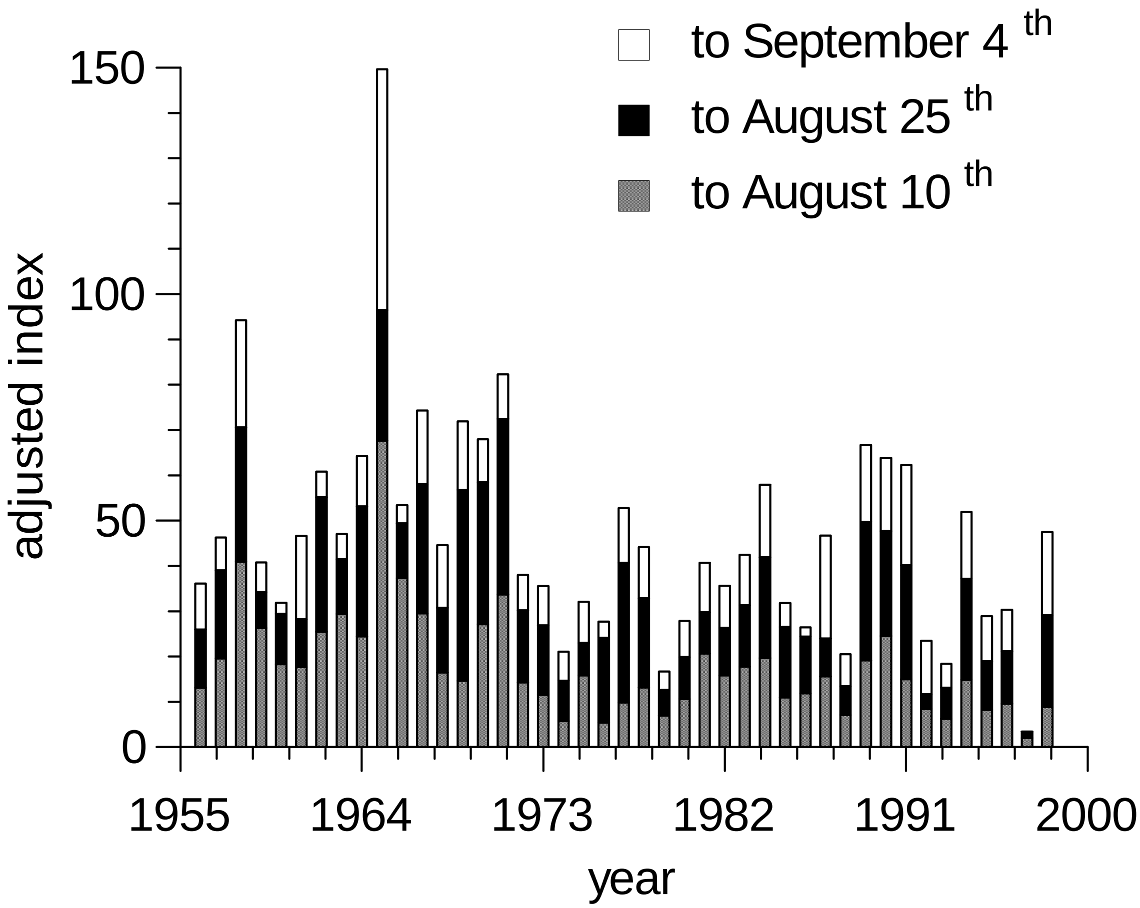

Figure 12. Tyee test fishing index summed to three fixed termination dates: August 15th, August 25th (the usual termination date), and September 4th. Index values have been adjusted for varying sockeye catchability.

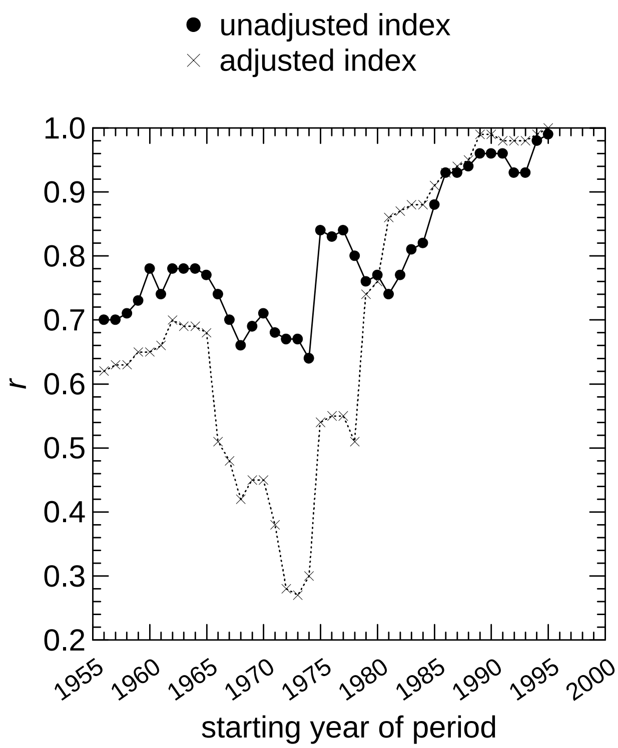

Figure 13. Correlations between the unadjusted and adjusted Tyee test-fishery indices and the total Babine coho escapement for periods beginning in 1956 to 1995 and ending in 1998.

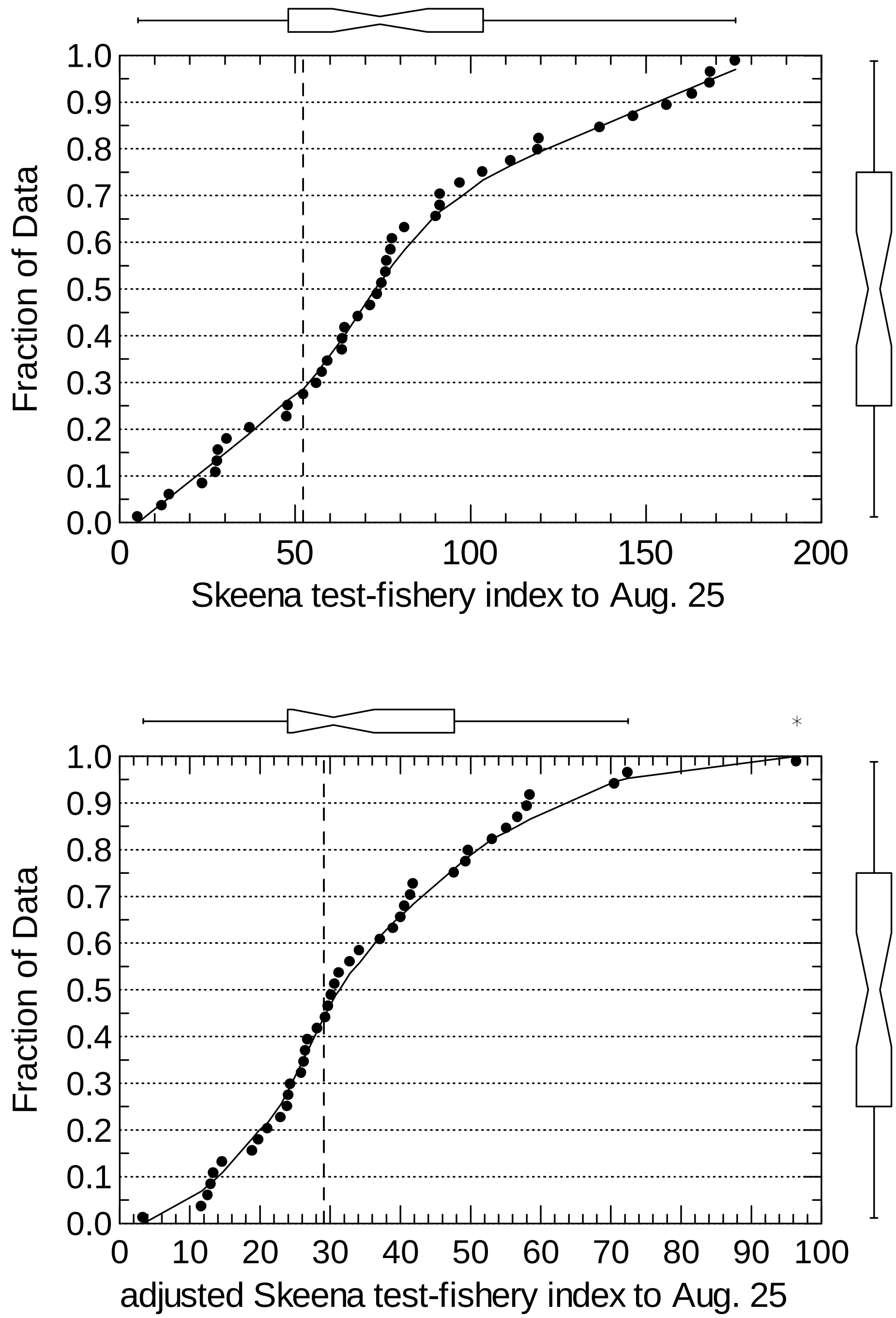

Figure 14. Quantile plots of the unadjusted (top) and adjusted (bottom) Skeena test fishery index to August 25th. Box plots of the index values are shown above the plots. The index values for 1998 are shown as vertical dashed lines. The solid curve is a LOWESS smooth.

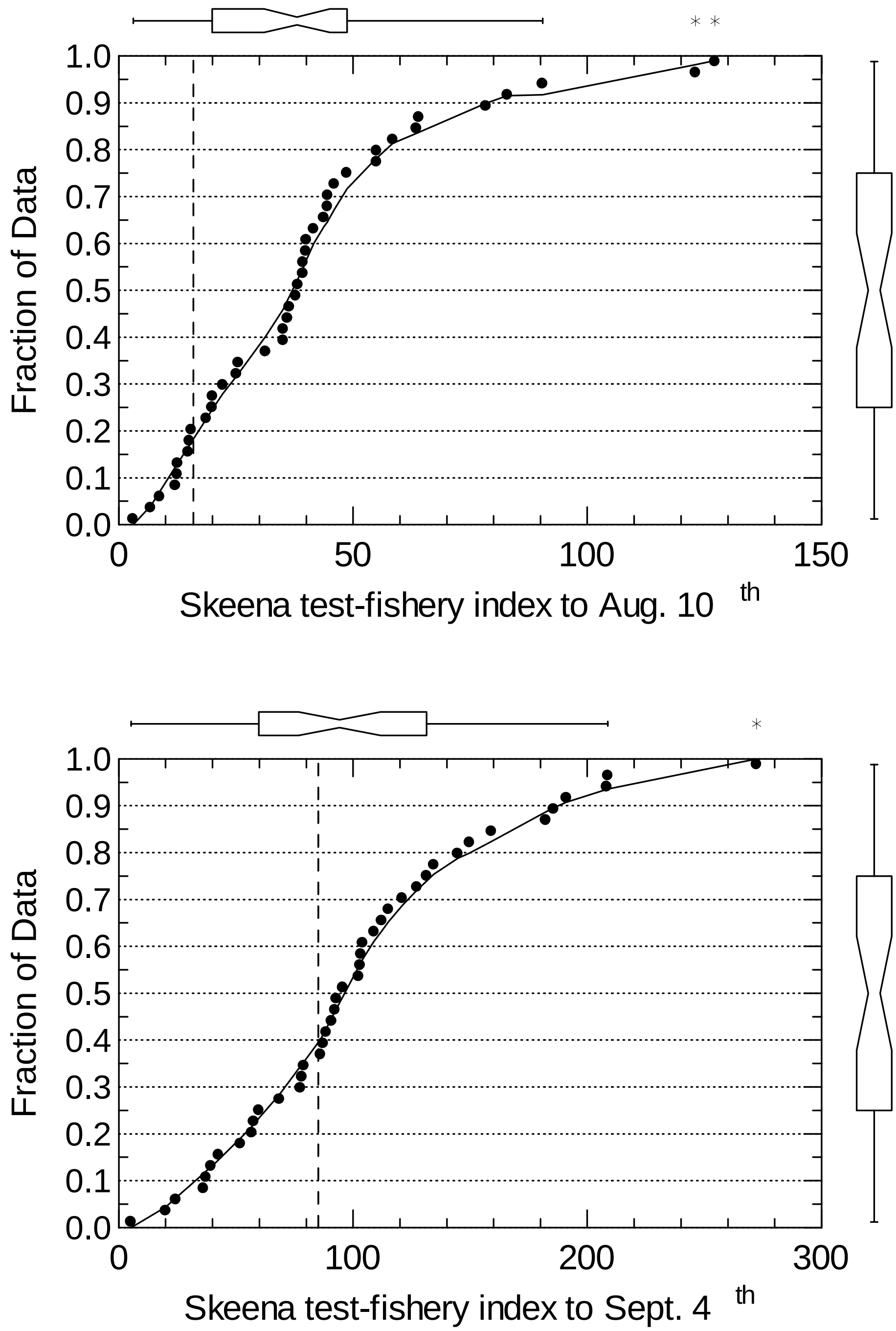

Figure 15. Quantile plots of the unadjusted Skeena test fishery index to August 10th (top) and September 4th (bottom). Box plots of the index values are shown above the plots. The index values for 1998 are shown as vertical dashed lines. The solid curve is a LOWESS smooth.

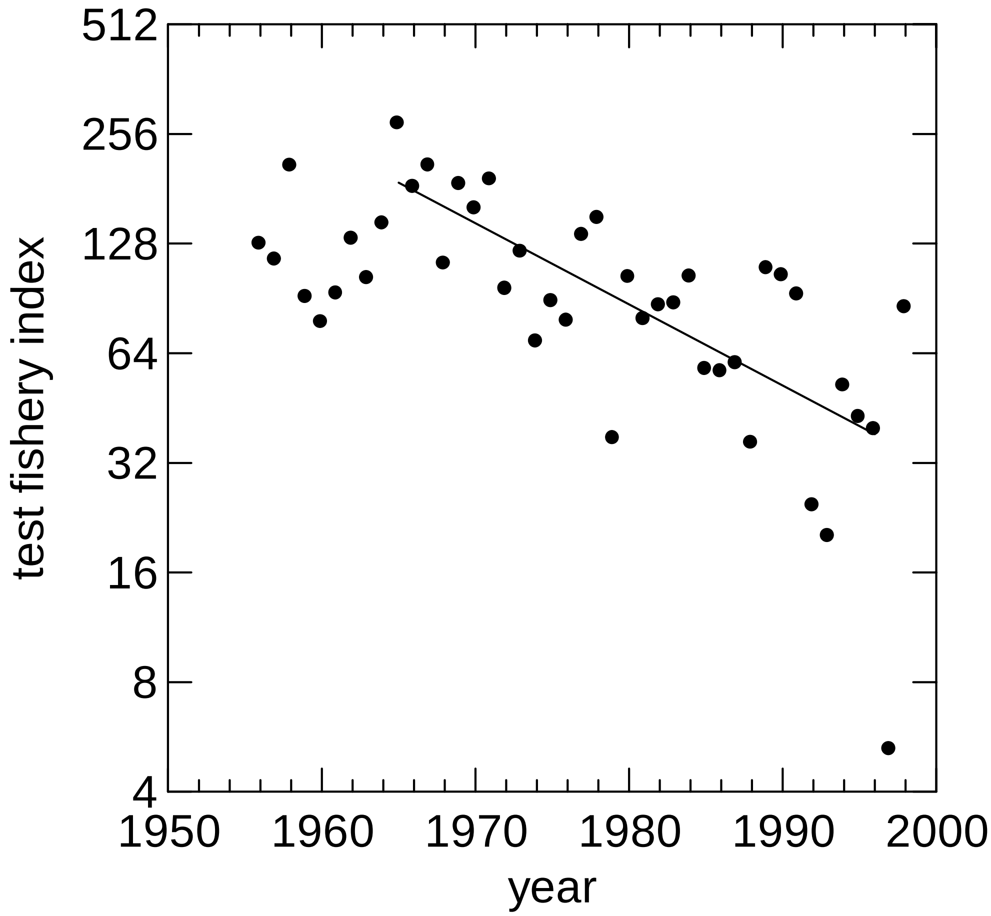

Figure 16. Unadjusted test-fishery index vs. time with a log-linear fit for the period 1965-1996.

3.4 Babine Lake coho aggregate

The Babine River counting fence has been operated since the fall of 1946 primarily to enumerate sockeye salmon returning to the Babine. In most years the fence operations stopped well before the end of coho passage. The fence was operated through all or nearly all of the coho run in 11 of the 51 years it has been operated (Table 12). Those years are referred to as the 'base' years. The base years were divided into two groups, with the second group beginning in 1992. The run-timing curve distinctly shifted in that year with smaller proportions of the run passing through the fence prior to the first week of September. On average approximately 25% of the run had passed through the fence by September 7 in years prior to 1992 but only 10% had passed in the more recent years. The latest date for which there is a count in every year is September 13th. Counts to that date are referred to as the escapement index and the period prior to and including September 13th as the 'index period' (Table 12).

To estimate total escapement we calculated for the base years the average proportion escaped for each date after the index date. For each year in which a total count had not been obtained we estimated it by dividing the last count by the average proportion escaped in the base years on the date of the last count. The fence was not operated in 1948 and 1964. Using the time series of estimated total escapement we applied the "fill-in" procedure (Brown 1974) using the catch per hook in the SE Alaskan troll fishery (Shaul 1998) in 1948 and the Tyee test fishery index for 1964. A large slide partially blocked the Babine River in 1951 severely restricting salmon passage. The "fill-in" procedure using the catch per hook in the SE Alaskan troll fishery (Shaul 1998) was used to estimate what the escapement would have been had the blockage not occurred. This number was used only in the calculation of recruitment for the 1947 and 1948 brood years. The fill-in procedure using the test-fishery was also applied in 1965. In that year the recorded count was 20,000 to September 13 which became approximately 31,300 after expansion to total escapement and over 62,000 when expanded to the total stock. An escapement this large is inconsistent with other returns that year we decided to estimate the total escapement indirectly.

Age data are quite incomplete for the Babine aggregate (Table 17). A relationship between the proportion of age-3 fish in BY+3 and the BY spawners was used to estimated age composition (Table 18). The overall mean age at return in the Babine Lake aggregate is 3.3.

3.4.1 Reconstruction of Historical Exploitation Rates

Direct measures of fisheries exploitation on the Babine aggregate are derived from CWTs and begin in return year 1994 (brood year 1991). Comprehensive data on fisheries effort by fishery[5] begin in 1963. However, effort data itself is of limited value in determining the pattern of historical stock specific fishery impacts, because the relative impact of a unit of effort on a specific stock varies widely among weeks, fisheries, and years. Our approach was to adjust that effort time series by fishery-specific estimates of the relative impact of a unit of effort on upper Skeena coho.

We began with a measure of effort E_{ijk} for each fishery i , week j and year k within the effort base period 1963-1997. Within the shorter "CWT" base period (1989-1997) tabulated the catch per unit effort of CWTs from upper Skeena release sites by fishery i, week j and year k (T_{ijk}). These included all releases from Fort Babine, Toboggan, and the upper Bulkley. To increase the number of tags available we pooled all release sites. We then derived a weekly weighting of impact for each fishery i and week j as

[5] Fisheries are defined by location, time and gear-type.

$$W_{ij} = \overline{T_{ij}} \Big/ \overline{\overline{T_i}} \qquad (8)$$

where:

W_{ij} : weighting factor for fishery *i* in week *j*

$\overline{T_{ij}}$: average catch per unit of effort of upper Skeena CWTs in fishery *i* in week *j*.

$\overline{\overline{T_i}}$: average weekly catch per unit of effort of upper Skeena CWTs in fishery *i*.

Then for each year from 1963 to 1997 the actual effort in each strata (of the weekly, fishery, year effort matrix) was multiplied by the relative upper Skeena coho impact weighting for that strata to give an index of effort adjusted for impact on upper Skeena coho:

$$E'_{ijk} = W_{ij} E_{ijk} \qquad (9)$$

There were additional adjustments to U.S. and the Canadian troll fishery indices to cover known changes in fleet efficiency among years. The U.S. troll time series was adjusted for years where there is a direct measure of the relative efficiency of the fleet on Alaskan coho stocks, essentially a measure of exploitation rate per unit effort (the assumption being these same time trend would apply to the efficiency on Canadian stocks). In Canada, the proportion of the troll fleet comprised of freezer boats increased through the base period. Freezer trollers generally had a higher coho CPUE than the ice-boats they were replacing. The annual troll effort time series was converted to ice-boat equivalents by multiplying the number of freezer boat-days by the ratio of freezer boat to ice-boat coho CPUE and adding this to the number of boat-days for the ice-boat troll each year. The effect of this adjustment was to increase the troll effort in recent years. No data were available to apply the same principle to the net fleet, although the general expectation would be that efficiency per unit effort also increased in those fisheries over time. No data was available to apply the same principle to the net fleet, although the general expectation would be that efficiency per unit effort has increased over time. After those adjustments we had an annual index of the relative fishery impacts on upper Skeena stocks for each fishery.

Since the indices are all relative to each other, the indices are additive and the fisheries and areas can be combined into two indices for all Canadian and all Alaskan fisheries. To estimate time series of exploitation rate we calibrated the indices of relative impact with ‘known’ exploitation rates in the CWT-period. Yearly exploitation rates were not significantly correlated with the indices over the short period of data for Babine coho (Table 3), so we calculated an average calibration factor, *X* as follows:

$$X_i = \overline{u_{ij}} \Big/ \overline{E'_{ij}} \qquad (10)$$

where:

X_i : calibration factor for fishery *i*

$\overline{u_{ij}}$: average exploitation rate observed in fishery *i* over the *j* years in the CWT-base period.

$\overline{E'_{ij}}$: average adjusted effort in fishery *i* over the *j* years in the CWT-base period.

Exploitation rates were estimated for years prior to the CWT-base period by multiplying the X_i by the estimates of adjusted effort. Observed exploitation rates were used in the CWT-base period and for years prior to the effort-base period average values of exploitation rate from 1963 to 1975 were used. Finally, rough estimates of the marine recreational and recreational and First Nations FW exploitation rates were added to the sum of Canadian and Alaskan exploitation rates to give the total exploitation rate (Figure 17).

3.4.2 Trends in abundance

Estimated total escapement of the Babine Lake coho aggregate has ranged between 453 to 22,985, an over 50-fold range (Table 12; Figure 19 & Figure 20). Decadal trends in total escapement and total stock size are also summarized in the following Table. The decadal median escapement for the 1990's is 21% of the median for the 1960's. The reduction in total stock size over the same period was only slightly less severe (to 36%).

decade	median escapement	median stock size
1946 to 1959	10206	23,586
1960 to 1969	12771	30,018
1970 to 1979	10156	23,363
1980 to 1989	3233	10,061
1990 to 1998	2669	10,728

The temporal patterns of the reductions in stock size and escapement are slightly different. The time series of escapement is noticeably stepped with a marked drop in escapement occurring in 1979 (Figure 20). The time series of total stock size is not stepped and shows a continuous decline since the early 1970's. (Figure 21).

When the logarithms of abundance are plotted against return year from 1970 onward the declines are approximately linear, especially in the case of stock size (Figure 22). These plots describe trends in abundance in the form:

$$S = be^{-at} \tag{11}$$

or in linearized form:

$$\log S = b + at\,, \tag{12}$$

where:

S : abundance, either stock size or escapement,
t : time, in this case year, and
a, b : constants.

The following regressions were fit to these data.

<u>total stock size</u>		
1946-1998	*log R* = 54.3 – 0.0226 *t*	(N = 53; adj. r^2 = 0.25; $P < 0.001$)
1970-1998	*log R* = 80.3 – 0.0357 *t*	(N = 20; adj. r^2 = 0.14; $P < 0.05$)
<u>escapement</u>		
1946-1998	*log S* = 72.6 – 0.0324 *t*	(N = 53; adj. r^2 = 0.42; $P < 0.001$)
1970-1998	*log S* = 120.3 – 0.0565 *t*	(N = 20; adj. r^2 = 0.42; $P < 0.001$)

Over the period 1970 to 1998 the size of the Babine Lake coho aggregate shrank every year on average by $1 - e^{-0.0357} = 0.035$ or 3.5%. This is termed the finite rate of decrease. The average age of a Babine coho at return is 3.3. Consequently, every generation the size of the aggregate shrank on average by $1-0.965^{3.3}=0.111$. Over the same period the finite rate of decrease in escapement was 5.5% with a generational rate of decline of 17%. These rates are modest compared to those seen in Thompson coho where generational decreases of 54% to 72% have been observed since 1988 (Bradford 1998). However, the decline of the Babine aggregate has been going on for a much longer period.

Table 12. Observational data from the Babine fence. Base years used to estimate total escapement are indicated by the "→". Total escapement estimated by "fill-in" are shown in italics.Two total escapement estimates are shown for 1951. The smaller is the actual escapement estimated. The larger is the estimated escapement had the 1951 Babine slide not occurred.

year	Date of first coho	Date count ceased	Count to Sept. 13th	Total observed count	Estimated total escapement
1946	Aug. 20	Oct. 04	8687	12489	13411
1947	Aug. 08	Oct. 07	4983	10252	10815
1948	Fence not operated-Total escapement estimated using the "fill-in" procedure and the time series of catch per hook in the SE Alaska troll fishery.				*13734*
1949	Aug. 13	Oct. 03	6044	11938	12961
→1950	Aug. 05	Oct. 15	5205	11654	11654
1951	Aug. 22	Oct. 04	444	2120	2276
					20427
→1952	Aug. 24	Nov. 06	1157	10554	10554
1953	Aug. 11	Oct. 28	5904	7648	7655
1954	Aug. 15	Oct. 03	1644	3094	3359
1955	Aug. 15	Oct. 03	4339	8947	9714
1956	Jul. 22	Sept.30	5675	9250	9857
→1957	Aug. 02	Oct. 29	2475	4421	4421
1958	Aug. 02	Oct. 01	5026	7606	8438
1959	Aug. 11	Oct. 02	6347	10947	12004
1960	Aug. 05	Sept.28	5191	6794	7942
1961	Aug. 02	Sept.21	7297	10024	14416
1962	Aug. 10	Sept.22	8088	11000	15183
1963	Aug. 09	Sept.13	3600	3600	7737
1964	Fence not operated. Total escapement estimated using the "fill-in" procedure and the Tyee test fishery time series to Sept. 4th				*10689*
1965	Aug. 02	Sept.13	20000	20000	*22985*
1966	Aug. 07	Sept.15	6784	7200	13377
1967	Aug. 05	Sept.23	7469	9378	12487
1968	Aug. 09	Sept.14	6393	6600	13054
1969	Aug. 02	Sept.21	2978	4660	6702
1970	Aug. 09	Sept.15	4968	5600	10404
1971	Aug. 05	Sept.24	4284	7700	9909
1972	Aug. 16	Sept.20	2415	3598	5381
1973	Jul. 26	Sept.15	5836	6247	11606
1974	Aug. 13	Sept.19	4886	8853	13661
1975	Aug. 17	Oct. 01	2059	4429	4913
→1976	Aug. 22	Oct. 28	2085	4499	4499
→1977	Aug. 06	Oct. 20	4324	10474	10474
1978	Aug. 06	Oct. 10	5600	11446	11861
→1979	Aug. 04	Oct. 31	1144	2909	2909
1980	Aug. 08	Sept.29	2172	4399	5046
1981	Aug. 12	Sept.29	1426	2167	2486
1982	Aug. 12	Sept.28	1704	2287	2673
1983	Aug. 05	Sept.25	1598	2704	3402

year	Date of first coho	Date count ceased	Count to Sept. 13th	Total observed count	Estimated total escapement
1984	Aug. 14	Oct. 02	1539	2956	3241
➔1985	Aug. 08	Oct. 24	914	2129	2129
1986	Aug. 14	Sept.23	1673	2757	3671
1987	Aug. 10	Oct. 01	867	1894	2101
1988	Aug. 08	Oct. 05	1639	3026	3225
➔1989	Aug. 06	Oct. 25	3140	5228	5228
1990	Aug. 09	Oct. 14	2477	5512	5619
1991	Aug. 08	Oct. 19	1558	4904	4941
1992	Aug. 08	Sept.29	584	1302	1714
1993	Aug. 15	Oct. 11	322	1974	2186
1994	Aug. 10	Nov. 01	695	3930	4053
➔1995	Aug. 10	Nov. 06	510	2345	2345
➔1996	Aug. 15	Nov. 04	640	2669	2669
1997	Aug. 05	Oct. 19	100	453	453
➔1998	Aug. 04	Nov. 15	1279	4291	4291

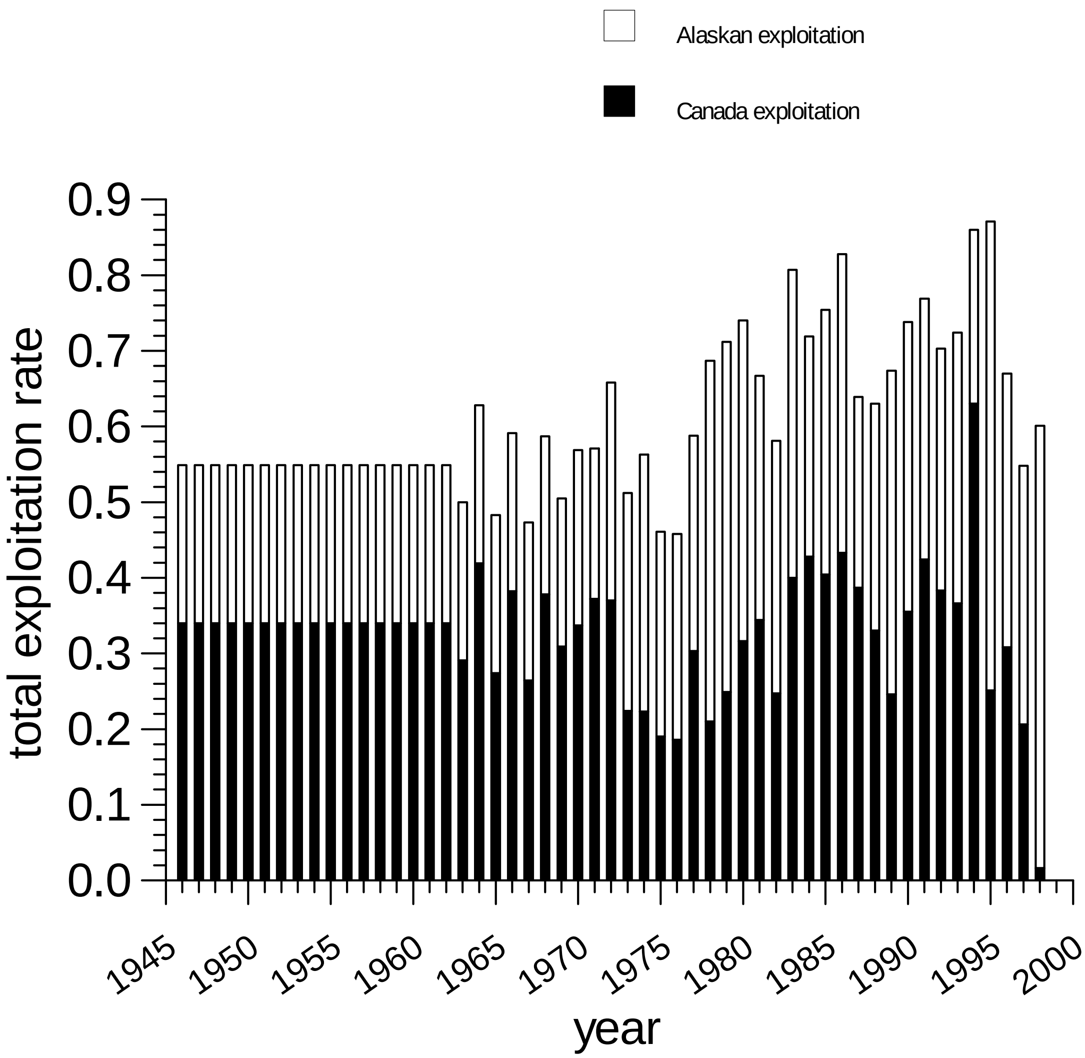

Figure 17. Total Canadian and Alaskan exploitation rates on Babine aggregate coho.

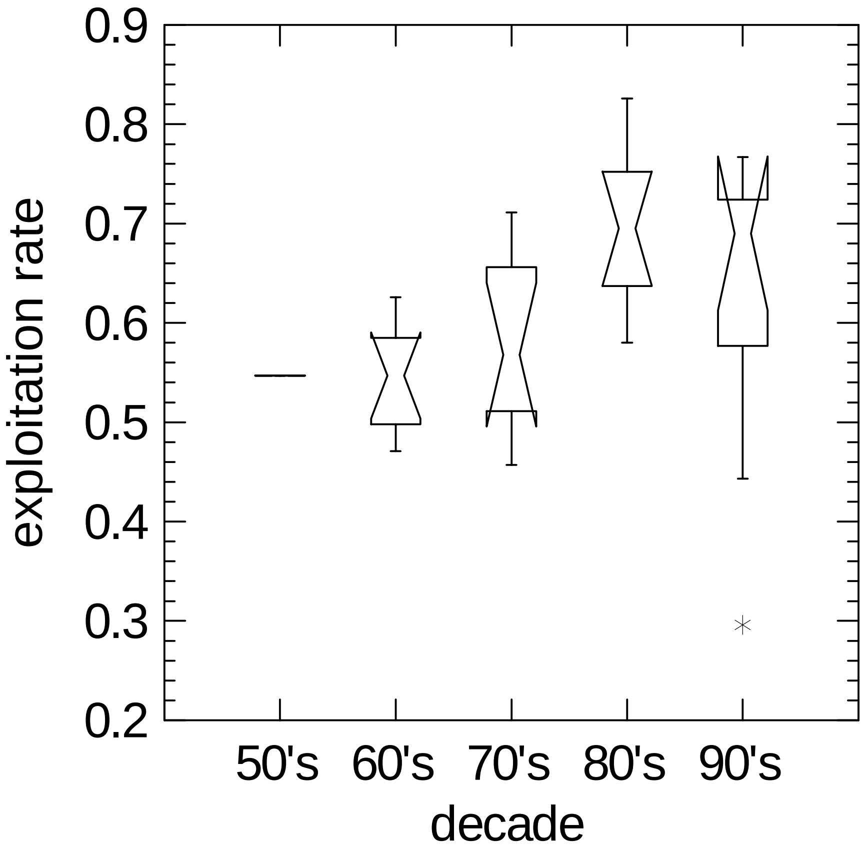

Figure 18 Box plots of the total exploitation rate on the Babine Lake aggregate coho. Note that the "50's" include the period 1946 to 1949.

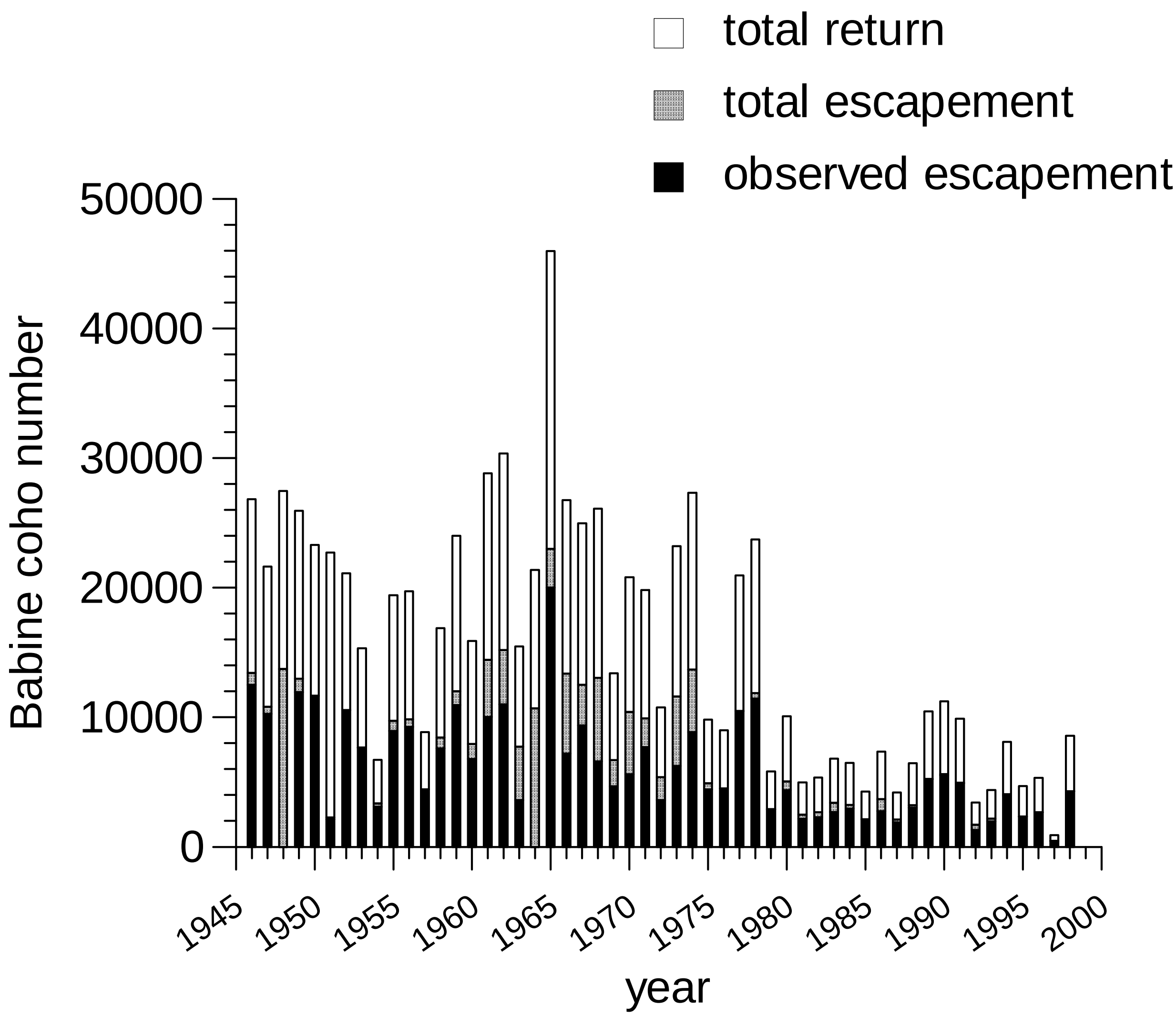

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Figure 19. Trends in observed Babine coho escapement, estimated total escapement and estimated total return (stock size) from 1946 to 1998.

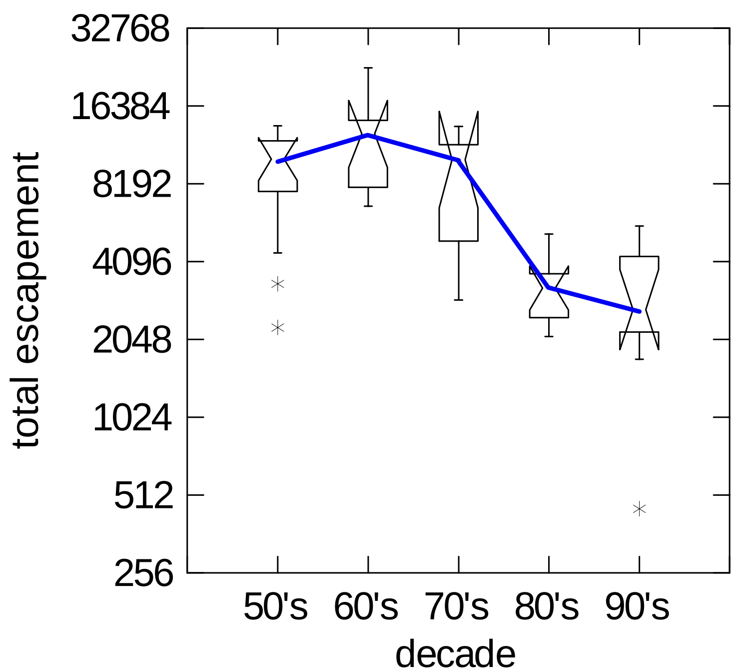

Figure 20 Box plots of total escapement of the Babine coho aggregate. The line links the decadal medians. Note that the '50's' includes the period 1946-1949.

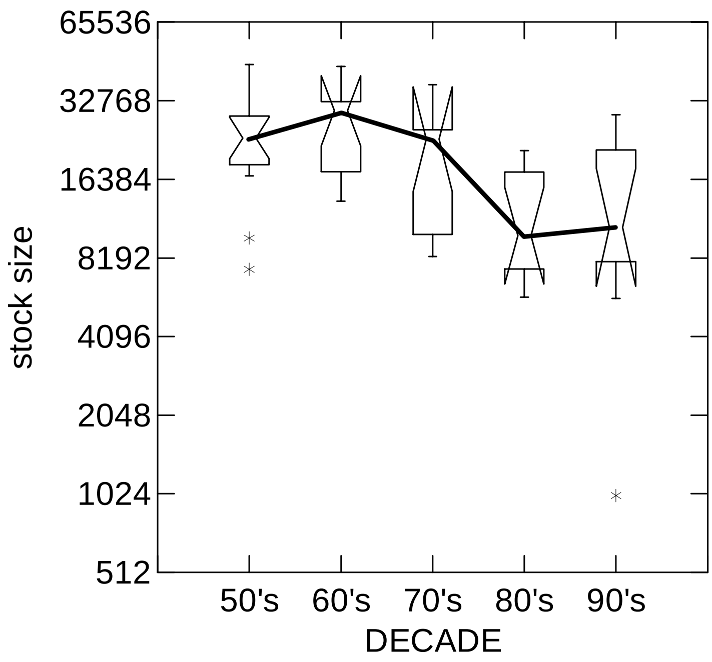

Figure 21. Box plots of total stock size of the Babine coho aggregate. The line links the decadal medians. Note that the '50's' includes the period 1946-1949.

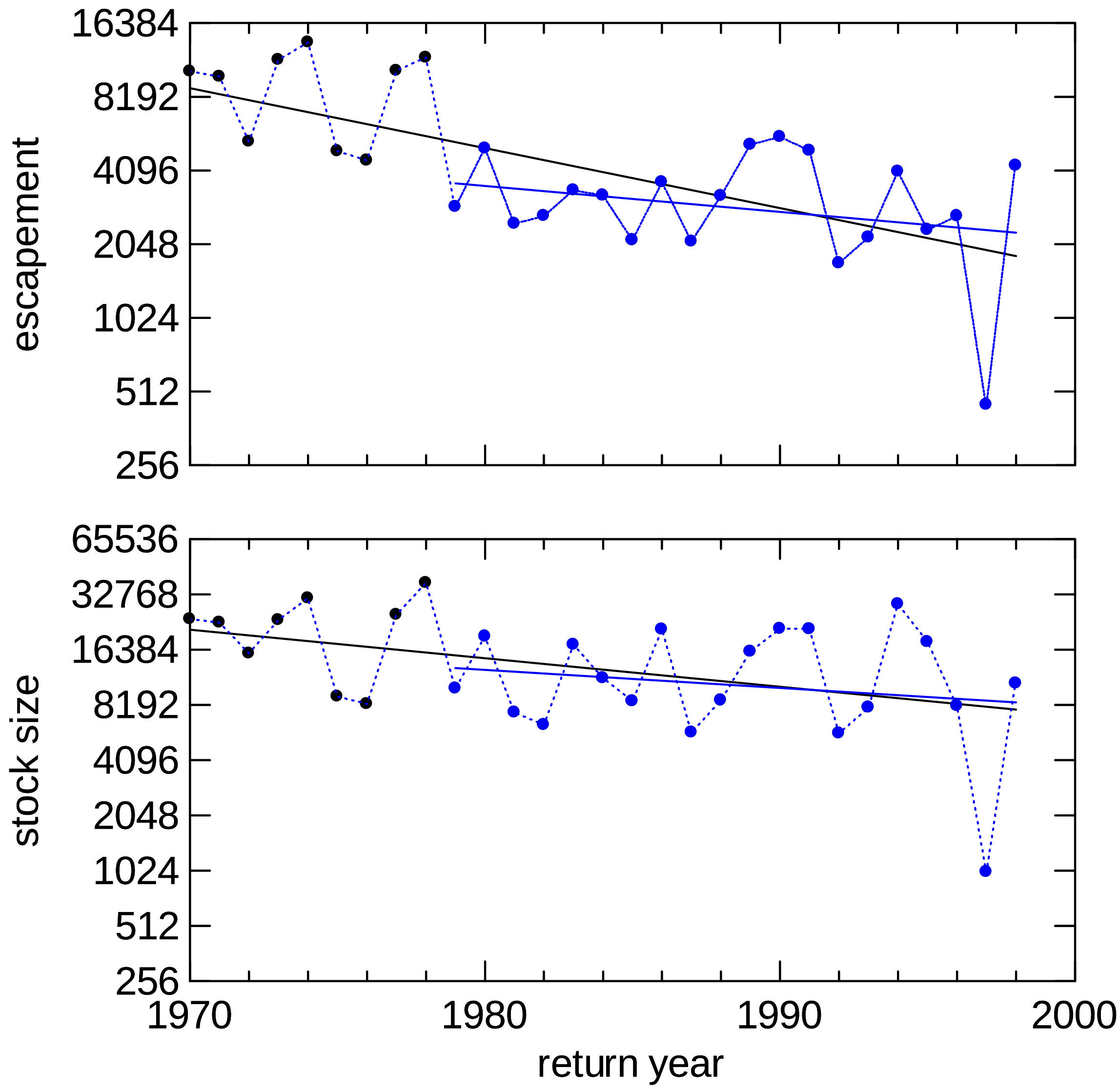

Figure 22. Trends in escapement (top panel) and stock size (lower panel) of the Babine Lake coho aggregate between 1970 and 1998. Because the y-axis is a logarithmic scale the linear trend lines with negative slopes actually represent exponential declines in abundance. Within each panel two trends lines are show: one for the period 1970 tto 1998 and tho other for the period 1979-1998.

3.4.3 Cause of decline of upper Skeena coho is Babine Lake Development Project sockeye enhancement.

Two hypotheses relating to the carrying capacity of the Babine Lake system have been advanced to explain observed declines in abundance. The hypotheses differ only in the reason for the decreased carrying capacity and the observed decline in abundance is interpreted as a rapid adjustment to the lower carrying capacity.

<u>Hypothesis 1</u> Coho juveniles in lakes feed on zooplankton, but are not obligate planktivores and are much less efficient planktivores than sockeye (Kyle and Koenings 1983; Kyle 1994). The increased numbers of rearing sockeye that were using Babine Lake after the construction of the Pinkut and Fulton spawning channels depressed zooplankton numbers below the level where coho could feed. Coho were thus competitively excluded from Babine Lake, which reduced the carrying capacity of the system for coho.

Unfortunately the extant zooplankton samples are inadequate to determine how the zooplankton community responded to increased numbers of rearing sockeye with sufficient spatial resolution and precision to resolve this issue. The number of sockeye smolts should be a rough indication of possible interactions between the rearing juveniles. There is a suggestive inverse relationship the total stock size of the Babine Lake coho aggregate and the number of sockeye smolts produced by Babine (r^2=0.091; P<0.05; Figure 23). However, there is no relationship between the residual of the fitted Babine stock-recruitment function and sockeye smolt production (Figure 24), which suggests that any interactions that might be occurring are not driving inter-annual variations in productivity.

In addition to the absence of a demonstrable relationship we would raise the following objections to the hypothesis:

1. Staff in the limnology and sockeye units in CDFO indicated that the zooplankton community in Babine has not changed to the species mix typical of lakes where sockeye are having a large impact. *Daphnia* and *Heterocope*, both large bodied forms that disappear from heavily grazed lakes, are less abundant than they were but are still quite common. For sockeye at least the main basin of the lake continues to be under-utilized
2. Sockeye are pelagic while coho are sub-littoral, i.e. the two species use very different parts of the lake which should reduce their interactions (Scarsbrook and McDonald 1970, 1973). In Cowichan Lake on VCI, coho coexist with abundant kokanee and feed predominantly on insects rather than zooplankton (unpubl. data, K. Simpson, StAD, Nanaimo)
3. Coho do not rear in the main basin of Babine Lake. Most coho come from Nilkitkwa Lake and Morrison Lake, where there are few enhanced sockeye juveniles. Wild sockeye, which do use the NE parts of Babine Lake and Nilkitkwa Lake, have become less abundant since enhancement. If sockeye and coho interact in the Babine system it is more likely that the intensity of that interaction has lessened following enhancement.
4. When CDFO Fishery Officer Management Escapement Goals for coho are summed by basin in the Babine Lake only 12% of the total target is from streams that empty into the main basin, a further indication that coho and enhanced sockeye are unlikely to interact.
5. It is difficult to understand how competition between coho and sockeye juveniles <u>in</u> Babine Lake has adversely affected coho in the entire upper Skeena, and in coastal and inlet populations to the south of the Skeena. Interactions in the estuary and in the ocean along the migration routes for sockeye smolts are possible, although such

interactions should also be detectable in the relationships plotted in Figure 23 and Figure 24. An interaction in the estuary or ocean would at least explain the region wide depression in coho numbers.

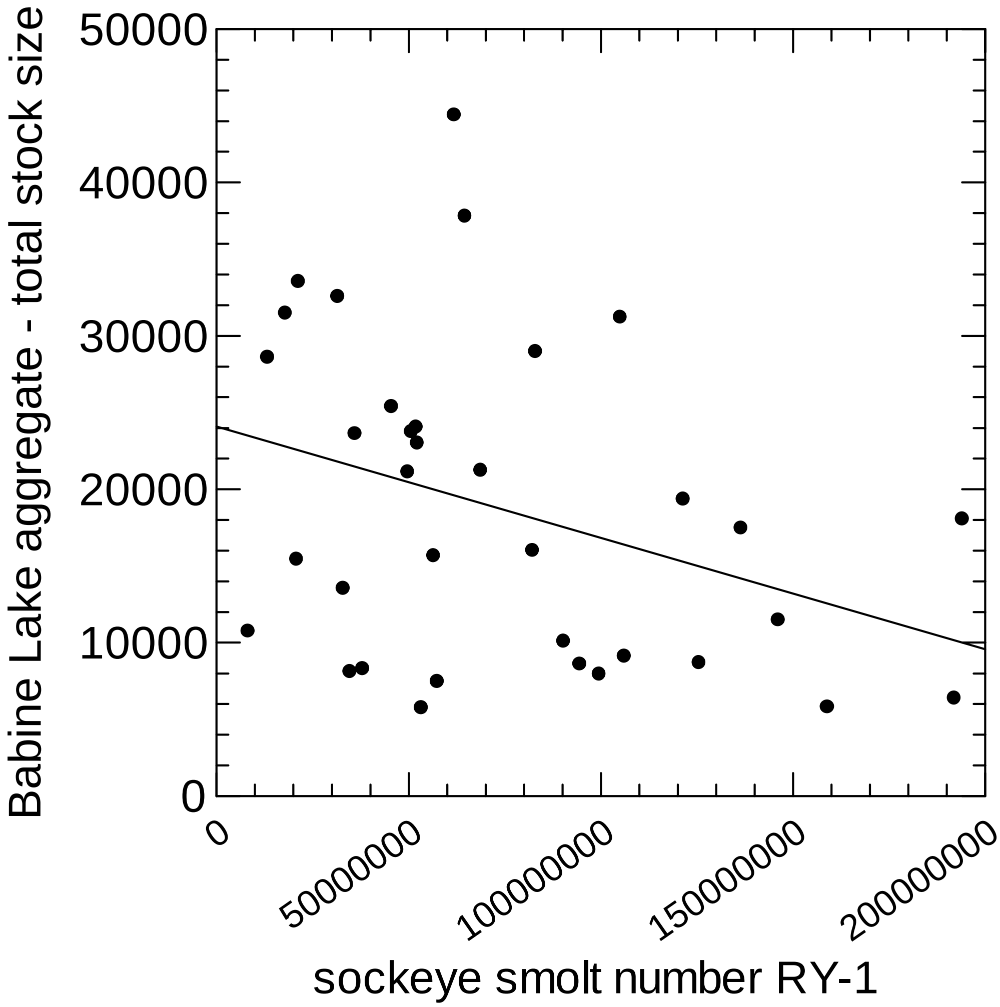

Figure 23. Relationship between the total size of the Babine coho stock and the number of Babine sockeye smolts.

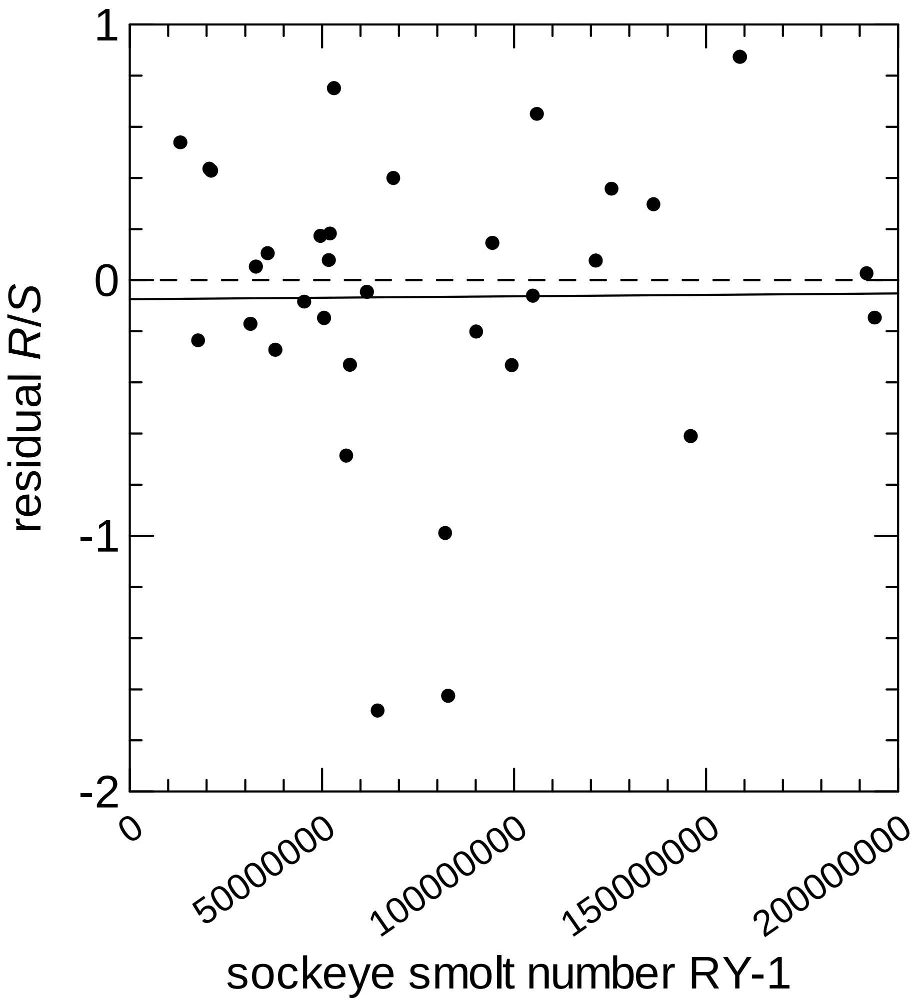

Figure 24. Relationship between the residual for the Babine stock-recruitment relationship and the number of sockeye smolts in the predominant smolt year.

Hypothesis 2: The decline in Babine Lake coho abundance is due to increased predation in freshwater. Enhancement of sockeye in the main basin of Babine Lake resulted in an increase in sockeye smolt production. On average, approximately 2.9-times more smolts left the lake in the 1980-1995 period than did prior to 1970. The enhanced sockeye smolts have a latter run timing that the smolts from the late spawning wild stocks, which were not enhanced. Consequently, enhancement has also acted to lengthen the duration of the smolt run (Wood et al, 1998). Both of these enhancement impacts have acted to increase the amount of food and its availability to predators and the predators have responded numerically. The increased number of predators has had direct impacts on coho smolt production but has also excluded coho from part or all of Nilkitkwa Lake.

The primary evidence for this hypothesis are stock-recruitment analyses for years before and after 1979, the year in which escapement appears to take a step down to a lower but stable level (Figure 19). We have added a third period that is approximately two generations after that apparent down-step, or from brood year 1983 to 1994. The stock-recruitment analysis (following Table) does indicate a substantial decrease in the carrying capacity (S_{MSY}) for the years after 1979. There was an associated modest increase in stock productivity. For the third period, which began with brood year 1983, there was a further reduction in carrying capacity and a corresponding increase in productivity. Graphically, the successive Ricker stock-recruitment curves seem to indicate that the equilibrium spawning stock size of the Babine Lake coho stock became progressively smaller between 1975 and 1983 as the stock became more productive. This progression is shown graphically in Figure 25 and Figure 26.

parameter	Brood years included in regression			
	whole period	1946 to 1975	1976 to 1994	1983 to 1994
a'	1.790	1.939	2.176	2.616
b'	20181	19608	10212	7832
u_{MSY}	0.67	0.71	0.76	0.83
S_{MSY}	7562	7143	3550	2482

Additional evidence in support of this hypothesis is the observed decline in abundance of late-run sockeye (Figure 27). This run-timing component spawns in the Babine River and the juveniles rear in Nilkitkwa Lake. Presumably, the juveniles of this run component would have been subject to the increased levels of predation.

Although the hypothesis is a reasonable one the observations available do not support it. First, there are no significant differences in either sockeye escapement or smolt production when the time series are divided on or around the year when coho escapement appears to have declined (1976 smolt year)[6]. If the predation field so rapidly as to produce a change in coho escapements, a simultaneous decrease in sockeye smolt production and subsequent escapement would be expected. The down-step in escapement in coho occurred at the same time that exploitation sharply increased (Figure 17) and does not appear in the time series of total stock size (Figure 22), suggesting that there was no abrupt change in the carrying capacity of the Babine Lake system. Analytical stock-recruitment results, which show increasing productivity and lower carrying capacity as time is restricted to latter periods, are either artifacts of stock-recruitment analysis of over-exploited and collapsing populations or the result of progressive elimination of less productive components from a stock aggregate. Numeric responses of predators following

[6] *P* values for H_0: difference in mean escapement or smolt production from *t*-tests with pooled variances are typically greater than 0.5.

enhancement of Tahltan Lake sockeye may have been responsible for declines in standardized smolt production with similar levels of sockeye enhancement (pers. comm. C. Wood, PBS). However, Tahltan Lake is much smaller than Babine Lake and the exposure of the juvenile sockeye would have been continuous. Numeric responses of predators to increased prey abundance over short periods are difficult to envisage. The short exposure to smolts would have lead to rapid satiation of the predators during the smolt run, which would limit direct impacts. Numeric responses would have been limited by increased levels of cannibalism and predation on the juveniles of the predatory species during the majority of the year when smolts were not present[7]. prey abundance would have fallen. Finally, the proposed mechanism fails to account for the simultaneous declines in coho abundance in other areas of the Skeena basin. However, the most efficient way to disprove these hypotheses is to observe the response to increased coho escapements.

[7] This effect would have been exacerbated by reduced abundance of sockeye and coho and the numeric response further limited.

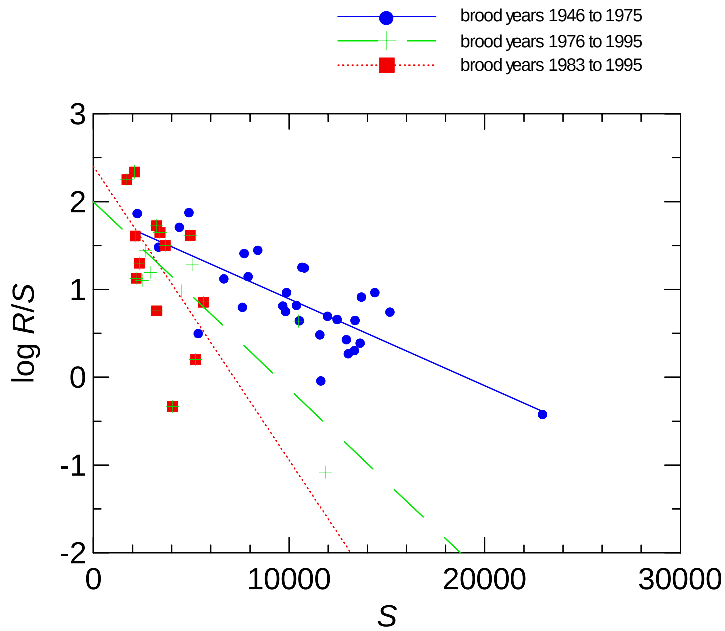

Figure 25. Ricker stock-recruitment curves for three periods for the Babine Lake coho aggregate. Linear fits to each dataset are shown.

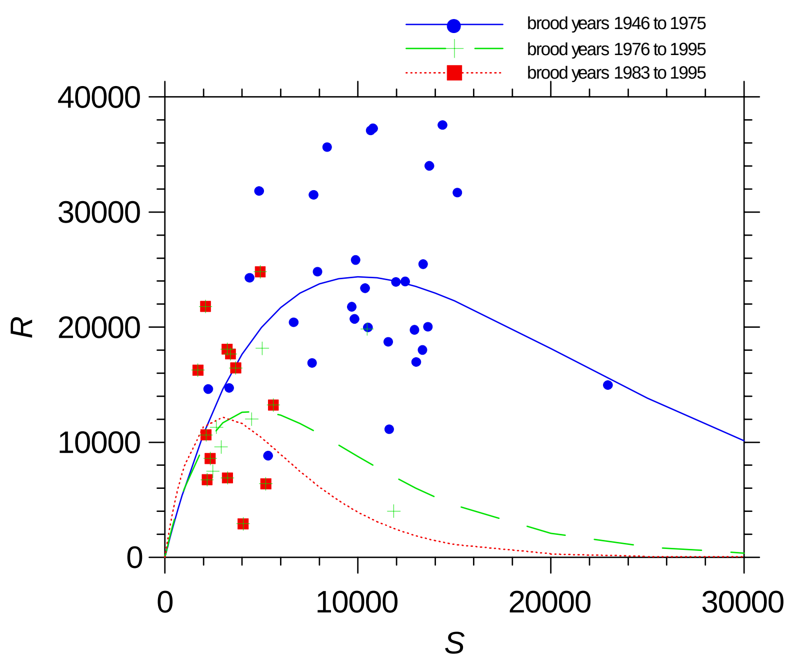

Figure 26. Non-linearized Ricker stock-recruitment curves for three periods fit to the Babine Lake coho aggregate.

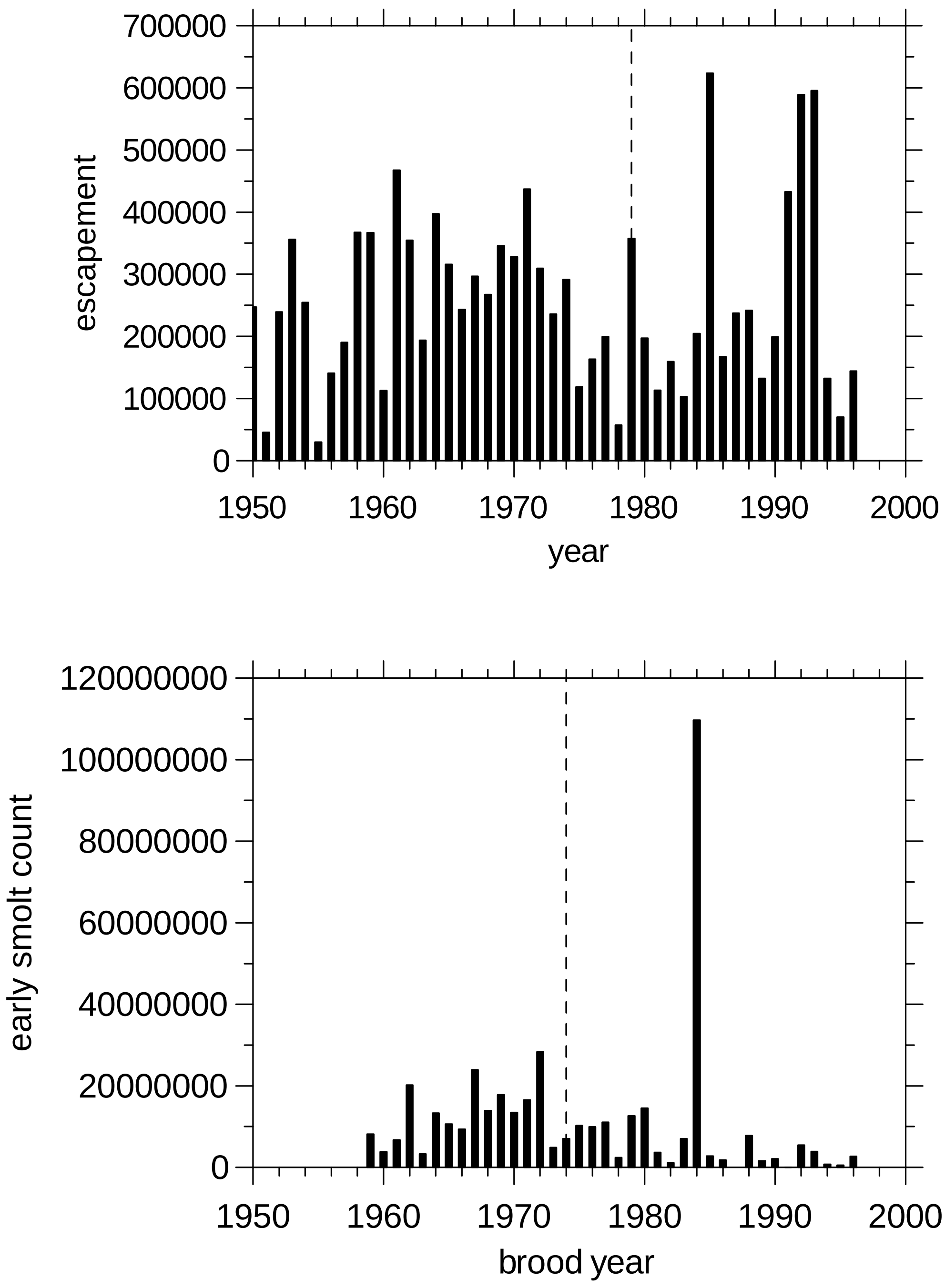

Figure 27. The top panel is the estimated escapement of the late-run component to the Babine River and Nilkitwa Lake. The vertical dashed line divides the time series at the 1976 smolt year.

3.4.4 Escapement targets for the Babine Lake coho aggregate

We used four approaches to establish escapement targets for Babine coho (Table 14).

1. Limit Reference Escapement (LRP) A tentative floor escapement of 3 females/km has been adopted by CDFO for conservation purposes. Operationally, this is interpreted as the escapement level that should be maintained for the majority of streams in a management unit. It is thus a floor and not a target and could be used to provide a criterion for determining permissible rates of fishing (FAO 1995). For Carnation Creek, a well-studied population on Barkley Sound, an escapement of between 9 and 13 females/km has been found to bracket the MSY escapement (Holtby 1988; Holtby and Scrivener 1989). Application of a LRP in the units of females/km requires an estimate of habitat. Estimates of accessible stream lengths for the Babine system were readily available (Smith and Lucop 1966, 1969; Table 13). Coho also extensively use the sub-littoral zones of all lakes in the area, and we have chosen to estimate this habitat as the length of shoreline. Coho were never common in the streams around the main basin of Babine Lake so the inclusion of that shoreline would possibly exaggerate the available habitat area. To estimate the effective shoreline length we included the shoreline north of Topley Landing including Morrison Arm. Also included were Morrison and Nilkitkwa Lakes. The effective shoreline length was 305.7 km. For Babine coho a LRP of 3 females/km corresponds to total escapement of between 1328 spawners (streams only) to 4347 spawners (stream + effective shoreline length) (Table 14). For 13 females/km the corresponding escapement is between 5,754 and 13,702. Concern has been expressed that inclusion of historical measures of accessible stream length might include habitat that has been damaged by logging and road construction or made inaccessible by landslides or beaver activity. The Sutherland River in particular was noted. We acknowledge that our measures of available habitat are crude and that it would desirable to explicitly account for varying quality (productivity) in determining the target escapement for a watershed. However, the provisional LRPs were derived from the same type and quality of habitat measurements and so already integrate diverse habitat qualities.

2. Stock-recruitment analysis (S_{opt}) The *MSY* escapement estimated by the stock-recruitment analysis is 7,561 (Table 19). The SRSHOW analysis gave a similar value of ≈6,600 (Figure 38). A simulation analysis of the uncertainty in the management parameters (Section 4.1.1, page 76) suggests that S_{MSY} is 7,782 (95%CI: 6,427–9,815). These values are highly uncertain but the simulation analysis suggests the value is more likely to be higher than lower than the point estimate.

3. Stock-recruitment analysis (R_{max}) The estimate of escapement for maximum recruitment (S_{rmax}) was 11,285. This could be termed the carrying capacity of the Babine Lake aggregate and might serve as an appropriate escapement target, i.e., an escapement around which the realized escapement should vary. The corresponding exploitation rate under average survival conditions would be 0.48 or approximately 68% of the average exploitation rate exerted in the last two decades. A protocol under development by the B.C. Ministry of Fisheries (pers. comm. Eric Parkinson, UBC, Vancouver), defines the limit reference point at 10% of the maximum smolt production. This provides some protection against irreversible damage to the most unproductive populations in an aggregate exposed to mixed-stock fisheries. A level defined in this way would correspond conceptually to the provisional *LRP* of 3 females/km (Wood and Holtby 1998; Holtby and Kadowaki 1998). When expressed in terms of females/km, an escapement floor of 1.13×10^3 corresponds to an escapement of between 1.1 and 2.6 females/km (Table 14).

4. Oregon Coastal Zone target escapements A target of 41 spawners/mile has been adopted in the Oregon coastal zone (Anon. 1997). This corresponds to escapement targets of between 3.3×10^3 and 11×10^3 spawners for the Babine Lake aggregate (Table 14).

An unweighted average of the target escapements indicated by four methods is 1.15×10^3 or approximately 10.9 females/km when the lake shoreline distances are included. Under mean survival conditions the corresponding exploitation rate would be 0.47 or about 66% of the exploitation rate that has been exerted since 1980. Since 1979 the Babine escapement has averaged 28% of this suggested target escapement but has fallen below the provisional floor of 3 females/km only once (in 1997; Figure 28).

Table 13. Linear measures of coho rearing habitat in the Babine Lake system.

coho bearing system	old code	Rabcode	length (km)	notes and alternative names
Nilkitkwa River	10-50-3	48-1800	80.5	
Onerka Lake	10-50-3A		1.9	
Babine River (lower)	10-50(L)	48-0000-000-000-000-000-993	1.3	
Boucher Creek	10-50(L)-1	48-2000	4.8	
Babine River (upper)	10-50(U)	48-0000-000-000-000-000-992	2.1	
Five Mile Creek	10-50B-1	48-2700	4.0	not noted but probably present
Nine Mile Creek	10-50B-2	48-3000	4.0	
Morrison Creek	10-50B-4	48-4800	5.6	Hatchery Creek-site of Dominion hatchery
Tahlo Creek	10-50B-4A-1	48-4800-000-000-000-000-991	8.0	Salmon Creek
Upper Tahlo Creek	10-50B-4B-1		12.9	
Fulton River	10-50B-5	48-6400	6.4	
Tachek Creek	10-50B-6	48-6500	6.4	
Pierre Creek	10-50B-10	48-7600	3.2	
Twain Creek	10-50B-11	48-7700	4.0	
Cross Creek	10-50-12	48-8300	3.2	Pendleton Creek
Pinkut Creek	10-50B-14	48-9000	1.3	15-Mile, Anderson Creek
Gullwing Creek	10-50B-15	48-9400	2.4	6-Mile, Wiggins Creek
Four-Mile Creek	10-50B-16	48-9530	1.6	
Sutherland River	10-50B-18	48-9800	65.0	Beaver River
Shass Creek	10-50B-18-1	48-9800-170	2.4	Grizzly Creek
		total	221.3	
Babine Lake (shoreline)	10-50	48-0000-000-000-000-000-992	503.2	approximate – includes large island perimeters
Effective shoreline (Nilkitkwa Lake, Morrison Lake, North Arm, Morrison Arm)			305.7	
shoreline length for coho			527	

Table 14. Ranges for target escapements of coho to the Babine system. Four targets (A through D) are shown. Their derivation is explained in the text. The arrow indicates the direction of the conversion between females/km and target escapement.

	LRP (females/km)		target escapements: streams only (221.3 km)	target escapements: stream + effective lake margin (length = 527 km)
A	1	→	443	1,054
	3	→	1,328	3,162
	9	→	3,983	9,486
	13	→	5,754	13,702
B	17.1	←	7,561 (S_{opt})	
	7.2	←		7,561 (S_{opt})
C	25.5	←	11,285 ($S_{R\mathrm{max}}$)	
	10.7	←		11,285 ($S_{R\mathrm{max}}$)
	2.6	←	1,129 (10% $S_{R\mathrm{max}}$)	
	1.1	←		1,129 (10% $S_{R\mathrm{max}\,x}$)
D	41† (spawners/mile)	→	5,638	13,426
unweighted average			7,560 (17.1 females/km)	11,493 (10.9 females/km)

† approximately equivalent to 12.7 females/km

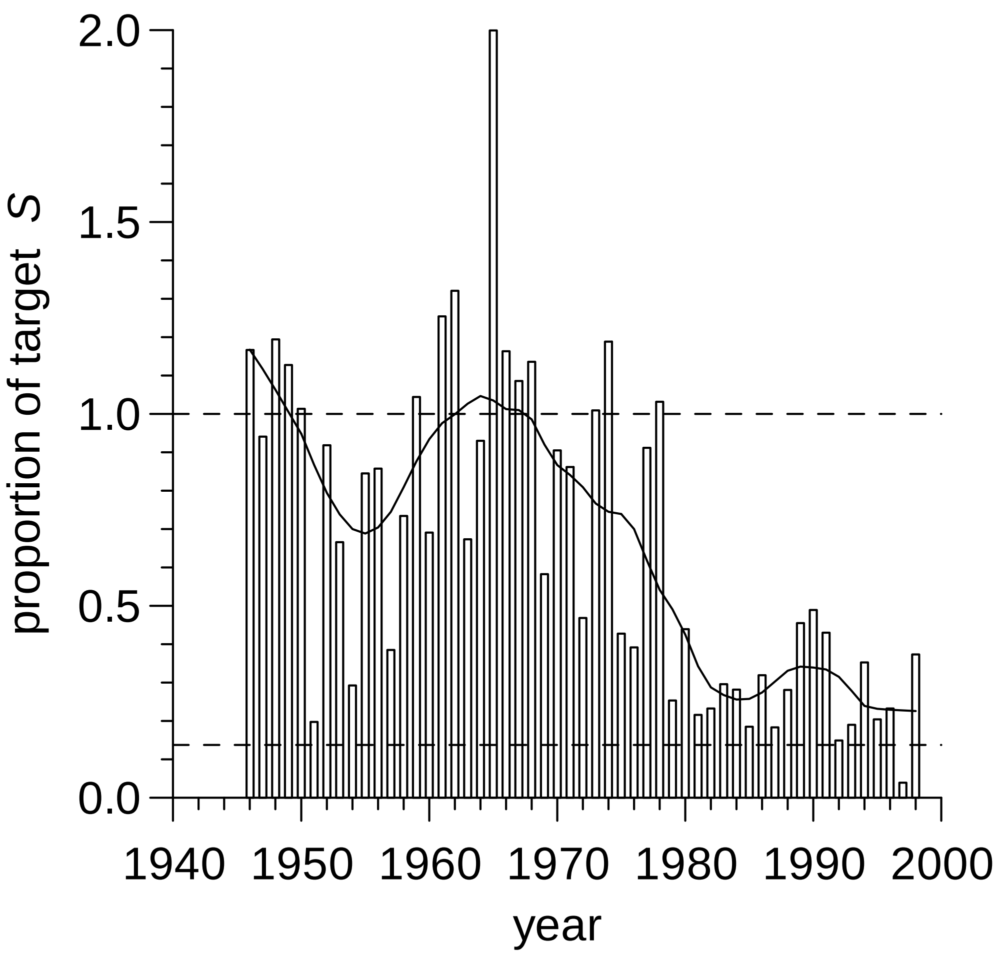

Figure 28. Babine coho escapement as a proportion of proposed escapement target (top dashed line) (see Table 14). The lower dashed line is the proposed escapement floor. The continuous curve is a LOWESS smooth of the proportion.

3.5 Bulkley/Morice coho escapement estimate

Moricetown falls is located along the Bulkley River on the eastern edge of the village of Moricetown approximately 25km northeast of Smithers, British Columbia (Figure 1). Studies conducted in the years 1945 to 1947 by what was then known as the Department of Fisheries of Canada indicated that the Moricetown falls were a significant barrier to adult salmon moving upstream to spawn. Fishways were installed along both the right and left sides of the falls in 1951(Palmer 1964). This project was designed to estimate the number of coho salmon migrating upstream past Moricetown falls.

The tagging and recapture of coho at Moricetown falls consisted of two parts. This work was carried out by Wet'suwet'en Fisheries Program staff. Tagging was conducted at an island approximately 500 meters downstream of Moricetown falls near a point locally known as Idiot Rock (Figure 29). Fish were captured using a 61 x 6 meter beach seine set from a 4.8 meter outboard jet powered boat. All fish captured were identified and counted. All coho and steelhead captured were measured to the nearest millimeter and tagged with a Floy FD68b anchor tag. All coho were given a secondary mark consisting of a caudal fin punch. A small diameter one hole paper punch was used for the secondary marking. A sample of caudal punches was preserved in 70% isopropanol for DNA analysis. The beach seine crew operated Monday to Friday from July 30 to September 18. Tagging was stratified by week, with uniquely coloured and numbered tags used during each tagging period.

Recapture and additional tagging was conducted at the left bank fishway. Fish were captured at the fishway with dipnets. The nets consisted of standard live release sport fishery type net bags attached to custom-built aluminum frames. Dipnet handle length varied from user to user and ranged from approximately 3 to 4.5 meters. All fish captured by the dipnet crew were identified and counted. All coho were inspected for tags or fin punches, measured, tagged with a Floy FD68b anchor tag, caudal punched and released. All steelhead captured were inspected for tags, measured, tagged and released. Recaptured tagged fish were measured and released. All tagged fish were released into a quiet backwater pool on the upstream side of the fishway. The fishway crew operated Monday to Friday from August 5 to September 18, 1998. Tagging at the fishway was not stratified by week. The intention was to use only two distinct tag colours for the entire tagging period. However, because of the large number of coho captured and some tag losses a variety of tag colors were used at the fishway.

Other recapture sites included the Toboggan Creek and Bulkley River adult counting fences. The Toboggan Creek fence operated continuously from August 8 to November 9, 1998 (M. O'Neill pers. comm.). The Bulkley River adult counting fence operated from September 4 to November 10, 1998 (J. Ewasiuk, 1998).

Swim surveys were conducted at various sites in the Telkwa River upstream of Howson Creek and in the lower 24 km of the Gosnell River (Figure 30). These surveys were intended to provide data on tag distribution and tagged versus untagged ratios in two additional coho spawning areas. The swim surveys began with a helicopter overflight of the stream to locate concentrations of adult coho. Areas where coho where located were immediately surveyed using one swimmer and one recorder/shore safety person. The swimmer moved slowly downstream through the areas of interest recording the total number of adult coho and the number and if possible the color of any tags.

A Schaefer method for stratified populations (Ricker 1975) was used to estimate the number of coho salmon moving upstream through Moricetown falls (Taylor 1999). The beach seine crew tagged and released 1526 coho salmon. Total coho catch at the fishway was 1113 including 80 tag recaptures. The fishway crew released approximately 997 additional tagged coho upstream.

Unfortunately, due to tag shortages and some data recording problems, some duplication of tag colors and numbers were found.

Total coho catch at the Toboggan Creek fence was 1920. Of these 163 were tagged at Moricetown, 19 were caudal fin punched with no tag. Total coho catch at the Bulkley River fence was 317. This includes coho that were captured by beach seining in a pool directly downstream of the fence. Of these 31 had been tagged at Moricetown, 1 was caudal fin punched with no tag. Tag recoveries were from throughout the tagging program and included tags from the beach seine and the fishway crews.

The first swim survey was conducted on October 16, 1998 in the Telkwa River upstream of Howson Creek. Conditions for the aerial count were fair with high overcast, light rain and some snow in the headwater areas and at higher elevations. Conditions for the swim survey were also fair. Despite low clear water, small amounts of glacial silt restricted underwater and cross-stream visibility to about 5 meters. Of the 128 coho that were counted 10 had been tagged at Moricetown. Only coho that could be reliably inspected were included in this count. Due to turbidity tag color identification was unreliable.

The second swim survey was conducted at various locations in the Gosnell River and Shea Creek a major lower river tributary on October 19, 1998. Conditions for aerial surveys were excellent, high overcast with no precipitation. Conditions for swim surveys were good with low clear water and close to bank to bank visibility. Of the 130 coho inspected, 6 had been tagged at Moricetown. This included 4 yellow, 1 pink/green and 1 blue tag. The beach seine crew put on the yellow tags in the week of August 10. The beach seine crew put on blue tags during the week of August 24. The pink/green tag was from the fishway tagging crew.

Due to problems with data records and the difficulty reconciling tag recoveries and releases by the fishway crew only tags released by the beach seine crew were used to estimate the coho population moving past Moricetown falls.

The data below were used to estimate escapement by the Schaefer method:

Total effective tags released = 1526
Total catches = 1113
Total tags recovered = 80

The matrix for these data before correction for tag loss is:

(i)	P1	P2	P3	P4	P5	P6	P7		
(j)								Rj	Cj
1								0	10
2	1							1	64
3		8	1					9	167
4		2	8	7				17	258
5			1	12	5			18	271
6				2	8	10		20	160
7					2	5	8	15	183
Ri	1	10	10	21	15	15	8	**80**	**1113**
Mi	62	230	245	398	274	155	162		**1526**

Where Ri = recoveries in each tagging week, Mi = marks released in each tagging week,
Rj = recoveries in each recovery week and Cj = catches in each recovery week.

No tag loss was detected between the seine location and the fishway. This is not surprising given the short distance between the two sites. Tag loss between Moricetown and the counting fences on Toboggan Creek and the Bulkley River was estimated to be 10%. This suggests that tag loss was between 1 and 10%. Therefore a series of estimates was prepared using 1%, 5% and 10% as correction factors representing tag loss. Additional estimates were also prepared by successively incorporating tag recoveries at the Toboggan Creek fence and at the Houston fence. These data are:

Toboggan Creek catch = 1883
Toboggan Creek recoveries = 102
Houston fence total catch = 317
Houston fence recoveries = 33

This resulted in the escapement estimates shown below:

	Estimate	Lower CI	Upper CI
1% tag loss			
Fish ladder	23802	21015	26958
Toboggan	27615	17172	44408
Houston	26027	14338	47802
5% tag loss			
Fish ladder	22840	20166	25869
Toboggan	26499	16478	42614
Houston	24975	13758	45871
10% tag loss			
Fish ladder	21638	19105	24507
Toboggan	25104	15611	40371
Houston	23660	13034	43457

The 95% confidence intervals were derived from log transformation of the estimates, as appropriate for a negative binomial distribution. Taylor's power law may provide a more precise transformation but the simplicity of calculation recommended log transformation. The resultant mean of the transformed data is equivalent to the geometric mean of the original data and this is always smaller than the arithmetic mean. Therefore to avoid an underestimate, the derived factor was applied to the arithmetic mean. This is a close approximation only, since there is no simple method that can be applied to a negative binomial to generate the true confidence limits. The expression used was :

$$y \pm t\sqrt{\frac{\mathrm{var}\,iance \cdot of \cdot transformed \cdot counts}{n}} \tag{13}$$

There are four years where an estimate of the Bulkley/Morice escapement was estimated using mark-recapture with the marks applied at the Moricetown fishway (following Table).

Although there are only four observations the Moricetown estimate is significantly correlated with the Skeena test-fishery index for Aug. 25 and Sept. 4 (r= 0.97 and 0.99, $P < 0.05$). The correlations with the adjusted test-fishery index are much weaker ($r = 0.63$ and 0.76, respectively). The test-fishery index and the Moricetown count are not proportional across the observed range however. The test-fishery index in 1997 was 6% of the 1998 value while the estimated Bulkley/Morice escapement in 1997 was 29% of the 1998 escapement.

year	estimate	95% CI	how
1961	2.6×10^4	?	mark-recapture (Palmer 1964
1994	1.4×10^4	$0.42–2.5\times10^4$	radio-tag mark recapture (Koski et al. 1995)
1997	6.5×10^3	$5.5–8.6\times10^3$	mark-recapture (BF, unpubl. data)
1998	2.28×10^4	$2.02–2.59\times10^4$	mark-recapture at fishway (BF unpubl. data)
1998	2.51×10^4	$1.56–4.04\times10^4$	mark-recapture at Toboggan

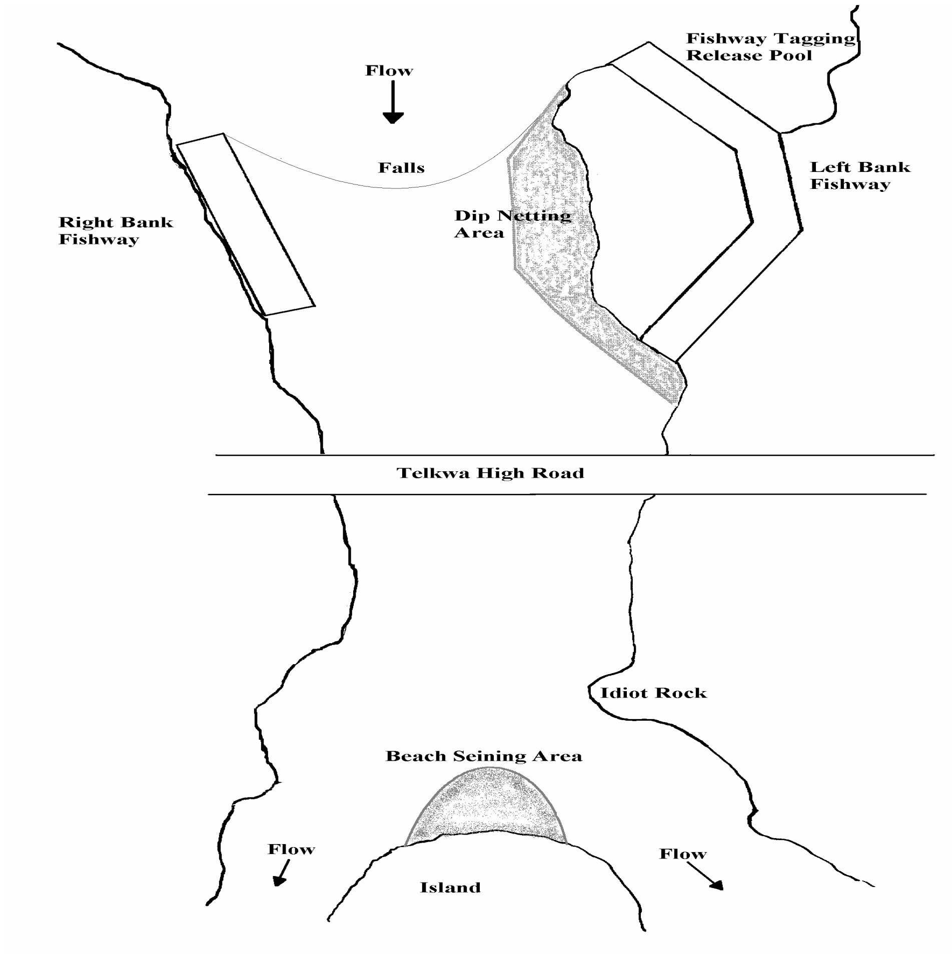

Figure 29. A diagrammatic map of the Moricetown Falls with beach-seining and recovery areas.

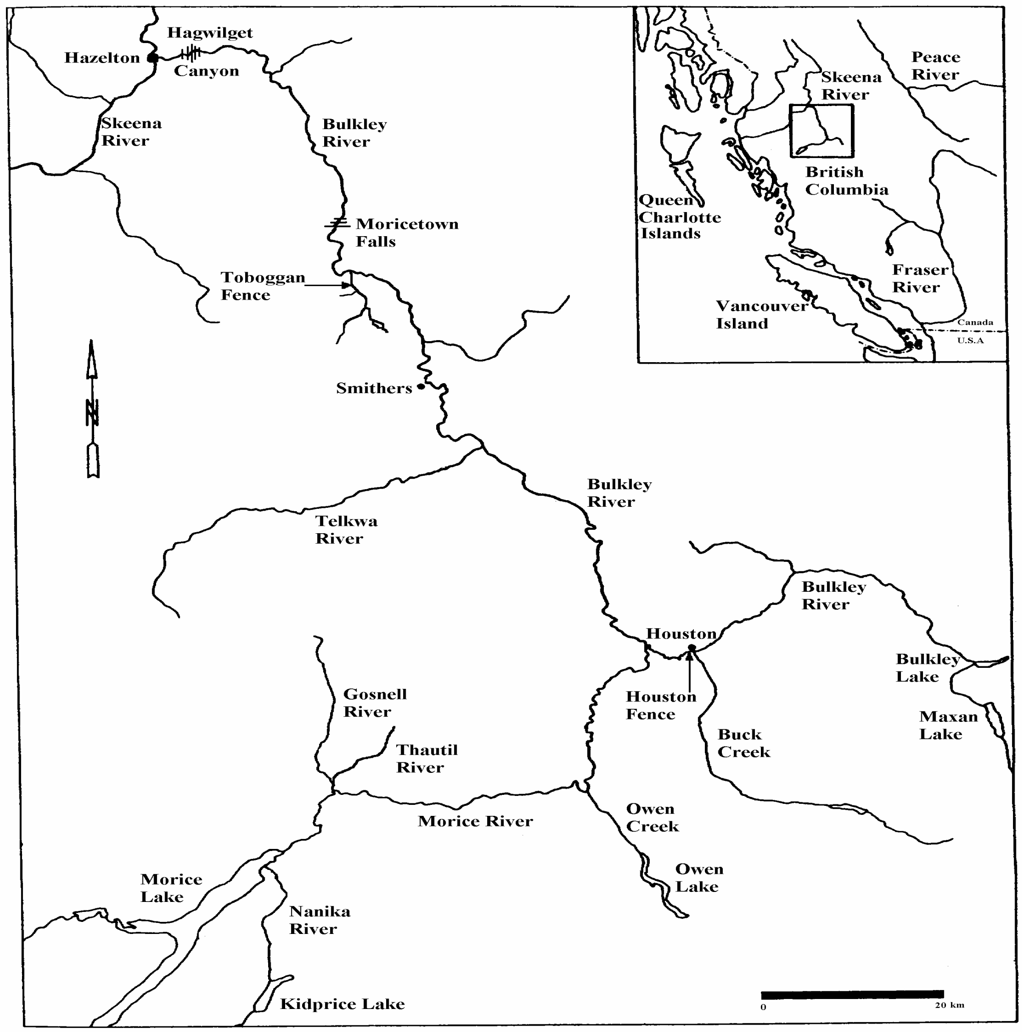

Figure 30. A map of the Bulkley and Morice River systems showing the tagging and recovery areas mentioned in the text.

3.6 Upper Bulkley Escapement

The portion of the Bulkley River upstream of Houston (Figure 30), commonly referred to as the upper Bulkley, used to be a significant producer of coho salmon. Visual escapement estimates, which are almost certainly underestimates of real abundance, indicate escapements as high as 7,650 in the mid-1950's (Table 15; Figure 31). Various groups have operated a fence on the Bulkley River at Houston since 1989 except in 1991. The primary function of the operation is to obtain coho brood-stock for smolt releases to the upper Bulkley, which began in 1989 (1987 brood year). The total escapement in 1998 was 317 of which 139 were the progeny of spawning in the wild, a number slightly greater than brood year escapement.

When visual counts and fence counts are treated on par, almost certainly giving an optimistic view of population trends, the finite rate of decrease between 1970 and 1995 was 11%/year $(1-e^{-0.116})$ or 32%/generation (Figure 32). That rate of decline is approximately double that seen in either the Babine or the test fishery indices.

There are chronic water flow problems in the upper Bulkley River around the time of coho return that affect fence operation and may dissuade coho from moving into the system. The occasional recovery of a CWT from a Bulkley release outside of the upper Bulkley can be used as evidence of this but there is no conclusive evidence that such fish would not have eventually found their way back to the system. The most precautionary interpretation of the near absence of juvenile coho in the upper Bulkley and the declining numbers of wild adults is that this particular population is near extinction.

The role that enhancement has played in the decline of upper Bulkley coho merits some attention. There is little doubt that numbers in the 1980's were lower than they had been in the 1950's. It would be interesting to know if the synchrony of enhancement, which began with a 1989 smolt release, and the rapid decline in wild abundance thereafter was merely a coincidence, and if so what was the probable cause of the decline.

Table 15. Escapement estimates for the upper Bulkley River. Where years are underlined the estimate is a fence count. In years marked by a '♦' good counts of wild and enhanced fish were obtained. The proportion of wild fish in those years was used to estimate the wild component in years between 1991 and 1995. In 1992 the only extant fence records are for the number of enhanced fish in the escapement. The same proportion was used to estimate the wild component and the total escapement in that year.

year	upper Bulkley River	Buck Creek	Maxan Creek	Richfield Creek	Houston fence	total escapement	enhanced escapement	wild escapement
1950	2000	250		50		2300		2300
1951	1000	300		30		1330		1330
1952	2500	300				2800		2800
1953	5000	300		100		5400		5400
1954	7500					7500		7500
1955	5000	60		15		5075		5075
1956	7500	75		75		7650		7650
1957	750	75				825		825
1958	1500	200		75		1775		1775
1959	3500	200				3700		3700
1960	3500	200		75		3775		3775
1961								
1962	2500	500		50		3050		3050
1963	300	400		300		1000		1000
1964	200	600		50		850		850
1965	500	200	100			800		800
1966	1000	200	200	100		1500		1500
1967	600	200				800		800
1968	1000	200	400			1600		1600
1969	1500	300	500	100		2400		2400
1970	600	300				900		900
1971	600	300	300			1200		1200
1972	2500		70	150		2720		2720
1973	1000					1000		1000
1974	200					200		200
1975	28	150				178		178
1976	22	200		25		247		247
1977	280	250		200		730		730
1978	1200	200		250		1650		1650
1979								
1980								
1981								
1982		50						
1983								
1984								
1985								
1986								
1987	18					18		18
1988	10					10		10
<u>*1989*</u>					1500	1500		1500

year	upper Bulkley River	Buck Creek	Maxan Creek	Richfield Creek	Houston fence	total escapement	enhanced escapement	wild escapement
♦ *1990*					965	965	587	378
1991	300					300	195	105
1992						123	80	43
1993					103	103	67	36
1994					141	141	91	50
1995					360	360	234	126
♦ *1996*					*170*	*170*	*109*	*61*
♦ *1997*					*88*	*88*	*69*	*19*
♦ *1998*					317	317	178	139

Table 16. Correlations between the Houston fence count of wild coho and test fishery indices and total Babine escapement. The correlations are only for those years where a fence count was available. The '*' indicates a $P < 0.05$.

upper Bulkley wild escapement correlated with:	*r*
Tyee test fishery – Aug. 10	0.66
Tyee-test fishery – Aug 25	0.75*
Tyee test fishery – Sept. 4	0.70*
adjusted Tyee test fishery – Aug. 25	0.68*
total Babine escapement	0.60

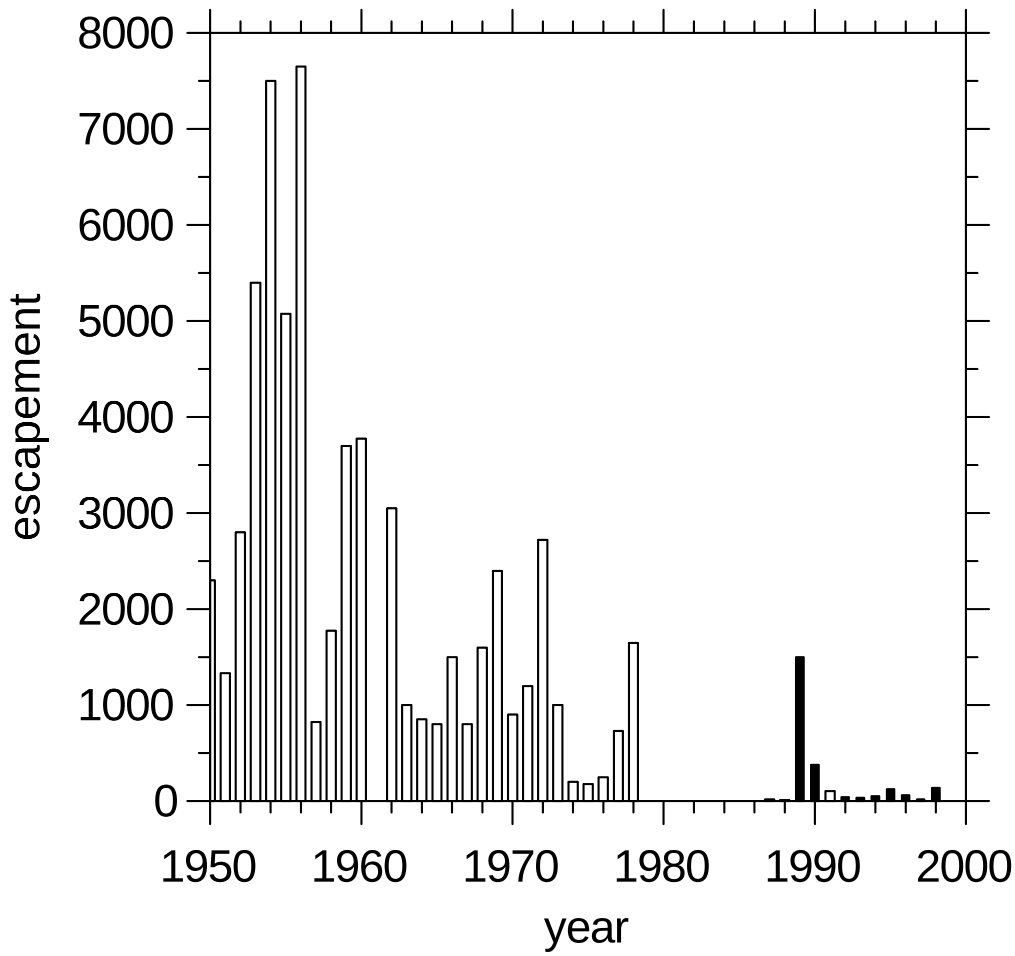

Figure 31. Wild escapement to the upper Bulkley River between 1950 and 1998. The clear bars are visual estimates while the solid bars were made at a fence in Houston.

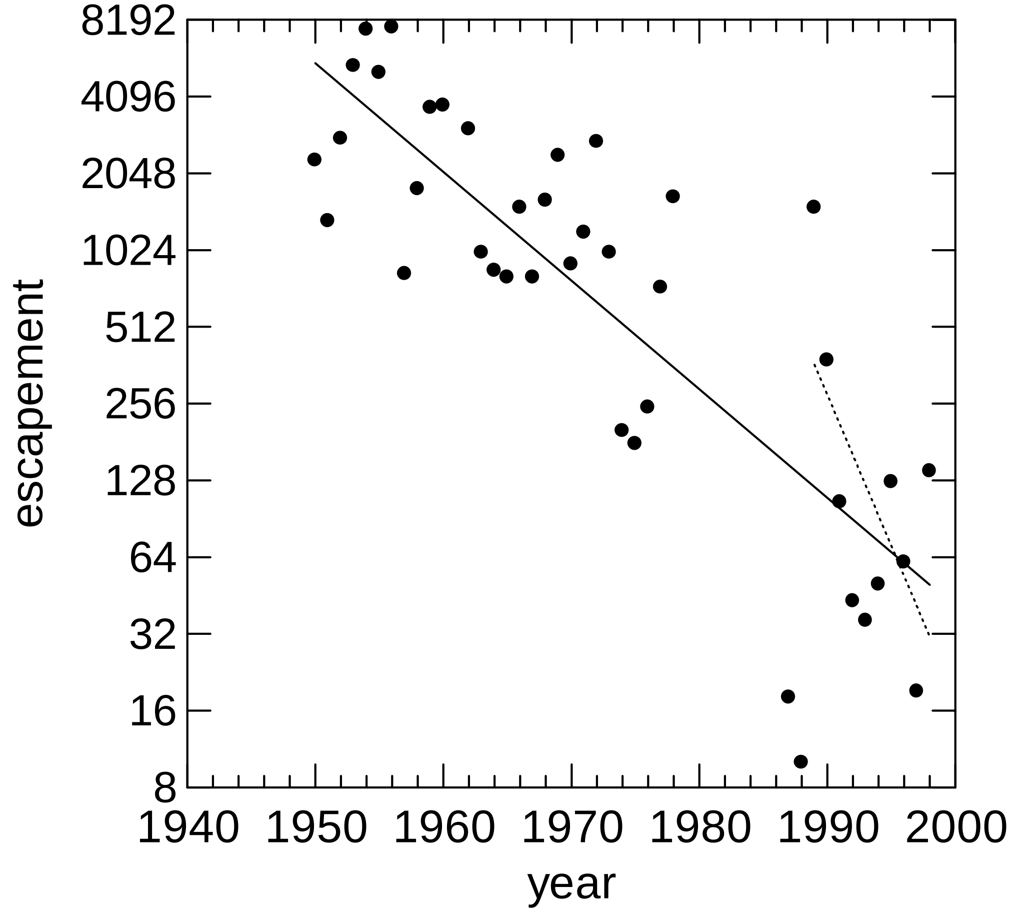

Figure 32. Upper Bulkley wild coho escapement plotted on a logarithmic scale vs. year. The solid line is a linear regression through all of the data. The dotted line also a regression line but includes only the years of fence operation.

3.7 Sustut River escapement

The Sustut River is one of the major river systems in the "High Interior" zone of the Skeena River watershed. From 1992 to the present one or two adult fences have been operated in the system. The mainstem fence is located 700m upstream of the confluence of the Moosevale Creek and provides the most inclusive count. Between 1992 and 1995 fences were operated near the confluence of the Sustut with Johanson Creek. Few coho were reported from these fences and the results are not included here. Between 1992 and 1996 the fences were operated by DFO with the primary objective to enumerate chinook salmon (Frith 1997). In 1997 and 1998 the fence was operated by the B.C. Ministry of Fisheries for steelhead enumeration (pers. comm. D. Atagi, BC Ministry of Environment Lands and Parks, Smithers; Williamson 1997, 1998, 1999).

Chinook, sockeye, steelhead and coho salmon are enumerated at the Sustut fence. Of these coho are the last to appear. The chinook run peaks in early August and the sockeye run in late August. Both steelhead and coho have protracted runs that have broad peaks in mid-September. Run timing is very comparable to the Babine aggregate, which also peaks in mid-September. The fence has been operated from the first of August to the end of September between 1993 and 1998, which may have been sufficient to enumerate most of the migrating coho. Coho were not enumerated in 1992.

year	coho counted	fence removed	comment	data source
1994	137	27-Sep	mainstem fence-700m above Moosevale confluence	Frith 1997
1995	28	16-Oct	mainstem fence	
1996	34	1-Oct	mainstem fence	
1997	5	30-Sep	mainstem fence, all adults were males	Atagi, pers. comm.
1998	64	30-Sep	mainstem fence	Williamson 1998

Escapement in 1998 was approximately twice that observed in 1995 but less than in the primary brood year of 1994. These ratios are similar to those seen elsewhere in the Skeena. Sustut escapement is correlated with other escapement time series for the Skeena (following Table), with the strongest and only significant ($P<0.05$) correlations with the adjusted Tyee test-fishery index and with Lachmach.

$N = 5$	r
Babine esc	0.79
Toboggan	0.78
Tyee-early	0.67
Tyee index	0.61
Tyee-late	0.53
Tyee-index (adjusted)	0.91
Lachmach	0.90

There are approximately 37km of stream habitat and at least 20km of lake margin above the fence site (Frith 1997). This suggests that the carrying capacity of the system is over 1,000 animals (9 females/km) and may be as much as 1,500 (13 females/km). That being so, the current escapements are less than 10% of the carrying capacity, or at a level that is consistent with other areas of the upper Skeena.

4 Productivity Analyses

The following analyses are all fits of the Ricker stock-recruitment model. Our purpose in fitting stock-recruitment models was not to define optimal exploitation rates or escapements. These data, except possibly the Babine Lake aggregate, are not adequate for that purpose. Instead we sought to illustrate that the potential magnitude of productivity differences between aggregates in the northern boundary area. For that reason we have included Hugh Smith Lake coho, a SE Alaskan indicator stream and an SE Alaskan aggregate comprised of 15 index streams where escapement is estimated visually in much the same way as the Canadian visual counts are obtained. We have also included aggregated visual estimates from Statistical Areas 3, 5 and 6.

4.1 Babine Lake aggregate

The data used for stock-recruitment analysis (Table 17) conforms to at least preliminary tests of suitability for this kind of analysis (Hilborn and Walters 1992). The estimates of spawner abundance are probably unbiased with reasonable levels of precision; the range in spawner abundance is nearly 51-fold and there is considerable range in the R/S ratio (0.46–10.4). Recruits per spawner (R/S) were between 1 and 3 through most of the 1940's to late 1970's (Figure 33). There were a few years with much higher values in the aftermath of the 1951 slide and dramatically lowered escapement. Values of R/S rose in the late 1970's and 1980's as escapements fell but then fell again in the 1990's despite even lower escapements (Figure 33).

The linearized form of the Ricker function ($\log R/S = a - aS/b$) was fit to the data followed by correction of the parameter values (a and b) after Hilborn (1985) (; Figure 34; Figure 35). Residual plots (Figure 36 and Figure 37) suggest that the stock-recruitment relationship has become non-stationary in the 1990's. A decrease in stock productivity could be anticipated by the decrease in R/S at low escapements observed in the 1990's. If this decrease in productivity is real then predictions of future performance must be treated with caution.

The stock-recruitment relationship was briefly explored using "SRSHOW", a software program under development by Carl Walters of the University of British Columbia, Vancouver. Among its features SRSHOW allows the user to explore the data and gain a sense of how uncertain the stock-recruitment analysis is. Figure 38 shows typical output from the program for the Babine coho data. The rightmost panel is a plot of the Bayes posterior distribution of u_{opt}. The MSY exploitation rate is poorly defined in this stock but clearly lower values than those produced by conventional analysis are more likely than higher ones. This does not mean that the true value is actually lower or higher than the nominal calculated value of 0.615, but only that the confidence interval is highly asymmetrical.

4.1.1 Estimating uncertainty in the Babine Lake aggregate stock-recruitment analysis

Estimating uncertainty in the parameter estimates that are outputs of the Ricker stock-recruitment analysis was accomplished by repeated fits of a Ricker curve to simulated data. The simulations were designed to treat each variable that was used to estimate escapement and total return as a randomly drawn value from a population with a defined distribution.

<u>Escapement data</u>: Escapement data were treated as observations without error in those years where a complete count was obtained. In all other years the total escapement was calculated from the observed fence counts by dividing them by the average proportion of counts through the fence

in years with complete counts. The random structure was introduced by assuming that the proportion was beta-distributed with the mean and standard deviation equal to the observed mean and standard deviation. The right panel in Figure 39 illustrates the relationship between the escapement estimates and the simulated escapement values.

Exploitation rates: To simulate uncertainty in the exploitation rate, it was assumed that the exploitation rate was uniformly distributed from 0.46 to 0.70 for brood years of 1946 to 1977; uniformly distributed from 0.56 to 0.85 for brood years 1978 to 1990 and uniformly distributed from 95% to 105% of the observed exploitation rates derived from CWTs for the brood years 1991 to 1995.

Age structure: To estimate the age 3 proportions for years in which no age data were available, we regressed the known arcsine square-root-transformed observed age-3 proportions in returning adults on the escapement in the parental generation (i.e., brood year minus 3). The regression results are summarized in Table 18. To implement the random structure for the simulation, we first sampled a from $N(1.171923, 0.078389)$, b from $N(0.000027, 1.01E\text{-}05)$ and ε from $N(0, 0.020772)$, and then back-transformed to get the age 3 proportion[8]. The left panel in Figure 39 shows the age 3 proportion calculated from the regression (labeled as “Page3 without random”) and a random sample for the age 3 proportion (labeled as “Page3 with random”).

Simulation for Ricker model parameters and the MSY parameters: Using the models outlined above we generated 1000 data sets and fit a Ricker model to each one. Estimates of *a*, *b*, and the management parameters are summarized in the following Table.

parameter	mean	*SD*	*CI*: 95%
a	1.668	0.105	1.454–1.868
b	0.0000835	0.0000121	0.0000585–0.000107
S_{MSY}	7,782	994	6,427–9,815
u_{MSY}	0.639	0.0282	0.58–0.69

Distributions of the parameter values output from the simulations are shown in Figure 40.

4.2 Indicator Streams

Stock-recruitment analyses were attempted on data from three of the wild indicators: Lachmach River (Area 3; Table 20), Toboggan Creek (Area 4, upper Skeena; Table 21; Table 22) and Hugh Smith Lake (SE Alaska, Shaul 1998; Table 23). Toboggan Creek is the site of a coho hatchery. Fortunately all of the smolts produced there are externally marked allowing us to determine the number of spawners in the wild (Table 21) and the number of recruits they produced. We assumed that the measured exploitation rate on the hatchery fish at Toboggan applied to the naturally produced coho. There was insufficient data from Zolzap Creek to attempt this analysis.

There are only six estimates of R/S for Lachmach, seven for Toboggan and 12 for Hugh Smith. Nevertheless the Ricker model fit was statistically significant for the Hugh Smith and Lachmach populations but not for Toboggan coho (Table 26). We think that the poor fit of the model to the Toboggan and the Lachmach data is primarily the result of large variations in marine survival and the very short time series. In both systems the log-transformed number of smolts/spawner is significantly correlated with the number of spawners (Lachmach: $r = 0.79$, $P < 0.02$. Toboggan: $r = 0.81$, $P < 0.01$). If recruitment is estimated using the smolt/spawner relationships and a

[8] i.e., $p=\sin(a+bS+\varepsilon)^2$

constant survival of 10%, which is the average, then the estimated productivities of both populations increase slightly (Table 27).

4.3 Areas with visual counts

Standardized escapement time-series were developed from visual counts for Statistical Areas 3, 4-upper, 4-lower, 5 and 6. These data series are tabulated in Holtby et al. (1999a). Time-series of recruits per spawner (*R*/*S;* Table 24) were calculated by assuming the age composition listed in the following Table. Escapement data for 15 consistently surveyed streams in SE Alaska for the period 1987 to 1997 were obtained from Shaul (1998) and processed in an identical fashion to the Statistical Area visual counts to give an average escapement index for SE Alaska. The exploitation rate and age composition for the Hugh Smith Lake was applied to this time-series (Table 25).

Area	exploitation rate time series	age composition time series
SE Alaska index streams	Hugh Smith Lake wild indicator	$p_{\mathrm{age3}} = 0.67$, the average of Hugh Smith Lake
Area 3 (Nass)	Babine Lake reconstruction	$p_{\mathrm{age3}} = 0.61$, the average in the Skeena test fishery
Area 4 (lower Skeena) Area 5 (Principe/Grenville) Area 6 (Kitimat)	average of Babine Lake and Toboggan reconstruction without FW fisheries	$p_{\mathrm{age3}} = 0.61$, the average in the Skeena test fishery
Area 4 (upper Skeena)	average of Babine Lake and Toboggan reconstruction	$p_{\mathrm{age3}} = 0.61$, the average in the Skeena test fishery

This time series of average “Area” escapement was then used in stock-recruitment analyses. The objective in doing so was to roughly characterize the relative productivities of the coho populations in each Area. To do so required time series of age composition and exploitation rate, which are identified in the preceding Table. The derivation of the indices and tabulated index values is given in Holtby et al. (1999a). Values of *R*/*S* for each Statistical Area can be found in Table 24. The results of the Ricker model fits are in Table 26.

4.4 Comparative productivities and status

A simple comparison of the relative productivities of the indicator streams and the average productivities of the aggregates can be made through comparison of estimates of u_{MSY} (Table 26), bearing in mind that data limitations probably make small differences meaningless. Values of u_{MSY} range from 56% in Area 6 to 82% at Hugh Smith Lake (Table 26). If smolt production data and average marine survival are used to estimate productivity then u_{MSY} could be as high as 88% at Lachmach (Table 27).

We considered two simple measures of status. The first was the raio of the average escapement over the past seven years (2 generations) to the escapement at *MSY* estimated by the Ricker models (Figure 50). The second was the finite rate of change between 1970 and 1996 in the index aggregates, the Babine aggregate, the test-fishery index, the upper Bulkley aggregate and the troll catch per hook in the SE Alaska troll fishery. The latter is one of several indices of abundance of SE Alaska coho (Shaul 1998). For the test-fishery index and the upper Bulkley aggregate we used the u_{MSY} value for Toboggan Creek coho. For both measures of status we found a significant relationship to our estimates of u_{MSY}. (Figure 50; Figure 51), i.e., status is directly related to estimated relative productivity. We emphasize that these measure of u_{MSY} should only be used in a relative or comparative sense. We do not wish to imply that these represent target exploitation rates for these populations.

4.5 Temporal trends in productivity

In Section 4.1 we commented that the pattern of residual suggested that productivity of the Babine population had decreased in the 1990's. To compare the temporal pattern in residual among the Statistical Areas we examined simple correlations between their residuals (Table 28) and used Principal Components Analysis (Table 29). The PCA suggests that there are three temporal patterns. The temporal pattern seen in the Babine is shared by the indices from Area 3 and the lower Skeena, as indicated by the loadings on the first component. Area 6 and the upper Skeena comprise the second grouping. The temporal pattern of Area 5, which loads on the third component, is distinctive. Area 6 and the upper Skeena share the large reversal in residual values between the 1994 and 1995 brood years (Table 24; Figure 52). The large positive residuals are due largely to the equally large increases to escapements in both areas (Figure 3). The problems with the 1998 index in the upper Skeena have been discussed previously leaving in doubt whether the increases in escapement were as large as indicated by the indices. However, when the 1995 brood year was excluded from the analysis the results remained largely unchanged.

The grouping of Areas might reflect underlying distributions of fish in the ocean. Babine Lake coho have a distribution in fisheries that is similar to Lachmach coho, while Toboggan and Kitimat (Area 6) coho are distributed more to the south (Anon. 1991, 1994; Holtby et al. 1994). The upper Skeena index is dominated by non-Babine sites, which might account for its similarity to Area 6 index. The distribution of lower and middle Skeena fish (e.g. Dry Creek) is intermediate. One possible inference from these relationships is that a major source of recruitment variability is marine survival influenced by fish behaviors.

Table 17. Stock-recruitment data for the Babine Lake coho aggregate.

brood year	p_{age3}	u	total escapement	total return	brood year recruitment (R)	recruits per spawner (R/S)	residual ln(R/S)	residual recruitment
1946	0.65	0.55	13411	29605	25419	1.895	0.17	4042
1947	0.65	0.55	10815	23874	37216	3.441	0.54	15513
1948	0.65	0.55	13734[9]	30318	33963	2.473	0.47	12689
1949	0.52	0.55	12961	28611	19710	1.521	-0.09	-1791
1950	0.59	0.55	11654	25726	11072	0.950	-0.67	-10637
1951	0.51	0.55	2276[10]	45093	14569	6.400	0.40	4826
1952	0.53	0.55	10554	23298	19916	1.887	-0.08	-1759
1953	0.57	0.55	7655	16899	16831	2.199	-0.19	-3501
1954	0.80	0.55	3359	7415	14665	4.366	0.12	1606
1955	0.60	0.55	9714	21443	21716	2.236	0.01	223
1956	0.67	0.55	9857	21760	20658	2.096	-0.04	-877
1957	0.78	0.55	4421	9759	24229	5.480	0.44	8586
1958	0.62	0.55	8438	18626	35591	4.218	0.53	14684
1959	0.62	0.55	12004	26499	23871	1.989	0.10	2193
1960	0.75	0.55	7942	17532	24758	3.117	0.19	4195
1961	0.65	0.55	14416	31824	37511	2.602	0.58	16492
1962	0.56	0.55	15183	33517	31638	2.084	0.43	10956
1963	0.67	0.50	7737	15413	31443	4.064	0.43	11042
1964	0.49	0.63	10689	28580	37036	3.465	0.53	15345
1965	0.47	0.48	22985	44373	14915	0.649	-0.05	-757
1966	0.67	0.59	13377	32547	17961	1.343	-0.17	-3426
1967	0.59	0.47	12487	23605	23911	1.915	0.10	2307
1968	0.27	0.59	13054	31456	16915	1.296	-0.24	-4562
1969	0.52	0.50	6702	13512	20366	3.039	0.05	996
1970	0.55	0.57	10404	24028	23332	2.243	0.07	1679
1971	0.53	0.57	9909	22990	25784	2.602	0.18	4235
1972	0.70	0.66	5381	15641	8773	1.631	-0.69	-8712
1973	0.60	0.51	11606	23735	18666	1.608	-0.15	-3046
1974	*0.71*[11]	0.56	13661	31189	19977	1.462	-0.06	-1322
1975	*0.60*	0.46	4913	9099	31780	6.468	0.65	15138
1976	*0.60*	0.46	4499	8285	12004	2.668	-0.28	-3806
1977	*0.46*	0.59	10474	25361	19842	1.894	-0.09	-1822
1978	*0.78*	0.69	11861	37775	4016	0.339	-1.69	-17677
1979	*0.77*	0.71	2909	10066	9587	3.296	-0.21	-2183
1980	*0.78*	0.74	5046	19332	18157	3.599	0.07	1266
1981	*0.36*	0.67	2486	7442	7473	3.006	-0.33	-2969
1982	*0.79*	0.58	2673	6365	11306	4.229	0.02	260
1983	*0.74*	0.81	3402	17447	17668	5.193	0.29	4492
1984	0.54	0.72	3241	11454	6897	2.128	-0.61	-5838

[9] The fence was not operated in 1948. Escapement was estimated from Alaskan catch/hk and total SE wild troll catch.

[10] A slide in the Babine River partially blocked access to Babine Lake. Total escapement in the absence of a slide would have been 20,427, which was estimated in the same way as the 2948 escapement.

[11] Italicized age proportions were observed. The remainder were estimated.

brood year	p_{age3}	u	total escapement	total return	brood year recruitment (R)	recruits per spawner (R/S)	residual ln(R/S)	residual recruitment
1985	*0.85*	0.75	2129	8585	10642	4.999	0.14	1411
1986	*0.81*	0.83	3671	21098	16457	4.483	0.17	2574
1987	*0.90*	0.64	2101	5788	21795	10.373	0.87	12662
1988	0.81	0.63	3225	8668	18086	5.609	0.35	5399
1989	0.77	0.67	5228	15988	6388	1.222	-0.99	-10832
1990	0.81	0.74	5619	21285	13232	2.355	-0.30	-4646
1991	0.78	0.77	4941	21205	24808	5.021	0.40	8113
1992	0.73	0.70	1714	5731	16272	9.495	0.75	8562
1993	0.72	0.72	2186	7921	6743	3.084	-0.34	-2689
1994	0.74	0.86	4053	28947	2906	0.717	-1.63	-11910
1995	0.81	0.87	2345	18038	8589	3.663	-0.15	-1386
1996	0.80	0.67	2669	8088	–	–	–	–
1997	0.76	0.55	453	1007	–	–	–	–
1998	0.80	0.60	4291	10728	–	–	–	–

Table 18. Regression relationship between BY escapement (S) and the proportion of age-3 adults in BY+3 ($p_{age\ 3}$).

$$\text{Arcsin}(\sqrt{p_{age3}}) = 1.171923(\text{s.e.}=0.078389) – 0.000027(\text{s.e.}= 1.01\text{E-}05)\ S$$

(N = 13; adj. r^2 = 0.35; MSE = 0.02077; $P < 0.05$)

Table 19. Ricker stock-recruitment function for the Babine lake coho aggregate.

$$\log R/S = 1.6558 – 0.0000887\ S$$

(N = 50; adj. r^2 = 0.39; $P < 0.001$; $MS_{residual}$ = 0. 2676)

S_{MSY} = 7,561; S_{rmax}=11,285; u_{MSY} = 0.67

Table 20. Stock-recruitment data for the Lachmach River coho indicator.

return year	escapement	u	total return	smolts/ spawner	$p_{age\ 3}$	recruits	R/S
1989	599	0.623	1590	45.3	0.221	2011	3.357
1990	971	0.764	4116	29.9	0.174	3758	3.870
1991	1141	0.728	4194	31.0	0.006	3739	3.277
1992	409	0.756	1679	112	0.340	3611	8.829
1993	720	0.651	2065	53.6	0.339	2163	3.005
1994	1317	0.712	4570	19.1	0.322	2062	1.565
1995	975	0.697	3223	22.5	0.303		

1996	1102	0.719	3925	7.1	0.312
1997	758	0.561	1728		0.462
1998	1086	0.464	2025		0.346

Table 21. Details of escapement to the Toboggan hatchery indicator. "Non-CWT hatchery escapement" was comprised of ventral-clipped fish. Brood stock were removed at the Toboggan Creek fence from the unmarked escapement.

year	total escapement	non-CWT hatchery escapement	total hatchery escapement	wild escapement	brood stock	spawners in the wild
1988	1401	0	397	1004	117	1284
1989	2356	225	503	1853	55	2301
1990	2807	56	393	2414	32	2775
1991	3336	0	614	2722	56	3280
1992	2025	44	206	1819	51	1974
1993	1437	30	297	1140	50	1387
1994	2416	31	623	1793	54	2362
1995	1762	1	313	1449	39	1723
1996	1185	4	220	965	61	1124
1997	394	0	73	321	35	359
1998	2470	3	443	2027	55	2415

Table 22. Stock-recruitment data for the Toboggan Creek indicator.

return year	escapement	*u*	total return	smolts/ spawner	$p_{\text{age 3}}$	recruits	*R*/*S*
1988	1284	0.404	1688	34.5	0.687	5845	4.552
1989	2301	0.663	5495	21.6	0.881	5349	2.325
1990	2775	0.723	8709	26.5	0.447	4549	1.639
1991	3280	0.663	8073	9.1	0.459	4479	1.365
1992	1974	0.691	5890	16.9	0.636	3196	1.619
1993	1387	0.683	3601	28.2	0.556	2291	1.651
1994	2362	0.686	5709	16.9	0.554	1752	0.742
1995	1723	0.466	2711	21.3	0.514		
1996	1124	0.739	3694	41.1	0.512		
1997	359	0.532	687		0.417		
1998	2415	0.282	2823		0.481		

Table 23. Stock-recruitment data for the Hugh Smith Lake coho indicator.

return year	escapement	u	total return	$p_{\text{age 3}}$	recruits	R/S
1982	2144	0.648	6091	0.664	3030	1.413
1983	1490	0.615	3870	0.664	3572	2.398
1984	1408	0.649	4011	0.664	2474	1.757
1985	903	0.626	2414	0.608	1358	1.504
1986	1783	0.601	4469	0.651	2723	1.527
1987	1118	0.523	2344	0.716	4173	3.733
1988	513	0.665	1531	0.481	6362	12.40
1989	424	0.821	2369	0.738	4309	10.16
1990	870	0.811	4603	0.788	6866	7.892
1991	1826	0.681	5724	0.905	8258	4.522
1992	1426	0.708	4884	0.757	5677	3.981
1993	830	0.806	4278	0.857	3861	4.652
1994	1753	0.814	9425	–	–	–
1995	1781	0.736	6746	–	–	–
1996	958	0.757	3942	–	–	–
1997	732	0.724	2652	–	–	–

Table 24. Time series of *R*/*S* for the Statistical Area average escapement indices.

brood year	Area 3	lower Skeena	upper Skeena	Area 5	Area 6
1950	2.3	2.3	2.3	3.0	3.0
1951	2.2	2.1	3.4	2.9	1.5
1952	4.4	2.1	2.4	2.9	2.0
1953	3.2	3.4	2.2	3.1	3.2
1954	2.9	3.5	1.8	2.4	2.1
1955	1.8	3.5	2.2	1.8	1.6
1956	2.9	2.2	1.9	1.8	0.9
1957	4.5	1.8	3.6	2.0	1.1
1958	2.7	1.0	2.1	3.3	2.4
1959	3.7	1.5	2.3	1.9	3.8
1960	5.0	2.6	2.6	3.4	3.4
1961	2.9	4.6	2.2	2.6	3.4
1962	5.4	5.2	1.3	4.1	2.3
1963	2.3	4.3	1.3	2.4	1.3
1964	2.1	2.0	1.4	1.4	2.0
1965	1.5	2.2	1.8	1.3	1.4
1966	1.1	1.4	2.5	0.5	1.2
1967	2.3	4.1	3.2	0.6	1.9
1968	1.6	1.3	4.0	0.6	1.4
1969	2.3	2.7	3.8	2.4	3.6
1970	1.1	1.5	2.3	5.2	1.8
1971	0.9	1.3	1.6	5.4	1.7
1972	1.5	1.2	0.5	3.4	1.4
1973	2.1	2.0	1.4	2.7	2.3
1974	3.4	2.7	3.6	3.0	2.2
1975	3.0	3.7	10.1	2.1	2.2
1976	2.0	2.7	4.7	2.5	2.7
1977	2.4	3.5	3.0	2.1	2.8
1978	2.3	1.9	1.4	1.8	2.4
1979	2.0	2.0	2.0	2.0	2.0
1980	8.7	4.8	2.8	3.6	3.9
1981	6.0	5.6	3.6	1.9	3.8
1982	8.4	7.0	4.6	19.4	4.5
1983	4.9	9.8	4.0	11.0	6.7
1984	1.8	1.9	1.4	5.1	1.9
1985	1.2	2.5	0.9	3.5	1.6
1986	3.2	2.2	1.5	1.0	2.1
1987	3.7	4.2	4.5	1.6	3.9
1988	5.5	13.0	7.0	1.0	4.3
1989	3.4	2.5	3.2	3.2	3.2
1990	4.6	1.8	4.0	4.9	1.9
1991	12.4	3.0	4.0	10.6	1.8
1992	4.4	2.3	2.8	5.5	1.6
1993	2.5	2.5	2.7	8.1	2.2
1994	0.7	1.2	1.4	3.0	2.2
1995	2.0	3.0	13.9	3.5	8.9

Table 25. Stock recruitment data for the SE Alaskan escapement index streams.

return year	p_{max}	escapement	u	total return	$p_{age\ 3}$	recruits	R/S
1987	0.425	378	0.523	793	0.668	1585	4.19
1988	0.338	301	0.665	899	0.668	1631	5.41
1989	0.495	440	0.821	2461	0.668	2148	4.88
1990	0.342	305	0.811	1613	0.668	3087	10.12
1991	0.547	487	0.681	1527	0.668	3268	6.71
1992	0.603	537	0.708	1838	0.668	2299	4.28
1993	0.604	538	0.806	2771	0.668	1876	3.49
1994	0.778	692	0.814	3721	0.668		
1995	0.699	622	0.736	2356	0.668		
1996	0.596	531	0.757	2184	0.668		
1997	0.389	346	0.724	1255	0.668		

Table 26. Stock-recruitment parameters and statistics for the indicator streams and the visual escapement indices. The average escapement were calculated for the period 1992 to 1998 for the Canadian data and for the period 1991 to 1997 for the Alaskan sites.

parameter	indicator or escapement index									
	Lachmach	Toboggan	Hugh Smith	SE index	Area 3	lower Skeena	upper Skeena	Babine aggregate	Area 5	Area 6
a'	2.422	1.555	2.667	2.595	1.834	1.978	1.774	1.790	1.874	1.394
b'	1,884	3,908	2,645	1,52	3,610	2,250	1,528	20,176	2,122	2,640
u_{MSY}	0.80	0.61	0.84	0.83	0.68	0.72	0.67	0.67	0.69	0.56
S_{MSY}	623	1,529	829	399	1,342	814	574	7,561	783	,1062
N	6	7	12	7	46	45	45	50	46	46
r	0.8	0.52	0.71	0.59	0.565	0.61	0.394	0.63	0.648	0.604
P	<0.06	0.23	<0.01	0.16	<<0.001	<<0.001	<0.001	<0.001	<<0.001	<<0.001
average 2-gen escapement	910	1,621	1,329	536	1,453	732	307	2,530	512	325
as proportion of S_{msy}	146%	106%	160%	134%	108%	90%	53%	33%	65%	31%

Table 27. Stock-recruitment parameters and statistics for the Lachmach and Toboggan indicator populations when the observed smolts/spawner and a constant marine survival of 10% is used to estimate recruitment. The values of *N*, *r*, and *P* are from the regressions of *Ln*(smolts/spawner) on spawners.

parameter	indicator stream	
	Lachmach	Toboggan
a'	3.173	1.845
b'	1500	3690
u_{MSY}	0.88	0.68
S_{MSY}	417	1369
N	8	9
r	0.79	0.81
P	<0.02	<0.01
average 2-gen escapement	910	1621
as proportion of S_{msy}	218%	118%

Table 28. Correlations between residual *Ln*(*R*/*S*) for the Canadian Statistical Area aggregates and the Babine Lake aggregate (*N* = 46). **P*<0.05; ***P*<0.01; ****P*<0.001.

	Area 3	lower Skeena	upper Skeena	Babine	Area 5
lower Skeena	0.610***				
upper Skeena	0.279	0.434**			
Babine Lake	0.374*	0.423**	0.291*		
Area 5	0.225	0.032	0.036	0.195	
Area 6	0.169	0.489***	0.594***	0.152	0.211

Table 29. Principal Components Analysis on residual *Ln*(*R*/*S*) for the Canadian Statistical Area aggregates and the Babine Lake aggregate.

escapement index	loading on VARIMAX rotated component		
	1	2	3
Area 3	0.845	0.094	0.106
lower Skeena	0.733	0.478	–0.135
upper Skeena	0.237	0.828	–0.066
Babine Lake	0.736	0.076	0.149
Area 5	0.129	0.064	0.979
Area 6	0.066	0.910	0.182
% variance explained	31%	29%	17%

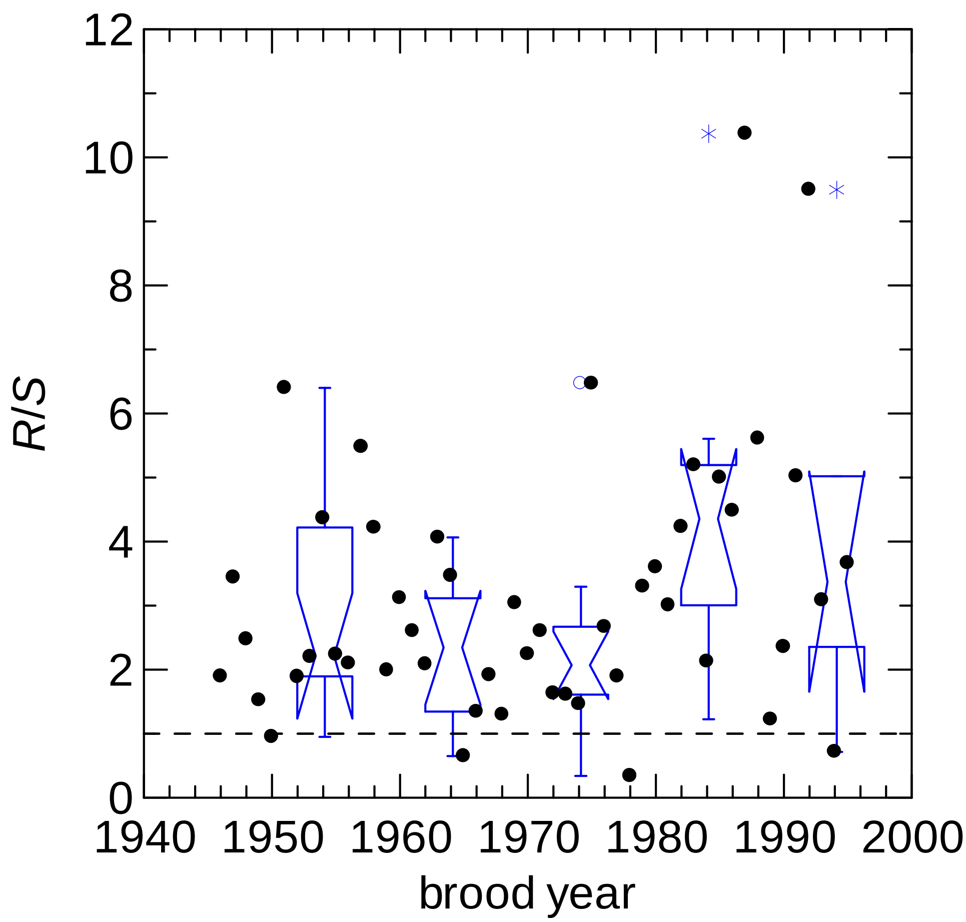

Figure 33. Recruits/spawner (*R*/*S*) vs. return year for the Babine Lake coho aggregate. The box plots summarize the residuals by decade, with the first decade including the few years in the 1940's were observations were made.

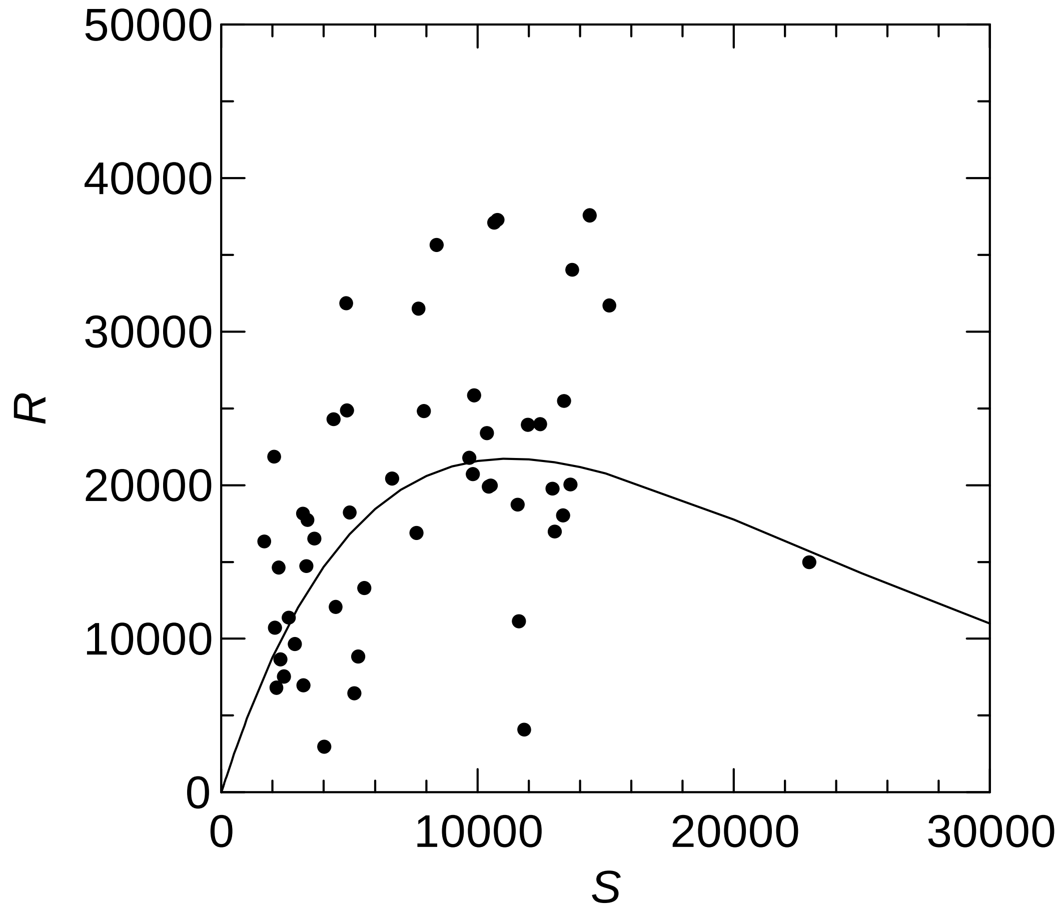

Figure 34. The stock-recruitment relationship for the Babine Lake coho aggregate. A fitted Ricker function is shown.

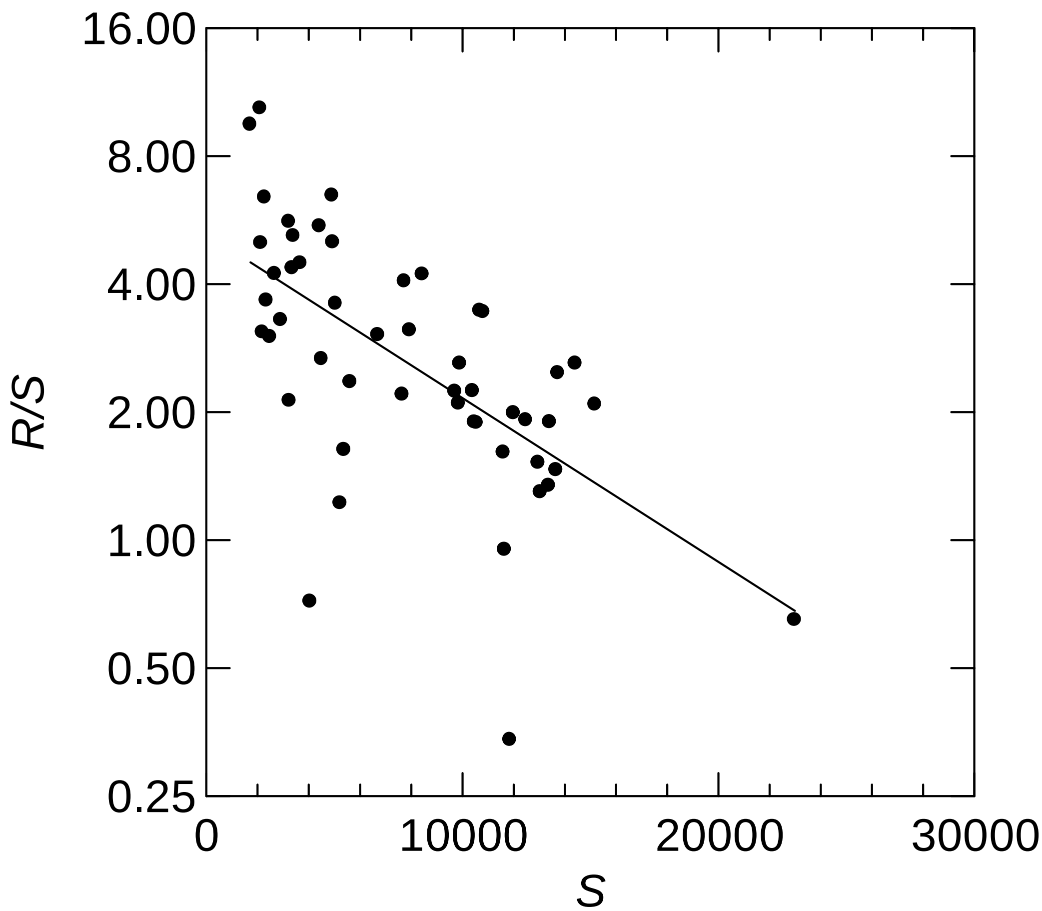

Figure 35. The stock-recruitment relationship for the Babine Lake coho aggregate shown in linearized form. The linear regression line fit to the data is detailed in Table 19.

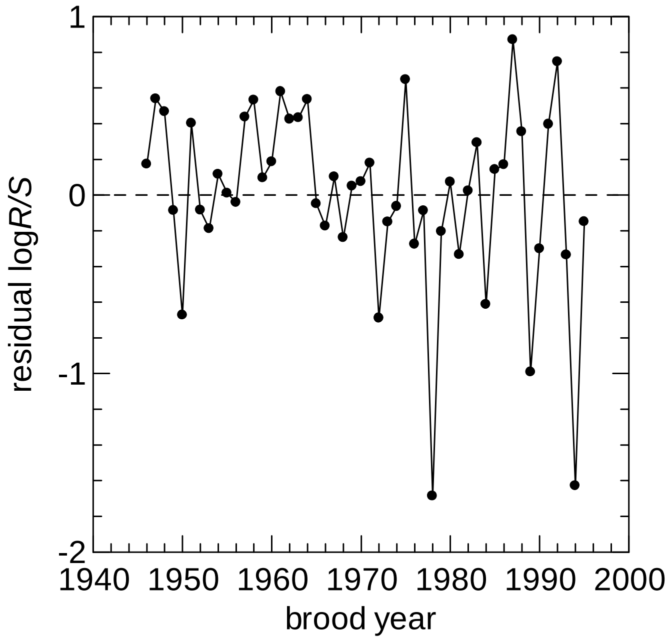

Figure 36. Time series of residuals for the Babine Lake coho aggregate stock-recruitment relationship in linearized form.

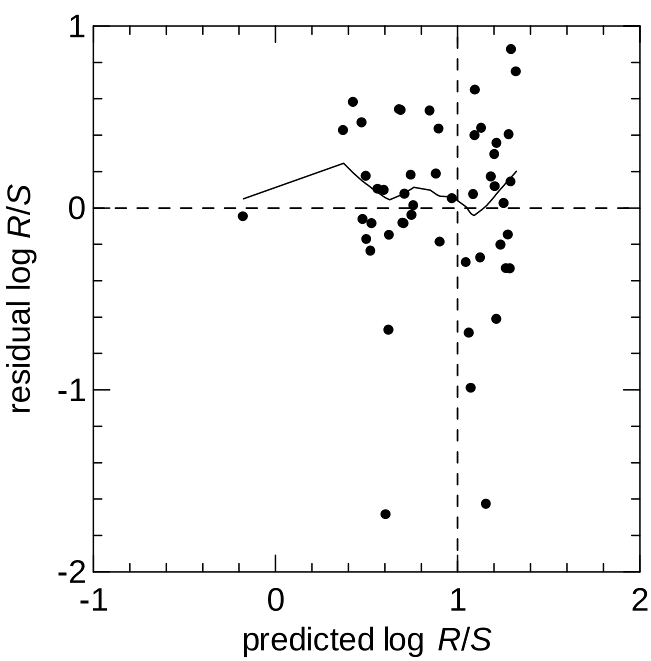

Figure 37. From the Babine stock recruitment analysis, residual log *R*/*S* vs. the predicted values of log *R*/*S*. The line is a LOWESS smooth .

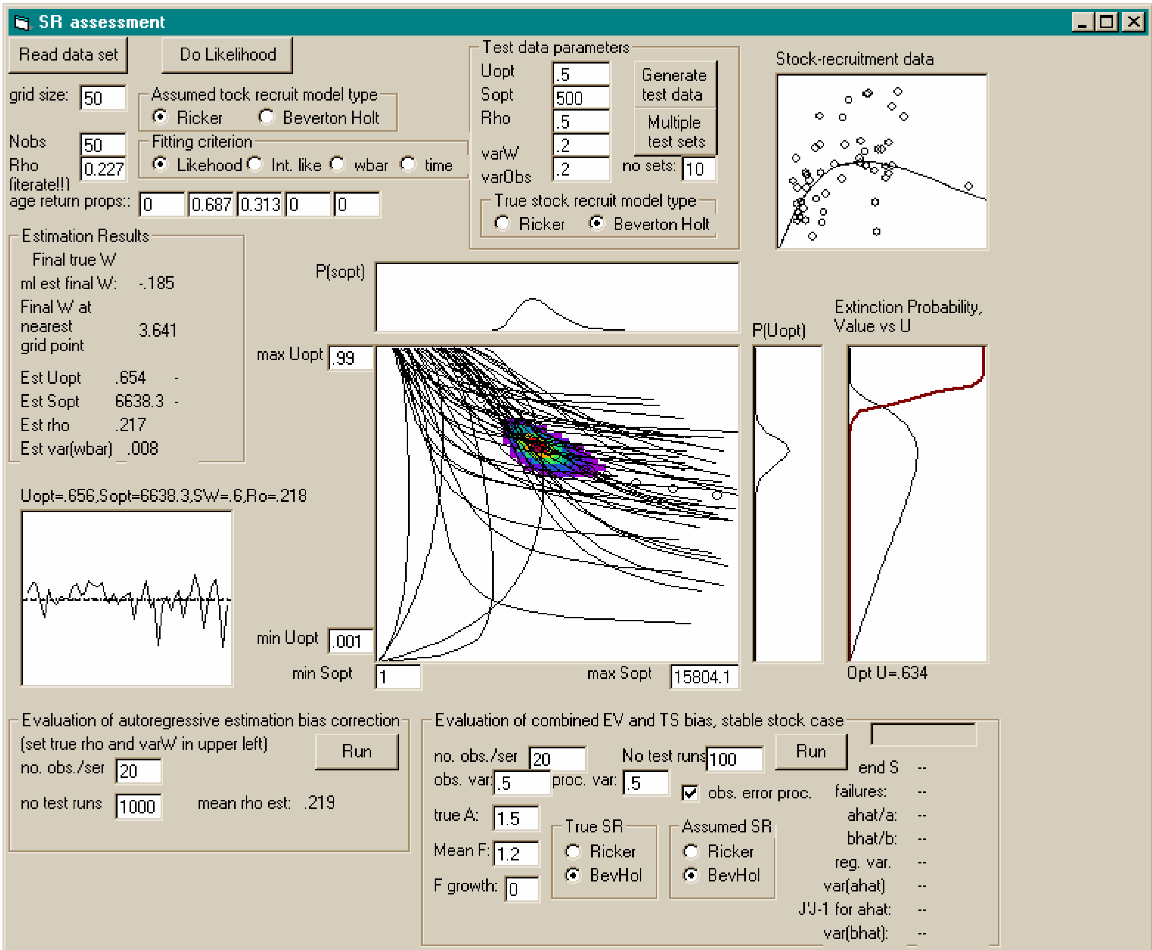

Figure 38. Output from "SRShow", a stock-recruitment tool under development by C. Walters, University of BC, Vancouver.

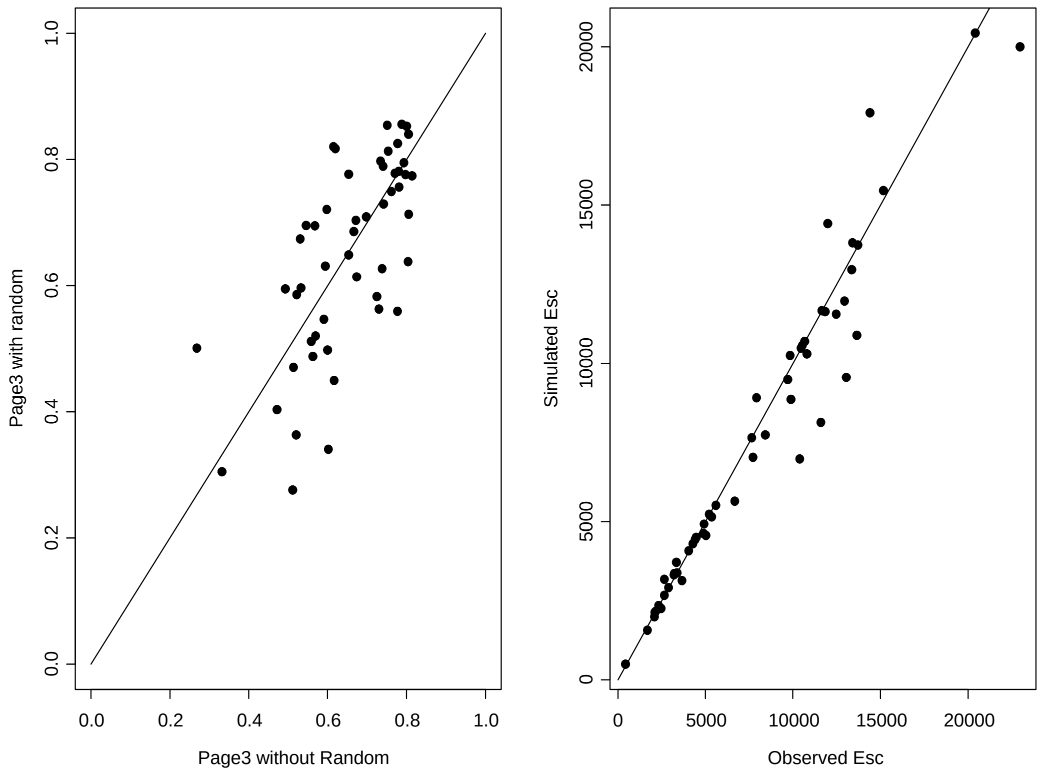

Figure 39. Illustrations of the age (left panel) and escapement (right panel) simulations used to estimate uncertainty in the Babine Lake aggregate stock-recruitment analysis.

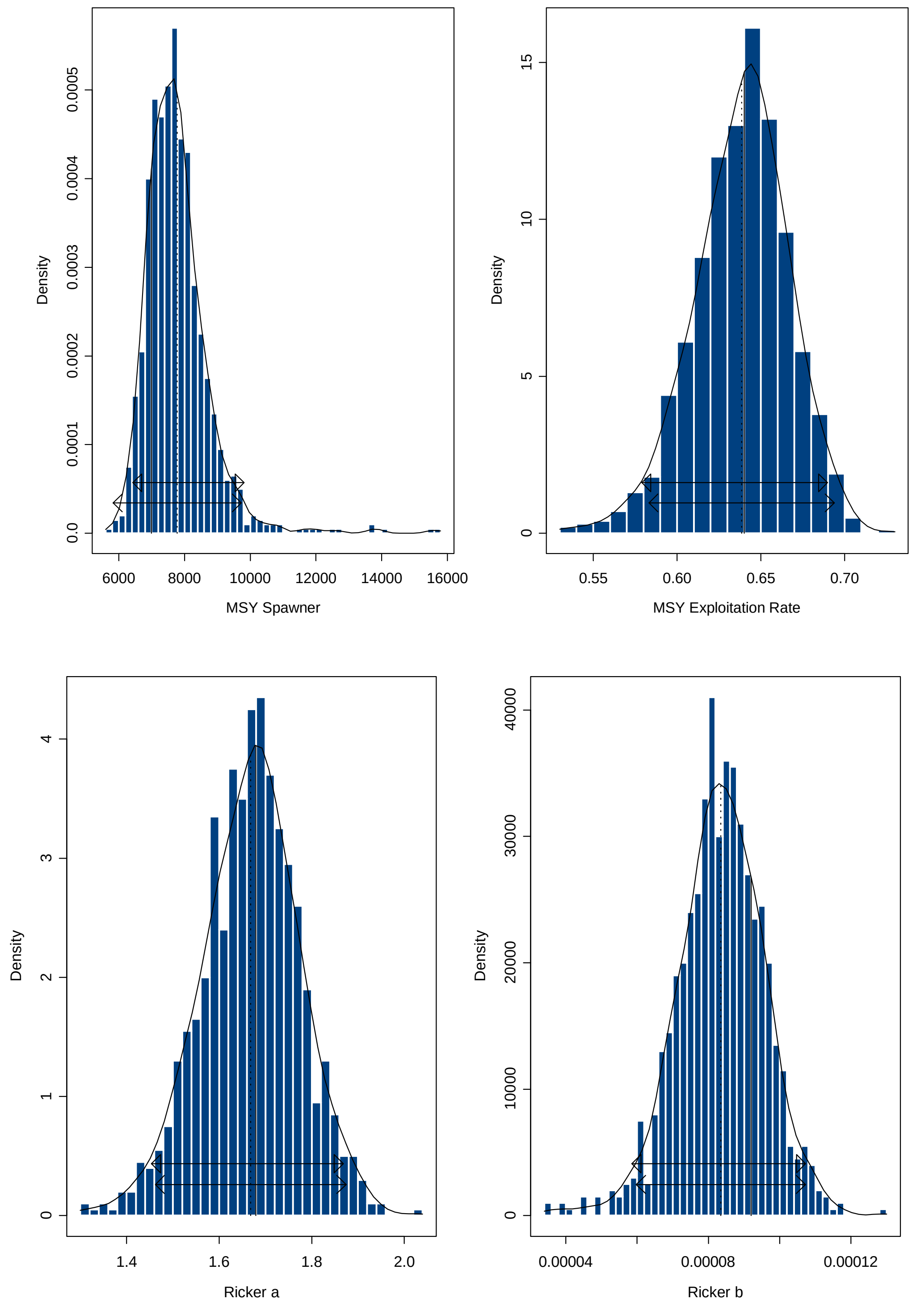

Figure 40. Simulated distributions for Ricker parameter *a* and *b* and for the management parameters S_{MSY} and u_{MSY}.

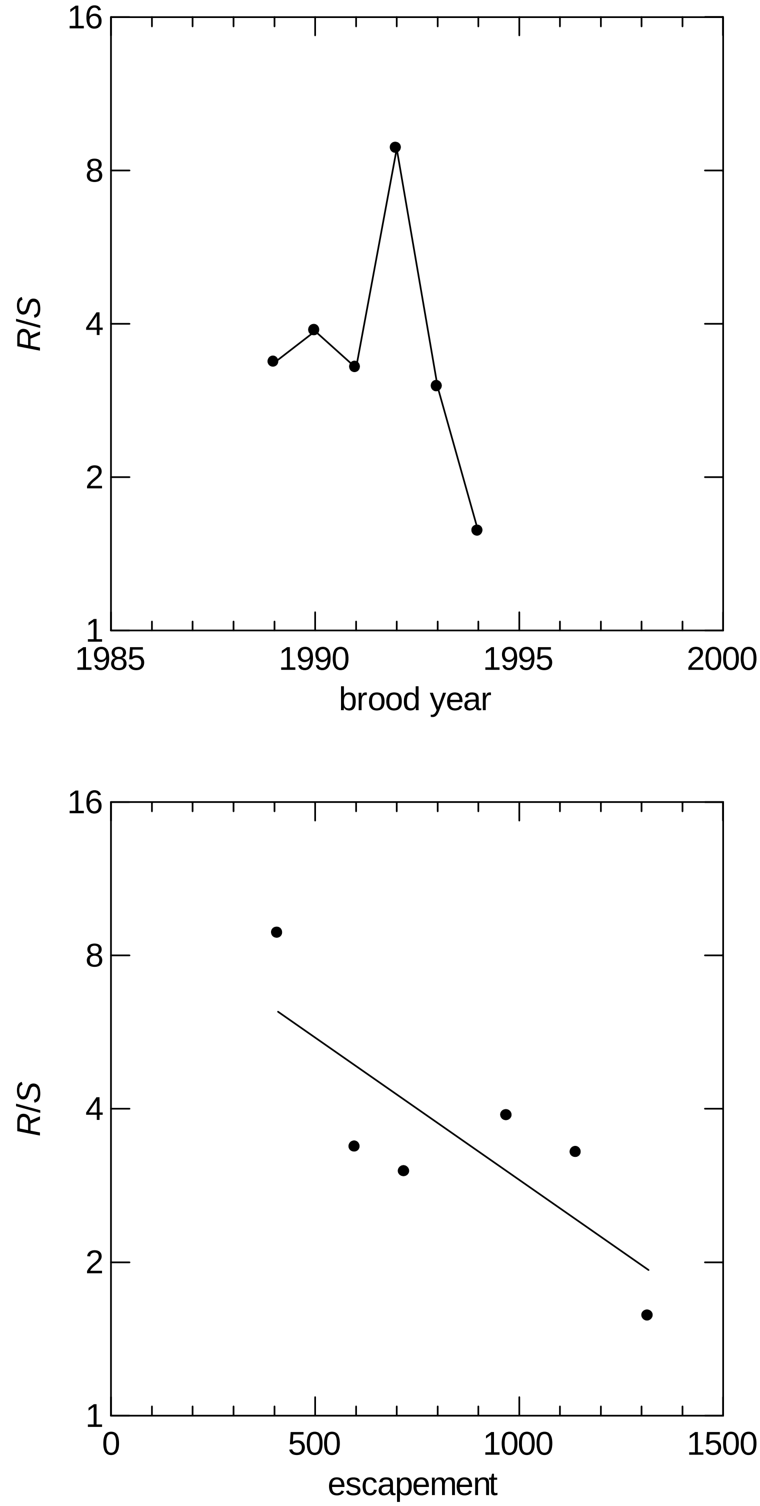

Figure 41. For the Lachmach River indicator population plots of *R*/*S* vs brood year (top) and against escapement (bottom).

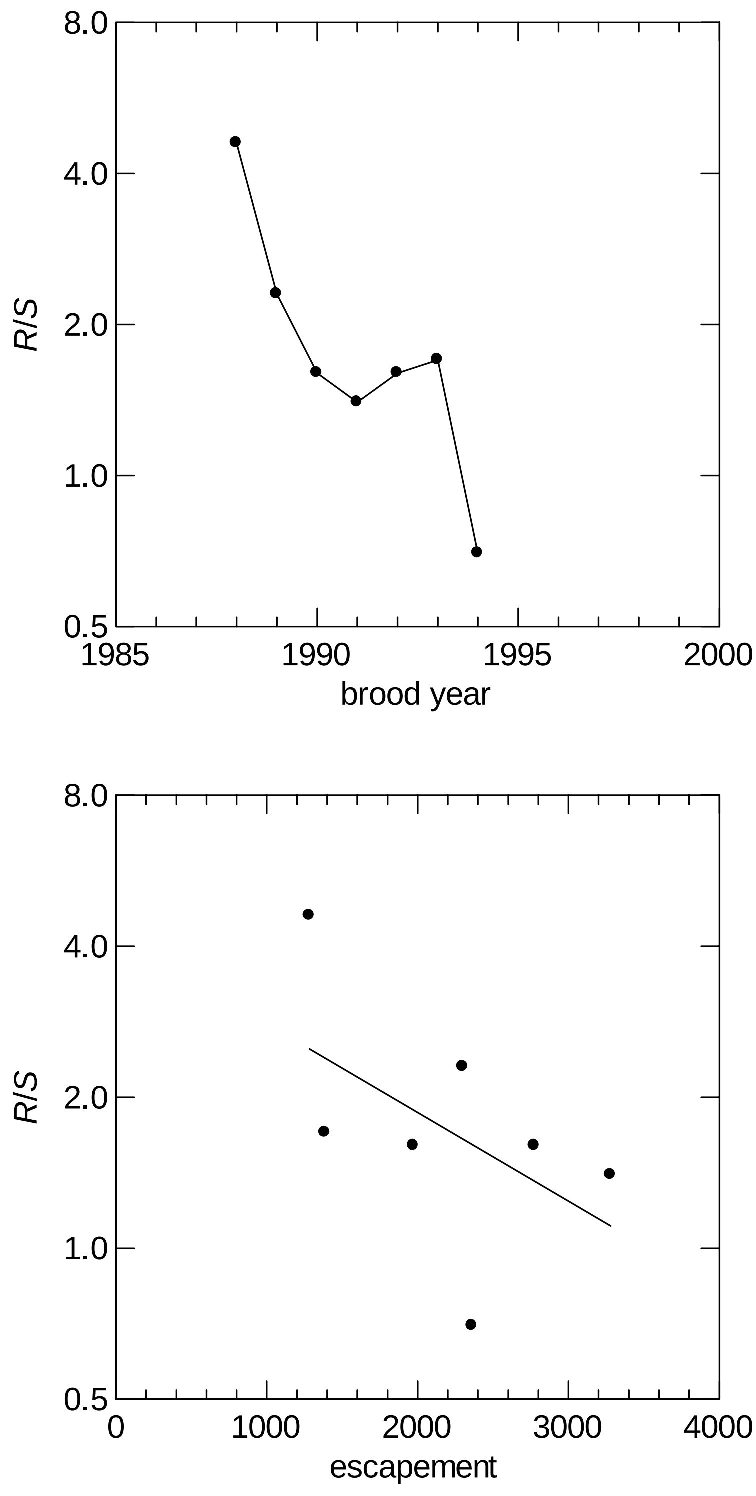

Figure 42. For the Toboggan Creek indicator population (wild component) plots of *R*/*S* vs. brood year (top) and against escapement (bottom).

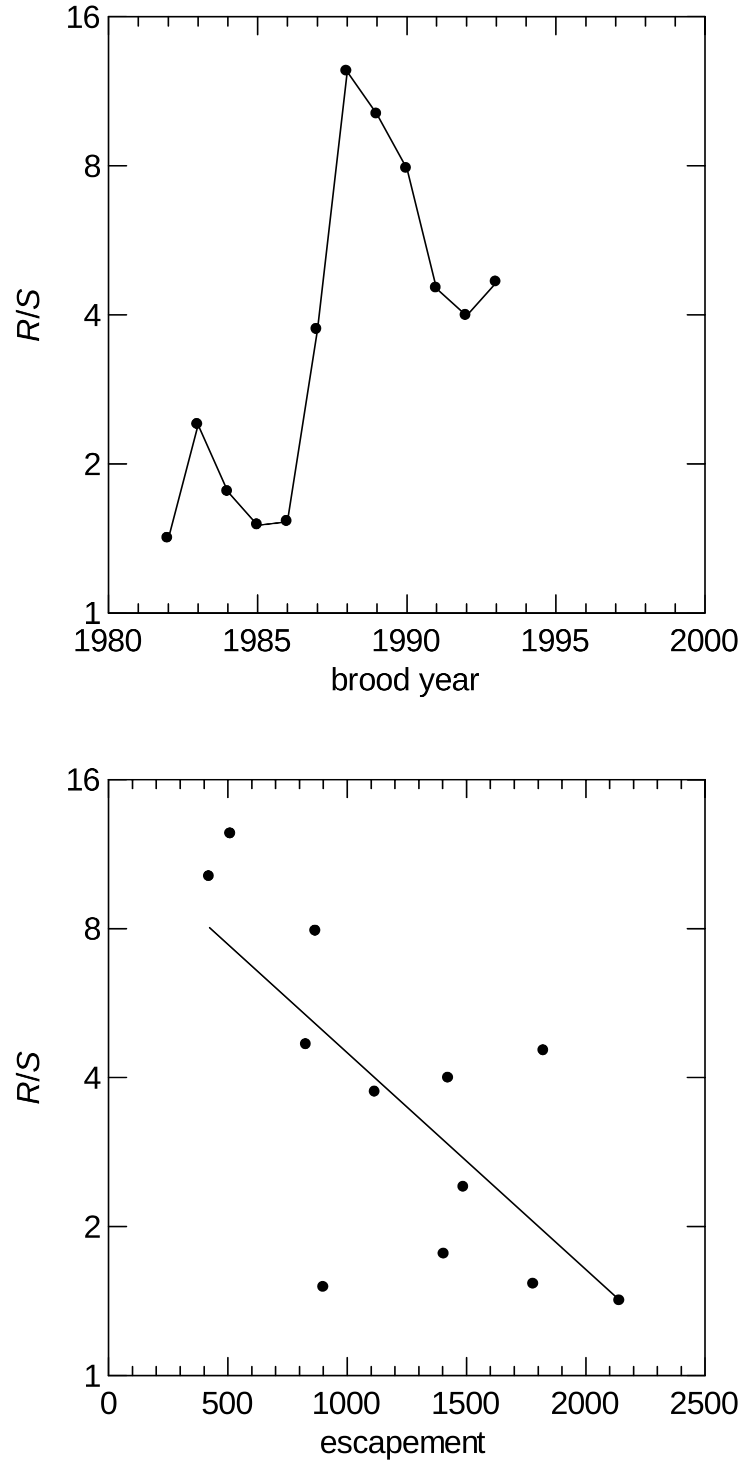

Figure 43. For the Hugh Smith Lake indicator population plots of *R*/*S* vs brood year (top) and against escapement (bottom).

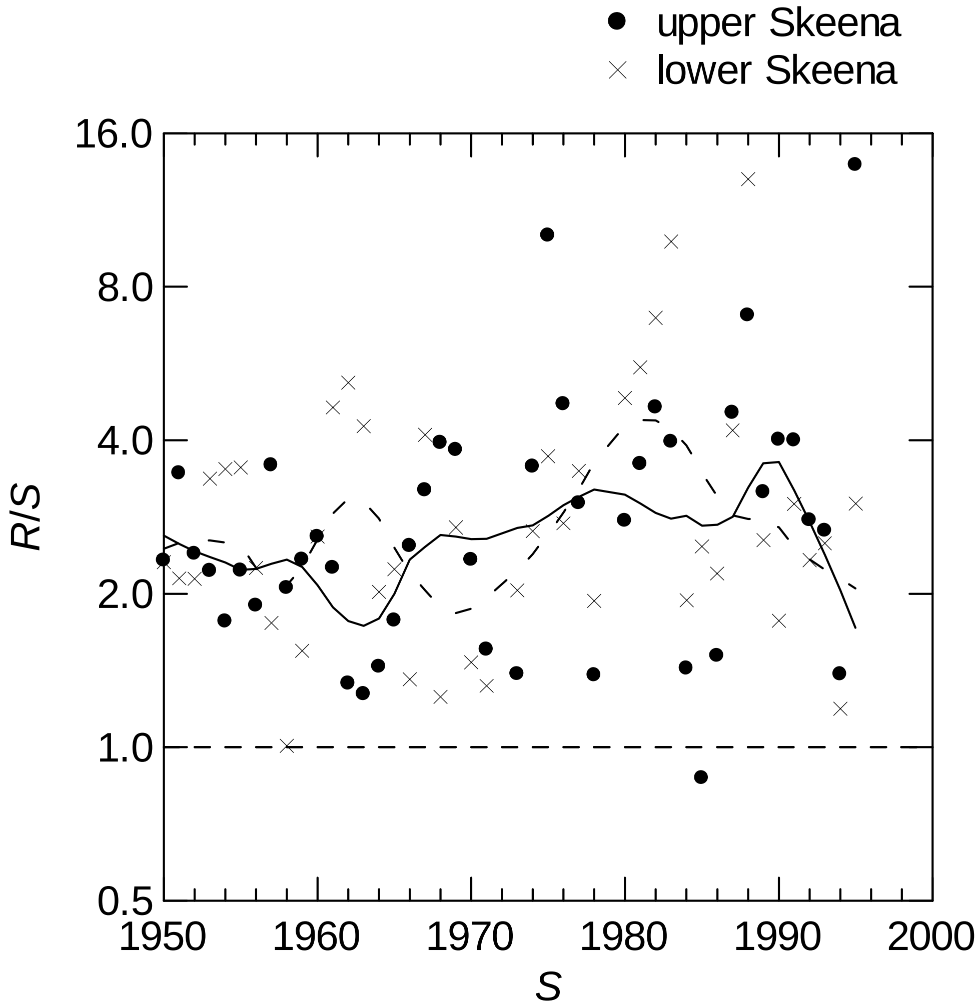

Figure 44. Time series of *R*/*S* derived from the visual coho salmon counts in the upper and lower Skeena.

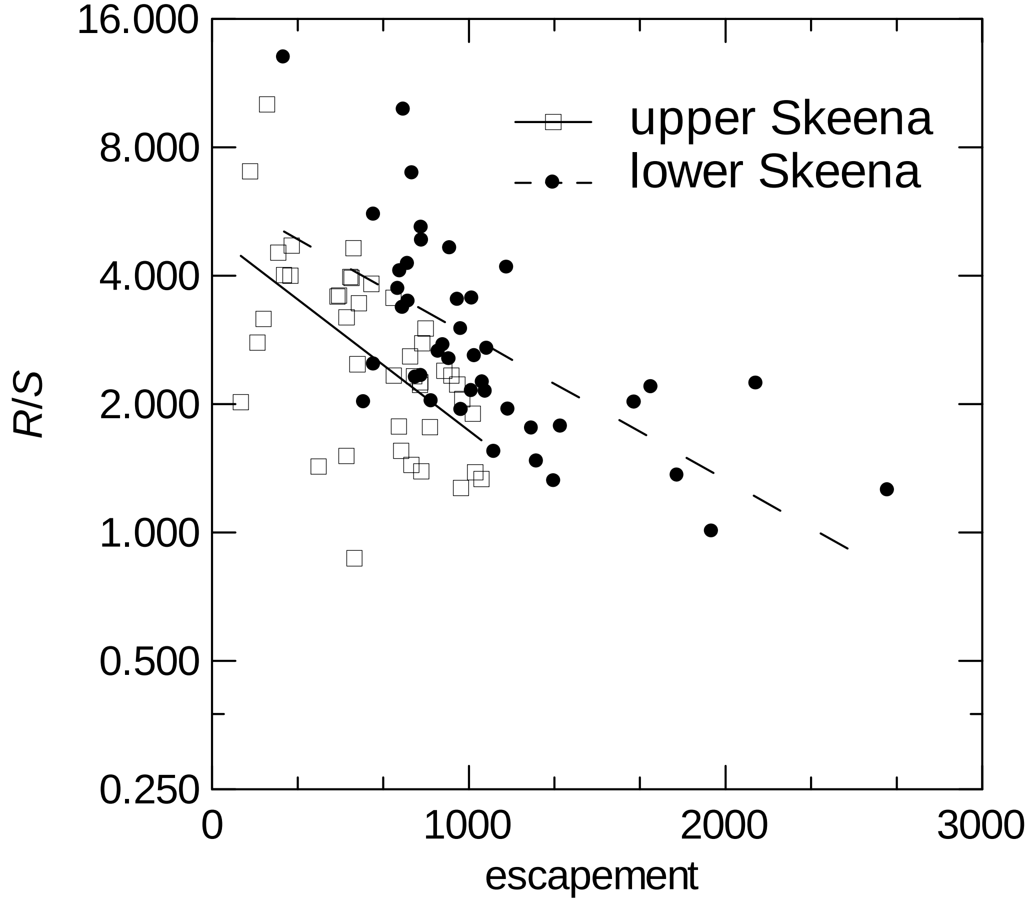

Figure 45. *R/S* vs. escapement for the upper and lower Skeena stock-recruitment data derived from the visual coho salmon counts in the upper and lower Skeena.

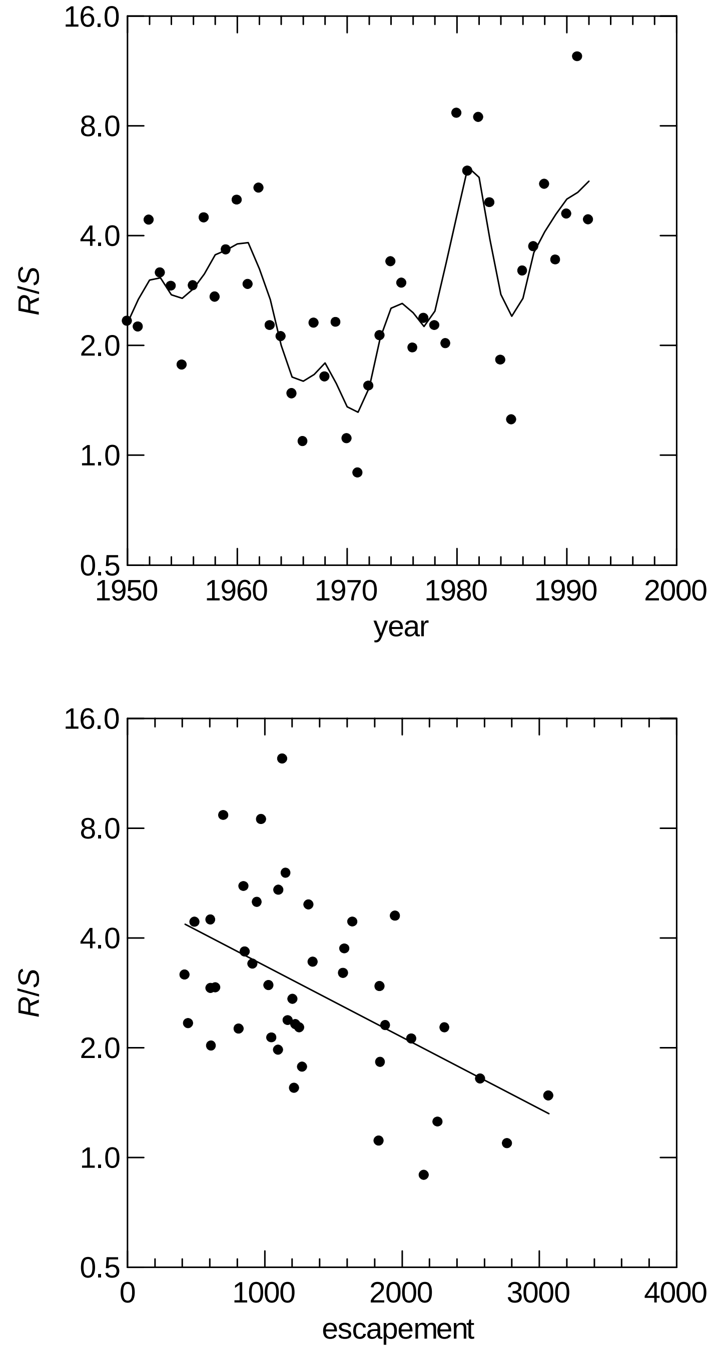

Figure 46. For Area 3 average escapements derived from visual counts, plots of *R*/*S* vs. brood year (top) and against escapement (bottom).

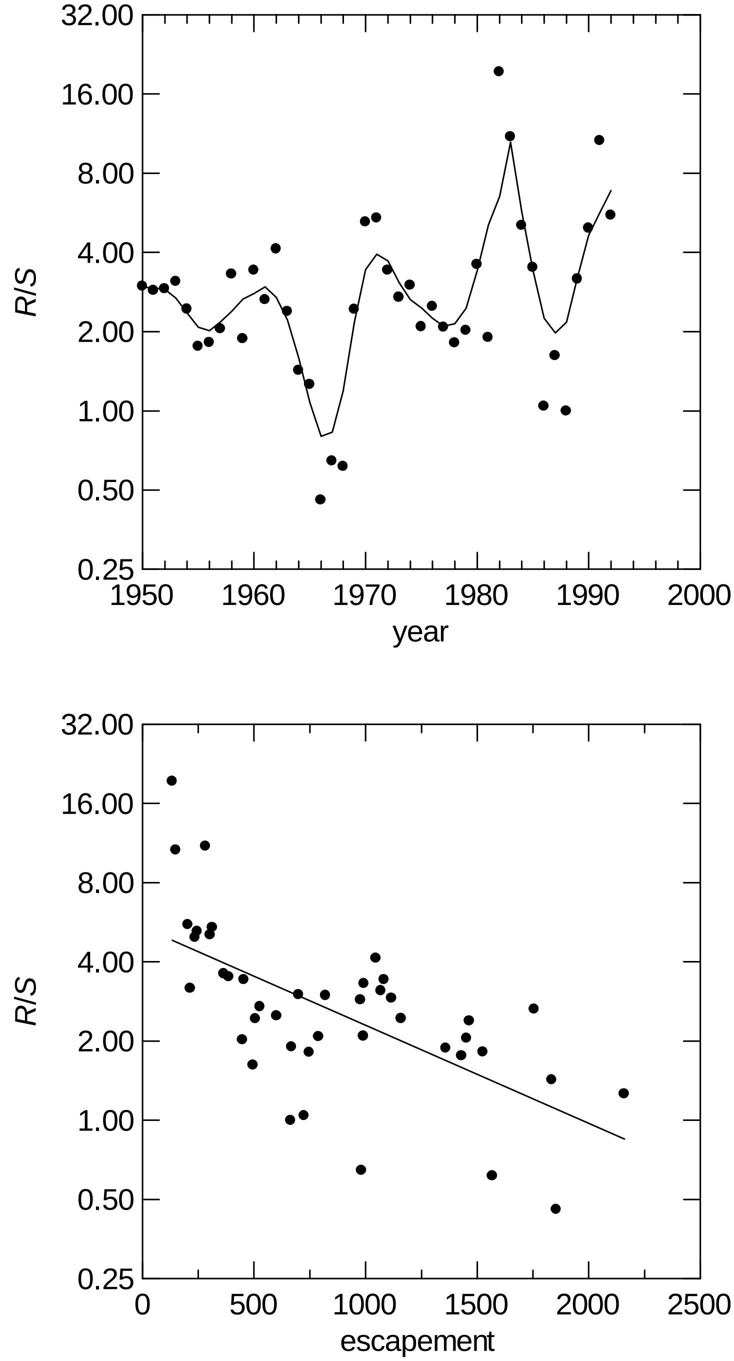

Figure 47. For Area 5 average escapements derived from visual counts, plots of *R*/*S* vs. brood year (top) and against escapement (bottom).

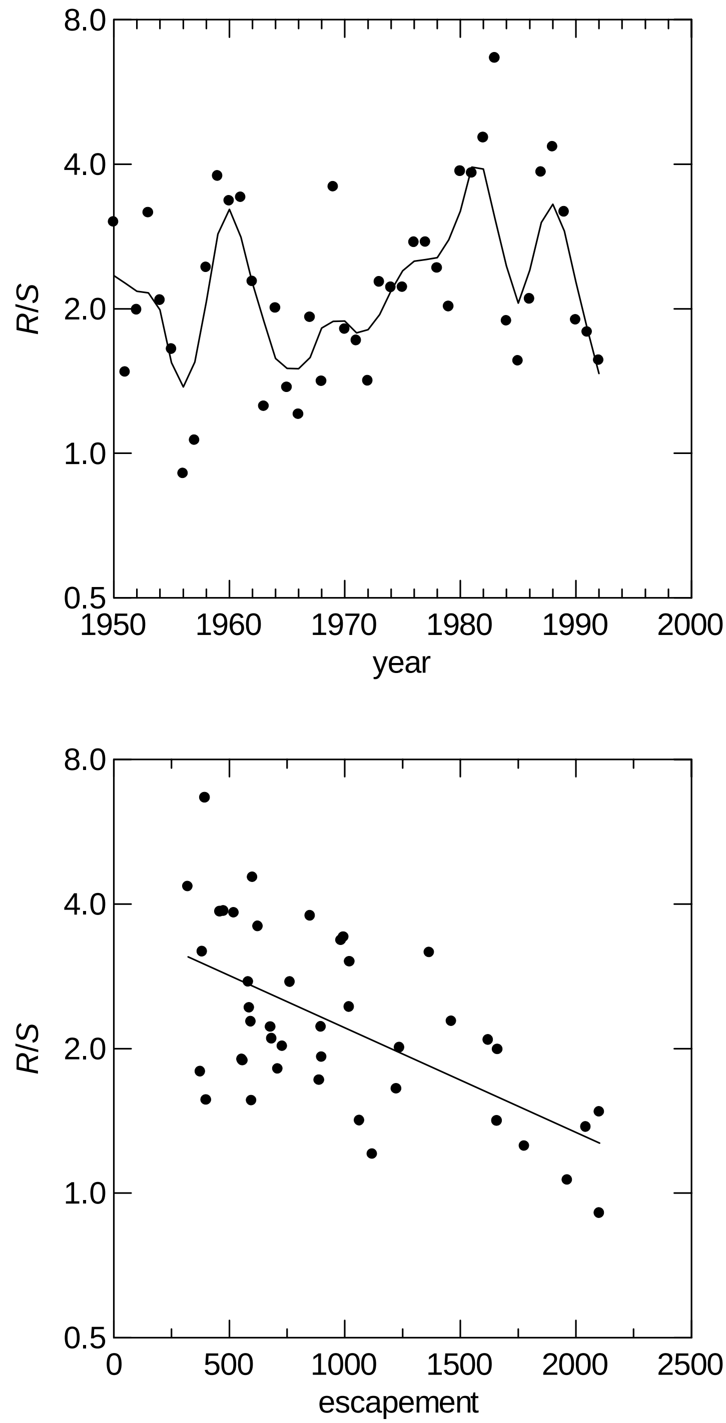

Figure 48. For Area 6 average escapements derived from visual counts, plots of *R*/*S* vs. brood year (top) and against escapement (bottom).

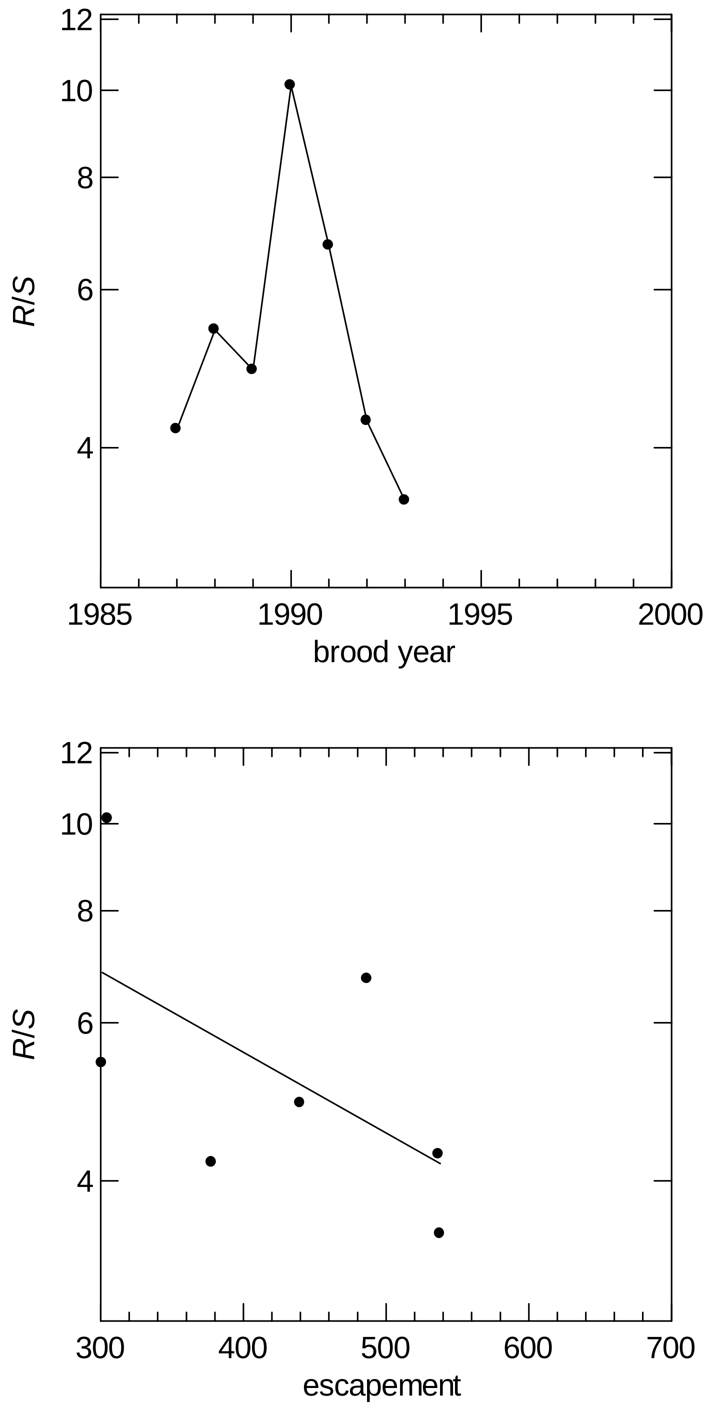

Figure 49. For average escapements derived from visual counts in SE Alaska index stream, plots of *R*/*S* vs. brood year (top) and against escapement (bottom).

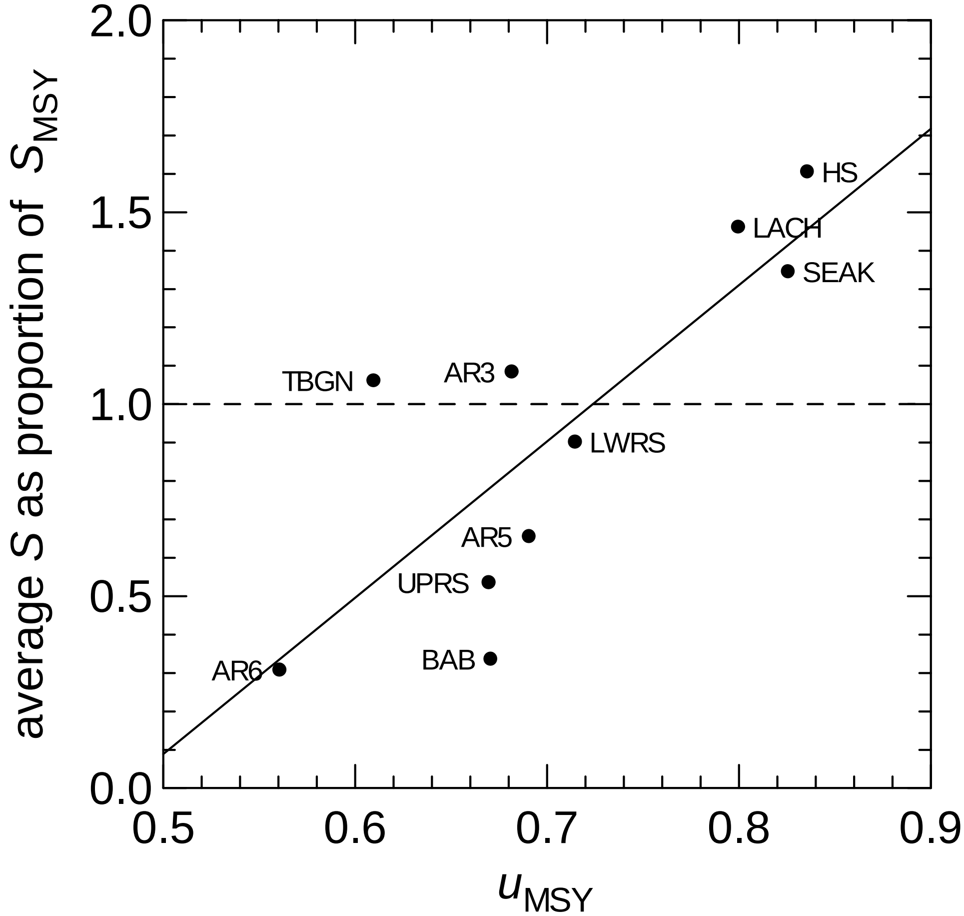

Figure 50. A plot of the recent average escapement to the indicator and index streams as a proportion of the *MSY* escapement vs. their optimal exploitation rate. The identification codes are: 'AR', Statistical Area; 'BAB', Babine Lake aggregate; 'LWRS': lower Skeena (Area 4); 'UPRS': upper Skeena; 'TBGN', Toboggan Creek wild indicator; 'LACH', Lachmach River wild indicator; 'SEAK', SE Alaska index streams; and 'HS', Hugh Smith Lake wild indicator.

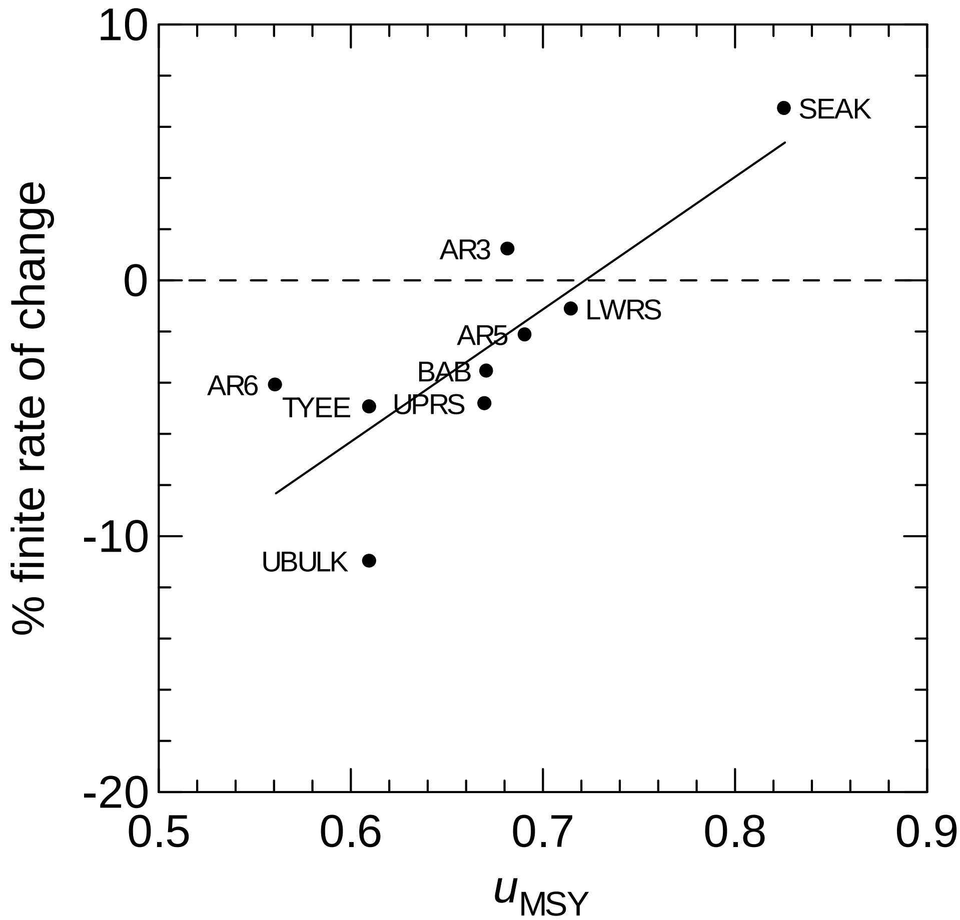

Figure 51. A plot of the finite rate of change to the indicator and index streams as a proportion of the vs. their optimal exploitation rate. The identification codes are: ‘AR’, Statistical Area; ‘BAB’, Babine Lake aggregate; ‘LWRS’: lower Skeena (Area 4); ‘LACH’, Lachmach River wild indicator; and ‘SEAK’, SE Alaska coho catch per hook in the troll fishery; ‘TYEE’, unadjusted test-fishery index, ‘UBULK’ upper Bulkley River, and ‘UPRS’: upper Skeena.

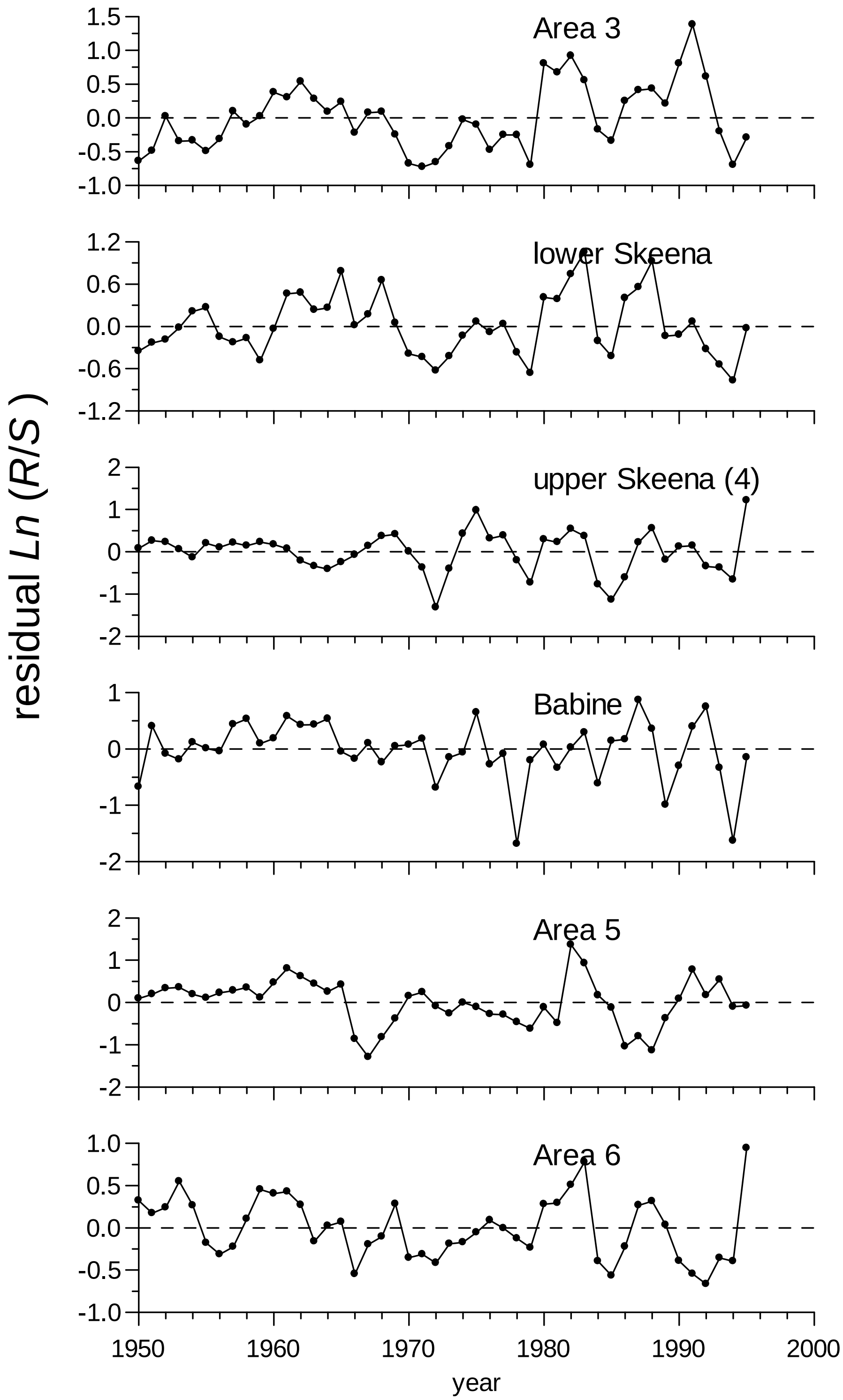

Figure 52. Residual plots for *Ln*(*R*/*S*) vs. time for the escapement indices and the Babine Lake aggregate.

5 Conclusions and summary

The data and analyses presented here strongly support several general conclusions about the status of coho in the Canadian northern boundary area:

1. All measures of abundance of Skeena coho originating upstream of the confluence with the Bulkley River, in the upper Bulkley River above the confluence with the Morice River and in some tributaries of the Bulkley River, indicate that these populations have been declining at a rate of approximately 15% per generation since the early to mid-1970's.
2. Declines at similar rates and beginning around the same time are present in some areas outside of the Skeena, notably in Statistical Areas 6 (Kitimat) and 2E (east QCI).
3. Abundance in the most northerly of the boundary areas, Area 3, is not trending. These populations are, on average, intermediate between those to the south, which are declining, and those to the north in SE Alaska, which are expanding.
4. Fishery exploitation rates measured on Canadian indicator sites are uniformly high and exceed sustainable levels for both indicator and aggregate populations in the upper Skeena and Areas 5 and 6. Exploitation rates on populations in Area 3 appear to be at optimal levels.
5. Two measures of status, the finite rate of change in abundance and the average escapement as a proportion of the optimal stock size are positively and significantly correlated with estimates of optimal exploitation rate. Those relationships indicate that current average levels of total exploitation rate are excessive for all but Alaskan and Canadian Area 3 (Portland/Nass) and lower Area 4 (Skeena) populations.
6. Coho originating in streams throughout the northern boundary area are exploited by the same fisheries and until quite recently, the marine exploitation rate was highly uniform over the entire area. Relatively small differences in exploitation rate between the indicators can be ascribed to differences in distribution. In addition, coho returning to the upper Skeena face modest in-river fisheries.
7. The uniformity of the exploitation rate and the spatial pattern of status over the area strongly suggest that systematic variation in productivity within the northern boundary area underlies the spatial patterns in status. Productivity declines from north to south and from the coast into the interior.
8. Productivity has two components: freshwater and marine. From the indicator populations we know that marine survival is considerably higher in SE Alaska than it is even to the immediate south and it is clear that there are very strong gradients in marine survival within the boundary area. The reasons for this gradient are unknown. There also may be a gradient on the coastal-interior or west-east axis but there is insufficient data to adequately resolve that possibility. Although there is again very little data, there does appear to be a coastal-interior gradient in freshwater productivity, with coastal coho having higher survival than interior coho. This apparent productivity axis might be more related to physical geography than proximity to the coast, which would account for the low overall productivity of streams in the fjord country of Area 6.

The evidence presented on abundance, time trends in abundance, exploitation rates, productivity and its variation across the northern boundary area, strongly support the Canadian view that a serious conservation problem exists for upper Skeena coho and that the problem has arisen because of a long-term or chronic mismatch of productivity and exploitation rate. A simple simulation study of future population size of the Babine Lake coho aggregate has indicated that recovery is contingent on both future survival and exploitation rates. With exploitation rates 15 to 25 percentage points lower than the rates exerted in the 1980's and 1990's and a continuation of present marine and freshwater survivals, slow recovery to escapement near carrying capacity is expected. With exploitation rates at pre-1997 levels recovery would be uncertain unless marine survivals improved substantially (Holtby et al. 1999). The reappearance of coho throughout the upper Skeena in 1998 and 1999 following reductions in exploitation rates do indicate that recovery is possible with prudent and conservative fisheries management.

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