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# A biological assessment of the coho salmon of the Skeena River, British Columbia, and recommendations for fisheries in 1998

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## Abstract

This assessment covers coho salmon of the Skeena River. We rely on two indices of aggregate abundance, two hatchery indicator populations, two wild indicators, one associated with a hatchery and the other not actually in the Skeena but close by, and surveys of juvenile densities that were made in 45 to 52 streams throughout the Skeena watershed.

Conservation concerns for the early run-timing component of Skeena coho were first raised by the Pacific Stock Assessment Review Committee (PSARC) in 1986 (Stocker 1987). Coho populations throughout most of the upper Skeena (Bear-Sustut, Babine and Bulkley-Morice subareas) continue to be severely depressed and heavily exploited, a combination which makes them extremely vulnerable to episodes of poor marine survival. The near-zero ocean survival that appears to have occurred in the 1996 smolt year (1997 returns) has produced a situation in the upper Skeena, particularly the upper Bulkley, the Babine and the high interior, that can only be described as perilous. Coastal populations appear to be more productive and have been stable despite high exploitation rates, probably because of a prolonged period of good marine survival. The status of Skeena coho epitomizes the problems faced in attempting to manage the coho salmon of a large and varied geographic region when nearly all of the exploitation is exerted in mixed-stock ocean fisheries. Although coastal populations may be able to withstand the prevalent exploitation rates even during episodes of relatively poor marine survival, the interior populations clearly cannot.

Marine survival rates for the smolts of 1997 are forecast to be 9.1%, or near average, for coastal populations and 8.2%, or below average, for upper Skeena populations. For a variety of reasons, the most important of which being that similar forecasts failed in 1996, we recommend that these forecasts be treated with extreme caution. Four approaches are outlined to provide recommended exploitation rate targets or floors for 1998 fisheries. The approaches yield target or maximum exploitation rates that range from 44% to 67% for coastal populations and 9% to 71% for interior populations. The wide range in recommended harvest rates is the consequence of different objectives and levels of assumed risk, and is not solely a reflection of uncertainty. The indicator populations used to generate these recommended exploitation rates appear to be among the most productive of some 45 streams where fry densities have been routinely surveyed, and the status of the most upper Skeena systems was judged to be considerably worse than the interior indicator (Toboggan Creek).

Given the continuing conservation concerns for upper Skeena area coho, the alarming further decline in abundance in 1997, and uncertainty in survival rates for coho returning in 1998, we caution that any exploitation of upper Skeena area coho poses a high risk to the viability of coho populations in this area.

Although conservation problems for lower and middle area Skeena coho were not indicated to 1996, because of the precipitous decline in abundance in 1997 and uncertainty in survival rates for coho returning in 1998, we recommend a more conservative approach to the harvest of these coho stocks.

Assessment of Skeena coho continues to be affected by limited information, and in particular the lack of effective forecasting tools for the Skeena coho and the lack of wild indictor sites where wild smolt production can be measured and their survival determined. Consequently we recommend the development of additional wild indicator sites in the Skeena, particularly in the interior, as well of the development of more effective forecasting tools for Skeena coho.

## Résumé

La présente évaluation a trait au saumon coho de la rivière Skeena. Nous avons utilisé deux indices de l'abondance totale, deux indices de populations piscicoles, deux indices de populations sauvages (l'un lié à une pisciculture et l'autre à une population étrangère à la Skeena, mais voisine) et des relevés de densités de juvéniles portant sur de 45 à 52 cours d'eau du bassin de la Skeena.

Le Comité d'examen de l'évaluation des stocks du Pacifique a été le premier, en 1986, à s'inquiéter de la conservation de la composante de remontée hâtive du coho de la Skeena (Stocker, 1987). Les populations de coho de la plus grande partie du cours supérieur de la Skeena (Bear-Sustut, Babine et Bulkley-Morice) continuent d'être fortement appauvries et exploitées, une combinaison qui les rend extrêmement vulnérables aux épisodes de faible survie en mer. La survie en mer presque nulle qui semble avoir affecté les saumoneaux de 1996 (remontée de 1997) a donné lieu à une situation dans la haute Skeena, plus particulièrement dans le cours supérieur de la Bulkley, le lac Babine et l'intérieur, qui ne peut être qualifiée que de dangereuse. Les populations côtières semblent être plus productives et sont demeurées stables en dépit de taux d'exploitation élevés, sans doute à cause d'une longue période de bonne survie en mer. L'état du coho de la Skeena résume bien les problèmes connexes à la gestion du saumon coho dans une zone géographique étendue et variée lorsque presque toute l'exploitation est exercée par des pêches en océan visant des stocks mixtes. Les populations côtières sont sans doute en mesure de supporter les taux d'exploitation actuels, même pendant les périodes de survie en mer relativement faible, mais les populations de l'intérieur ne le peuvent certainement pas.

Le taux de survie en mer des saumoneaux de 1997 devrait être 9,1 %, ou presqu'égal à la valeur moyenne, pour les populations côtières et de 8,2 %, ou inférieur à la moyenne, pour les populations du cours supérieur de la Skeena. Pour diverses raisons, dont la principale est que des prévisions semblables se sont avérées inexactes en 1996, nous recommandons d'utiliser ces prévisions avec la plus grande circonspection. Quatre stratégies sont exposées pour la recommandation de cibles d'exploitation, ou planchers, pour les pêches de 1998. Elles permettent d'obtenir des objectifs de rendement ou des taux d'exploitation cibles qui vont de 44 % à 67 % pour les populations côtières et de 9 % à 71 % pour les populations de l'intérieur. Cette large gamme de taux de récolte recommandés résulte de l'utilisation de divers objectifs et niveaux de risque et n'est pas le simple reflet de l'incertitude. Les populations indicatrices utilisées pour obtenir ces taux d'exploitation recommandés comptent parmi les plus productives des 45 cours d'eau où la densité des alevins a été contrôlée de façon routinière et l'état des populations des bassins les plus en amont de la Skeena a été jugé considérablement inférieur à celui des populations indicatrices de l'intérieur (ruisseau Toboggan).

Étant donné les préoccupations constantes à l'égard de la conservation du coho du cours supérieur de la Skeena, le déclin de l'abondance alarmant encore noté en 1997 et l'incertitude quant au taux de survie des cohos revenant en 1998, nous soulignons que toute exploitation des cohos de la haute Skeena constitue un risque pour la viabilité des populations de coho de cette zone.

Bien que des problèmes de conservation n'aient pas été décelés en 1996 pour les bassins inférieur et moyen de la Skeena, le déclin rapide de l'abondance en 1997 et l'incertitude quant au taux de survie des cohos qui reviennent en 1998, nous font recommander une formule plus prudente pour la récolte de ces stocks.

L'évaluation du coho de la Skeena continue de souffrir d'un manque de renseignements, notamment de l'absence d'outils de prévision efficaces et de sites indicateurs pour les poissons sauvages où la production et le taux de survie de saumoneaux pourraient être mesurés. Nous recommandons par conséquent l'établissement de sites indicateurs de populations sauvages supplémentaires dans la Skeena, surtout dans l'intérieur, de même que l'élaboration d'outils de prévision plus efficaces pour le coho de la Skeena.

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# 1. Introduction

Skeena coho were last formally assessed in 1994 (Holtby et al. 1994) when an update was provided on the status of the early run-timing component. Conservation concerns for this run-timing component were first raised by the Pacific Stock Assessment Review Committee (PSARC) in 1986 (Stocker 1987). The recommendations contained in subsequent PSARC Working Papers (Kadowaki 1988; Kadowaki et al. 1992; Holtby et al. 1994), and the responses of Fisheries Management and Stock Assessment (Science Branch) to them, are summarized in Table 1.

In this Working Paper, geographic coverage has been extended to the entire Skeena watershed (Figure 1). The status of coho populations grouped by sub-regions is presented, and recommendations are made for the further development of an assessment program for Skeena and other North Coast coho stocks.

Summary descriptors of the geography of the Skeena watershed are used throughout this Working Paper. Those descriptors and the areas they refer to are delimited on Figure 23. In addition, the descriptor 'mid-Skeena' refers to the Terrace and Kispiox regions, and the descriptor 'upper Skeena' to the high interior, Babine, upper Bulkley and Bulkley/Morice regions.

# 2. Data Sources

Canadian catch data up to and including 1996 were obtained from the commercial catch database maintained by StAD at PBS, Nanaimo. Data for 1997 were obtained from the sales-slip database maintained by Fisheries Management in the North Coast Division Office in Prince Rupert (pers. comm. B. Spilsted, StAD, Prince Rupert). 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). Data for 1997 troll fisheries are preliminary and possibly incomplete. No retention of coho was permitted in Area 1 to 5 seine net fisheries in 1997 and consequently there were no recoveries of CWTs in that fishery. There are known problems with the reporting of CWT recoveries in Area 3 and 4 gill-net fisheries during 1997 (pers. comm. D. Peacock, DFO, Prince Rupert), with the result that only 1 CWT was reported recovered. To estimate actual net exploitation rates in 1997 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) was used to estimate the probable coho encounters during the 1994 through 1997 fisheries. All coho encountered were considered killed except in 1997 when only 20% of coho encountering seine nets were assumed to have died. Coho abundance in Area 4 was estimated using the run-reconstruction model and a terminal (post-fishing) abundance index derived from the Tyee sockeye test fishery (see Section 4.1). The total net exploitation rate was then estimated for the three indicators (Lachmach, Toboggan and Fort Babine) by regressing the observed net exploitation rate on the estimated Area 4 harvest rate for 1994 through 1996. The results are shown in the following Table. The estimated exploitation rates for 1997 shown in the following Table appear more reasonable than the estimates of zero exploitation calculated from the tag recoveries taken at face value, but nonetheless must be treated with some skepticism.

| | | exploitation rate in net fisheries | | |
|---|---|---|---|---|
| year | estimated harvest rate in Area 4 | Lachmach | Toboggan Creek | Fort Babine |
| 1994 | 0.21 | 0.064 | 0.078 | 0.051 |
| 1995 | 0.23 | 0.133 | 0.164 | 0.075 |
| 1996 | 0.32 | 0.181 | 0.201 | 0.055 |
| 1997 | 0.17 | *0.047*[a] | *0.157*[b] | *0.060*[c] |

[a] exploitation rate = 0.902×harvest rate – 0.102
[b] exploitation rate = 0.911×harvest rate + 0.006
[c] harvest rate uncorrelated with exploitation rate, 1997 value set equal to 1994–1996 average

Alaskan CWT recoveries in the 1997 fisheries were obtained from the Alaskan Department Fish and Game, Commercial Fisheries Management Division (CFMD) database available on the internet[1], and although preliminary, are thought to be mostly complete (pers. comm. L. Shaul, ADFG, Douglas, AK).

Skeena test fishery data were obtained from a database maintained by Fisheries Management staff in the DFO Prince Rupert office (pers. comm. L. Jantz). The Tyee test fishery is described in detail by Kadowaki (1988) and by Cox-Rogers and Jantz (1993). The uncorrected test-fishery index is the cumulative catch per 1000 fathom·minutes from mid-June to August 25th. A procedure for adjusting the index to account for changing catchability is discussed in section 4.1.

Fishery Officer escapement estimates or "BC 16's" were obtained from a database maintained in the Prince Rupert regional office (pers. comm. Brian Spilsted, StAD, Prince Rupert). The estimates of spawner abundance by stream are derived from visual observations, but the derivation methods are largely undocumented. Records of "none observed" were assumed to be zero escapement but otherwise non-numeric entries were left blank. Additional problems in attempting to derive an abundance index from the BC-16's are that very few streams were consistently visited, and the total number of streams visited has varied over time, although the number of streams for which escapement is estimated has dropped significantly only in the last four years (Figure 2). On average there were 59 estimates (range 25 to 89), 28 below Terrace (range 1 to 46) and 31 above Terrace (range 8 to 53). To convert the BC-16's to an escapement index the estimates for each stream were divided by the maximum recorded escapement for that stream. This proportion ($p_{max}$) was then averaged over the entire watershed or the sub-areas below and above Terrace. As noted in Kadowaki et al. (1992), Fishery Officer escapement estimates are not necessarily accurate or consistent indicators of spawning escapement. Rather they may be used, with caution, as trend indicators or indicators of presence and absence.

Adult counting fences are operated on the Lachmach River, Toboggan Creek, the Bulkley River at Houston, and the Babine River. At the Lachmach River and Toboggan Creek all coho are processed[2] at a fence located in the lower

[1] http://tagotoweb.adfg.state.ak.us

river and a systematic proportion are given an external tag. In the event that either fence tops during fall freshets, visual estimates of tagged and untagged fish made by swimmers (Lachmach) or stream-side observers (Toboggan) are used to estimate the number of fish that passed the fence undetected using a Bayesian estimator described by Lane et al. (1994b). Both fences operate for the entire duration of the run (Lane and Finnegan 1991; Lane et al. 1994a, b, unpubl. data B. Finnegan, StAD, PBS). The Houston fence is operated primarily to collect brood-stock for the Toboggan Creek hatchery. Coho are counted at the fence and in recent years an estimate of the numbers of adipose-clipped fish has been made. The Houston fence has been plagued with operational difficulties and counts are not available for some years. 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. In most years fence operations have not ended before October 1st. Escapement to the two dates are treated as indices of escapement. Biological data have not been collected routinely at the fence. 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 have been made when traps were in use. All smolts captured are CW tagged 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 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. Three 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 sufficiently similar to allow a simple ratiometric estimate of 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 ($N_h$):

$$N_w = {N_h n_w}/{n_h} \tag{1}$$

No other smolt data are available from the Skeena drainage.

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[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

Juvenile densities and fork length (FL) frequency distributions were obtained from between 64 and 70 sites on 45 to 52 streams throughout the watershed (LBH and BF, unpubl. data; Taylor 1995, 1996, 1997). Sites were selected on a variety of criteria that included accessibility and fishability. Most of the Skeena upstream of the confluence with the Bulkley and on the southern shore downstream of the Lakelse is accessible only by plane or helicopter. Most sampling was done in the second and third weeks of August. Where feasible, stream sections of between 30 and 50 meters were isolated with fine-mesh nets. Juveniles in the isolated section were removed with a combination of beach and pole seines and/or back-pack electro-fishers with a minimum of three passes of equal effort. In most cases fish removed in the first two passes were given a distinguishing mark, usually an upper or lower caudal fin clip, and replaced prior to the next pass. This enabled comparison of population estimates made with two mark-recapture estimators (modified Petersen formula (Chapman 1951) and a sequential Bayes estimator (Gazey and Staley 1986)), and three removal estimators: Seber-LeCren two-pass (1967) and the Zippin (1958) and Schnute (1983) multiple pass estimators. Dimensions of the reach were taken and a simple polygonal algorithm was used to estimate the wetted surface area of pools and glides combined, which was used to calculate fish densities. Scales were taken from a representative sub-sample of the fish captured (all of the fish in many interior sites) for subsequent aging. Where it was not feasible to apply the removal method (in ponds for instance), and where there were habitat features that provided some form of isolation, fish were captured using baited Gee-minnow traps (Cuba Specialty Manufacturing Ltd., NY) soaked over night. Fish captured were given a distinguishing mark (usually a caudal clip) and released. Recaptures were made using baited traps soaked overnight 4 to 7 days latter. Abundance was estimated using the modified Petersen formula. In the most remote site (Kluatantan River), logistics and the habitat configuration precluded both removal and mark-recapture estimates. There, catch-per-unit-effort (number caught per second of electro-shocking) was used to estimate density using a density-CPUE relationship derived from similar streams in the interior.

## 3. Fisheries

### 3.1 Catch

Skeena coho are mostly caught in four mixed-stock fisheries: the Canadian northern troll operating in Statistical Areas 1 to 5, the Canadian northern net operating primarily in Statistical Areas 3 and 4, the NW, SW and SE Alaskan troll and the SW and SE Alaskan net fishery. Coho are an incidental species in both the Canadian and Alaskan net fisheries, which are directed mainly at sockeye and pink salmon returning to the Nass and Skeena Rivers. FW sport catches are significant only for the Toboggan Creek stock[4].

Catches in the Area 3 & 4 seine and gill-net fisheries, the northern troll, and southern Alaskan fisheries (all sectors) are shown in Figure 3. Catch estimates for 1997 are preliminary. The contribution of Skeena coho to catch is not

[4] There is a recreational fishery confined to a small area at the mouth of Toboggan Creek that is directed at coho returning to the Toboggan Creek hatchery.

known with certainty for any fishery. Kadowaki (1988) estimated the Skeena "early-run" component as 45% and 10% in Area 3 and 4 net fisheries respectively. Alaskan catches increased between the mid-1970's and 1994 (5.12 million caught) and have decreased since, falling to 1.94 million in 1997. During most of the period of expanding catch in Alaska (1975 to 1994) the northern troll catch also increased, but at a considerably slower rate[5]. Average catches by decade are shown in the following table:

| | catch (millions) | | |
|---|---|---|---|
| period | Canadian northern troll | Area 3 & 4 net | SE Alaska |
| 1952-1959 | 0.470 | 0.063 | — |
| 1960-1969 | 0.564 | 0.078 | 1.124 |
| 1970-1979 | 0.394 | 0.095 | 1.045 |
| 1980-1989 | 0.570 | 0.110 | 1.862 |
| 1990-1997 | 0.555 | 0.105 | 3.098 |
| overall | 0.510 | 0.091 | 1.713 |

Catches in all three fisheries covaried significantly with correlation coefficients varying between 0.44 and 0.60 (1997 included) and between 0.52 and 0.57 (1997 excluded; $P<0.005$ for all), suggesting that year-to-year variations in coho abundance were similar over a large area off northern BC and southern Alaska.

## 3.2 Total and fishery-specific exploitation rates

Since the contributions of Skeena coho are not known for any fishery, trends in catch do not necessarily reflect either changing abundance or changing impacts on component stocks. Fishery-specific exploitation rates do provide direct measures of stock-specific fishery impacts. Exploitation rates can be estimated for three coho populations: the Lachmach River, Toboggan Creek and Fort Babine (Table 2). Prior to 1997 total exploitation rates averaged 0.70 at Lachmach, 0.61 at Toboggan Creek and 0.70 at Fort Babine. For the two stocks with the longer time series (Lachmach and Toboggan) there has been a gradual but erratic reduction in the total exploitation rate since 1990 when total exploitation rates were 0.76 at Lachmach and 0.69 at Toboggan (Figure 4). The highest total exploitation rate observed (0.782) was exerted on Fort Babine coho in 1995. Exploitation rate on that stock dropped sharply in the next two years (Figure 4). Compared to values observed in 1996, the total exploitation rate was lower by 0.16 for wild coho from the Lachmach River, by 0.15 for Toboggan Creek CDP, but only 0.065 for Fort Babine CDP coho. (Table 2; Figure 4). These reductions were in part the result of restrictions in the Canadian net and troll fisheries during 1997.

There are three significant trends in the fishery-specific exploitation rates experienced by the three indicator stocks (Table 2). First, there has been a gradual reduction in the exploitation rate exerted by the northern troll fishery (Figure 5). The reduction has been consistent over time for the Lachmach stock. Reductions for the Toboggan stock

[5] about 12% of the rate of increase in the Alaskan catch

were achieved in the early 1990's and maintained until 1997 when there was another decrease. The exploitation rate in the northern troll on Fort Babine coho decreased from 1994 to 1995 and has been consistently around 0.13 in the last three years. There are no data for Babine before 1994. Second, the exploitation rate in the northern net fishery has fluctuated between 0.05 and 0.21 with no clear trends (Figure 6). Third, and in contrast to the trends in Canadian fisheries, Alaskan exploitation on Lachmach and Toboggan stocks is trending upward, and in the Lachmach reached a new height in 1997 (Figure 7). Alaskan fisheries are now, and by a large margin, the most significant fisheries on Skeena coho. In 1997, the most significant individual Alaskan fishery was the NW troll, followed by the SW and SE troll. Net fisheries were not significant (Table 3). This catch distribution reflects a slightly more northward distribution of fish in 1997.

## 4. Status indicators

### 4.1 Skeena sockeye test-fishery index

The number of coho captured in the Tyee test-fishery has been recorded daily for the period July 1st to August 25th since 1956. 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:

$$q_{so} = T_{so} / E_{so} \tag{2}$$

where:

$T_{so}$ : sockeye test fishery index, and

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

Escapements can be estimated using eq. 2 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 38053. The test-fishery index in 1994 was 37.17. Applying eq. 2 gives a value for coho catchability in 1994 $(q_{co,1994})$ 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:

$$q'_{co} = {q_{so} q_{co,1994}} \Big/ {q_{so,1994}} \quad (3)$$

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

$$T'_{co} = {q_{so,1994} T_{co}} \Big/ {q_{so}} \quad (4)$$

The adjusted test-fishery index ($T'_{co}$) has a stepped appearance (Figure 10). Escapements appeared to be increasing slowly from 1956 to the early 1970's, whereupon there was a precipitous drop to a lower level. Escapements then remained approximately stable until the early 1990's until another smaller drop (possibly) occurred, followed by a large drop in 1997. The drop to a new and lower level in 1992 is suggested more by the time series of visual counts (see sect. 4.3, p. 12). Box and whisker plots of the escapement estimates grouped into these time periods (Figure 11) indicate that the differences between the median escapements in each of the four periods (medians are 43265, 27649, 19764, 3970 in the four periods) are significantly different.

## 4.2 Babine Lake fence index count

Coho passing through the Babine fence have been enumerated since 1951. The fence is operated to count sockeye, and in many years fence operations have stopped well before the coho run had finished. The latest date that the fence has operated in all years is Sept. 13th, but in most years and nearly all years since the mid-1960's the fence has operated until Oct. 1st. Coho escapement to the Babine has the appearance of periods of stable escapements punctuated by periods of sharp declines. Counts to the two index dates (Figure 12) show stable escapements from 1951 to approximately 1974, followed by drop to a new level that was maintained until 1991. Escapement took another step downward in 1992 and again in 1997. When separated on those years there is only minimal overlap between escapements during these periods (Figure 13; Figure 14). In 1997, escapement to Sept. 13th was only 99 animals or approximately 0.02× of the escapements in the 1946-1974 period. Escapement to October 1st in 1997 was 412 or 0.05× the average escapement in the 1946-1974 period. A gradual divergence of the two index counts is evident in this comparison and in a comparison of the smoothed time series (Figure 12), providing some evidence that either the timing of Babine coho is later now than it was two decades ago or that the relative strengths of early and late migrating populations, if they exist, has changed over time.

## 4.3 Escapement estimates

There were two distinct temporal patterns in the BC-16 escapement estimates. Escapements to streams below Terrace increased through the 1950's to a peak in the mid-1960's and then fell slowly to a minimum around 1980 and then slowly increased again, although escapements in 1988 and 1993 were record lows Figure 15B). In upper Skeena streams escapements were stable and relatively high from 1950 until the mid-1970's. From the mid-1980's onward escapements have trended downward (Figure 15C). Overall, the escapement record has a distinct stepped appearance with relatively high and increasing escapements from 1950 to the mid 1960's, followed by a rapid decrease to a lower stable escapement with no marked trend from the mid 1970's to the present (Figure 15C). The simple sums of escapements in the same areas show similar temporal patterns (Figure 16B,D). When compared to the time series of the adjusted Skeena test-fishery index (Figure 16) and the Babine fence count to Oct. 1st (Figure 16) the similarity of the BC-16 escapement records and the two indices is apparent. Although index values in the Skeena test fishery and the Babine fence are significantly correlated (Table 4), index values for the Skeena test fishery are most strongly correlated with $\bar{p}_{max}$ values for the lower river grouping of the BC-16's, while the Babine fence index is most strongly correlated with $\bar{p}_{max}$ for the upper Skeena. This suggests to us that the early timing component of Skeena escapement returns to systems throughout the Skeena, with some concentration in the lower river, and that the Babine fence count is probably a better indicator of status for the upper Skeena.

## 4.4 Indicator stocks

There are two hatchery indicator stocks in the Skeena and one wild indicator on Work Channel. Smolt survivals at the three indicators have shown similar patterns over the period of record (Figure 18) but survival for the coastal wild indicator has been substantially greater than for the two interior hatchery stocks. However, that difference may not apply to wild coho in the interior. In 1995 and 1996 the number of wild smolts leaving Toboggan Creek was estimated. Assuming that wild and hatchery fish were exploited at the same rate and that all of the unmarked fish counted at the fence originated in Toboggan Creek, then the survival of wild smolts can be estimated using the calculated exploitation rate on Toboggan Creek hatchery fish and the number of unmarked coho counted at the fence (Figure 18). The 1995 and 1996 wild smolts had an apparent survival rates that were respectively 4.53× and 3.98× those of the hatchery smolts. Using the measured survival rate of hatchery fish and the numbers of unmarked fish counted at the Toboggan fence and, assuming an average survival difference of 4.26×, the number of wild smolts produced can be estimated and simple measures of the productivity of the wild stock calculated (Figure 19). Similar calculations can be made for the Lachmach River wild coho population (Figure 20). Average survival at Toboggan may actually have been slightly higher than at Lachmach over the period of record[6]. Although these calculations should be regarded with caution, the results do provide an explanation for the persistence of interior stocks that cannot be made if smolt survivals actually were as low as those measured at the hatcheries.

Stock-recruitment analyses were attempted for both the Lachmach River and wild Toboggan populations but failed because $\log_e$ recruits·spawner$^{-1}$ was positively correlated with escapement for both indicators. For both populations marine survival was positively correlated with brood-year escapement. in the parental generation ($r$ = 0.69 and 0.64, $N$ = 9 for both, Lachmach & Toboggan respectively). Because most density-dependence is expressed in FW, we estimated recruitment using the observed smolts·spawner$^{-1}$ and fixed smolt survivals ranging between 2% and 25%, and fit Ricker stock-recruitment curves of the form

[6] min–mean–max, Toboggan: 0.019–0.11–0.23; Lachmach: 0.044–0.090–0.17.

$$R = Se^{a(1-S/b)}e^{w} \tag{5}$$

The expected value of $e^{w}$ is $e^{\sigma^2}$, where $\sigma$ is the standard deviation of the residuals for the fitted line (Hilborn and Walters 1992):

$$\log\frac{R}{S} = a - \frac{a}{b}S \tag{6}$$

Estimates of the two parameters, a and b, were corrected with the formulae given by Hilborn (1985), and values for the exploitation rate $(u_{MSY})$ and stock size $(S_{MSY})$ at the maximum sustained yield point were calculated (Table 5).

The Lachmach population is approximately 2.9-times more productive than the Toboggan population[7] (average ratio of recruits·spawner$^{-1}$ , Table 5), and is able to sustain substantially higher exploitation rates at all marine survival rates. However, this analysis must be treated very cautiously for several reasons. There are very few observations at either site (five at both sites), and one of five observations at Lachmach was omitted because it was a clear outlier, (although its inclusion would have made Lachmach significantly more productive.) The Toboggan smolt production was estimated using a wild:enhanced survival differential derived from only two years of trapping results.

The productivity of the Lachmach population is slightly higher than that of Carnation Creek, a well-studied coho population on the west coast of Vancouver Island (Hartman and Scrivener 1990), when the marine survival rate is matched to the average observed at Carnation Creek (1971–1996), while Toboggan Creek is substantially less productive than both coastal populations:

| | Lachmach | Carnation Creek | Toboggan Creek |
|---|---|---|---|
| recruits/spawner @ 12% marine survival† | 4.87 | 3.28 | 1.99 |
| $u_{MSY}$ | 0.81 | 0.77 | 0.57 |
| smolts/spawner observed averages | 28.7 | 28.5 | 20.4 |

average marine survival at Lachmach is 0.09, Carnation 0.12 and Toboggan 0.11.

Assuming that the productitivities measured at Lachmach and Toboggan are typical of coastal and interior populations, the differences in intrinsic productivity between the two regions are so large that it would be difficult to manage mixed-stock ocean fisheries to fully exploit populations in both areas simultaneously. This dilemma is shown graphically in Figure 21. In this Figure we have plotted $u_{MSY}$ vs. smolt survival for the two indicator populations and superimposed the actual exploitation rate–smolt survival pairs. Pursuit of a "optimal" fixed-escapement strategy would be seen as exploitation rates tracking smolt survivals. A conservative strategy might be to keep exploitation rates "under the curve" and to go to near-zero exploitation rates before the optimal curve

[7] If the 1992 brood year is included the average ratio is 3.5-times.

descends rapidly to zero exploitation. Conversely a high-risk strategy would be to allow numerous and large excursions "above the curve". For the Lachmach population, exploitation rates have tracked the optimal strategy (Figure 21). For the Toboggan population exploitation rates have been in what is quite probably the high risk zone for most years.

## 4.5 Regional survival patterns

Most of the sites that release CWT tagged fish do not have the freshwater (FW) recovery programs necessary to estimate the number of tagged fish in the escapement, making it impossible to determine the numbers of tagged fish that survived to spawn. Consequently, the total stock size, the marine survival rate and the total exploitation rate cannot be calculated with any certainty. However, assuming that variations in exploitation rates were similar for all populations originating on the North and Central Coasts, survival indices can be calculated by broad application of the exploitation rates observed at the indicator sites.

Release sites were grouped into four sub-regions:

| North Coast | Skeena | QCI | Central Coast |
|---|---|---|---|
| Lachmach (W)[8]<br>Kincolith<br>Zolzap (W) | Fort Babine<br>Toboggan<br>upper Bulkley | Chown (W)<br>Deena (W)<br>Marie Lake (ff)<br>Pallant (ff)<br>Tasu (ff) | Kitimat<br>McLaughlin Bay<br>Thorsen Creek |

Exploitation rates at Lachmach were applied to releases in the North Coast, the Central Coast and the Charlottes. Exploitation rates at Toboggan were applied to upper Bulkley releases.

The temporal patterns in smolt survival was similar for North Coast[9] and Skeena sites. Apparent survival was high in 1990, 1991, 1994 and 1996, and relatively low in 1988 and 1997 (Figure 22). The same pattern is present at Kitimat, but it is considerably damped. This is the same temporal pattern observed in marine survivals at the three indicator sites (Figure 18). The temporal pattern at McLaughlin Bay is distinctive among the sites considered. There, survivals were trending upward and, although there was variability, the years of relatively good and poor survival were different (Figure 22). There is insufficient data for Thorsen Creek for comparisons. Comparisons with QCI release sites is difficult because the QCI releases were mostly fed-fry . The data for Tasu Creek, which is the only wQCI release site, is fragmented but is consistent with the pattern seen in the Skeena. There are only two years of data for the Deena and Chown Rivers. Both are wild study sites and both show lower survivals in 1997 compared

[8] (W) indicates a wild stock. (ff) indicates that fed fry are released, in which case survival variations include both FW and marine sources of variability.
[9] With the exception of Kincolith, which has had numerous production difficulties.

to 1996. Survival for Pallant Creek releases declined steadily throughout the entire period. The only site where survival may have increased in 1997 compared to 1996 was Marie Lake (Yakoun River), but survivals there have been near zero.

The decline in smolt survivals between 1996 and 1997 was greatest in the Skeena (0.178[10] over 3 sites) and the North Coast (0.201 over 2 sites, Lachmach excluded), and less severe at Central Coast sites (0.329 over 2 sites) and QCI sites (0.390 over 2 wild sites). Interestingly the decline in smolt survival at Lachmach River (0.76) was the smallest observed. This is of some concern because we generate forecasts for North Coast and Skeena coho using Lachmach returns (see Section 5), and is one of the reasons why additional exploitation and survival rate indicators are needed in the Skeena and in the Central Coast. Nevertheless, the generality of the survival decline suggests that the factors driving survival variations are operating on a very broad regional scale.

## 4.6 Juvenile densities

Juvenile densities are available for the Lachmach and for some sites in the Morice from 1987 to 1996, but at most sites densities are known only for 1994 to 1996. Surveyed sites have been grouped into seven geographic zones, within which average densities were calculated by year (Figure 23).

The same temporal pattern is evident in five of the seven regions as densities increased from 1994 to 1996. Since the juveniles are mixtures of age-$0^+$ and age-$1^+$ an increasing trend over this period could be expected because escapements in 1992 and 1993 were the lowest on record until 1997 (Figure 10, Figure 12). Densities in the upper Bulkley, the Babine Lake tributaries and in many of the upper Skeena sites were very low throughout the study period, averaging less than 0.4 coho·$m^{-2}$. Very few coho were detected in most of the sites surveyed in the upper Bulkley. Densities less than 0.5 coho·$m^{-2}$ should be cause for some alarm, and certainly the situation in the upper Bulkley is desperate and entirely consistent with the poor and declining escapements.

The within-year, with-sub-region coefficient of variation in juvenile densities may be a crude indicator of the diversity of intrinsic productivities of the coho populations surveyed within the sub-regions. For this analysis the Lachmach was broken out of the coastal group and the Morice River side-channels were broken out of the Morice/lower Bulkley group. Averaged over the three years of system-wide sampling, the CV's show an interesting spatial pattern:

| Lachmach | coastal | Terrace | Morice side-channels | Morice/lower Bulkley tributaries | upper Bulkley | Kispiox | Babine | upper Skeena |
|---|---|---|---|---|---|---|---|---|
| 60% | 86% | 132% | 86% | 118% | 201% | 144% | 93% | 88% |

[10] This is the ratio: {smolt survial in 1997} ÷ {smolt survival in 1996}.

The lowest CV's were seen in the sites with the most uniform habitat (Lachmach and the Morice side-channels. Relatively low CV's were also seen at the geographic extremes: on the coast and in the high interior. Relatively high CV's were seen in the middle Skeena sub-regions like Terrace and the Kispiox. The highest CV was found in the upper Bulkley.

## 5. Forecasting

The only forecasting tool available for North Coast coho is a sibling relationship at Lachmach (Figure 24). The relationship predicting $R_{adult}$, the total return of age 1.1 and 2.1 adults (catch + escapement) from the jack escapement, $R_{jack}$ is:

$$\log_e R_{adult} = 5.451 + 0.471 \log_e R_{jack} \tag{7}$$

$$\left(n = 8, r^2_{adj.} = 0.751, P < 0.005\right)$$

57 jacks were observed at Lachmach River in 1997 which gives a forecast total return of 1565. The number of smolts produced at Lachmach in the spring of 1997 is uncertain because the fence was damaged for two days during a freshet around the time of peak emigration. Most of the fence continued to fish and a fyke and rotary trap were operated until the fence was repaired. Interpolation through the period would suggest that a maximum of 2,000 fish may have passed undetected, but the actual number is probably lower. Adding 2,000 to the number actually counted (8,938) and multiplying by the average expansion factor of 1.581 gives an estimated total run of 17209. The forecast return is then equivalent to a forecast survival of 0.091, which is equal to the average survival (Table 2). The probability distribution for lower returns and smolt survival (Figure 25) gives the following total returns and smolt survivals for a range of probabilities:

| probability of a lower | total return | smolt survival |
|---|---|---|
| 1% | 719 | 0.042 |
| 5% | 968 | 0.056 |
| 10% | 1096 | 0.064 |
| 25% | 1309 | 0.076 |

A corresponding Table for the 1997 return:

| probability of a lower | total return | smolt survival |
|---|---|---|
| 1% | 1321 | 0.043 |
| 5% | 1759 | 0.057 |
| 10% | 1954 | 0.063 |
| 25% | 2245 | 0.072 |
| 50% | 2556 | 0.082 |
| **observed** | 1695 | 0.055 |

indicates that the total return and smolt survival observed in 1997 had a probability level of approximately 4%.

We can only speculate about the reasons for the poor performance of the sibling forecast. One possible explanation is that the relationship is based on a small number of observations.. In general, smolt size is inversely related to juvenile densities (Holtby 1988), and large smolt size is positively related to the 'jacking-rate' (Bilton 1980; Bilton et al. 1984). However, juvenile densities and sizes, and smolt sizes in the brood years involved were not unusual, so explanations involving a change in the age of maturity do not seen appropriate. Sibling regressions assume not only that the jacking-rate is constant but that the ratio of mortalities for smolts that jack to smolt that don't is constant (but not necessarily one). The distribution of fish sizes in the Lachmach escapement was unusually broad in 1997, with numerous small age 2.1 individuals, and there have been anecdotal reports of unusually small coho returning to other locations on the North Coast. Those observations suggest that there were poor feeding conditions sometime in 1997. If those conditions existed over the winter and second summer in the ocean, they may have resulted in higher than normal second-year mortality that would not have been experienced by the jacks. However, it then becomes difficult to explain the apparent high survival of jacks returning in 1997, unless the poor conditions only existed in areas that few jacks reached.

Marine survivals of the two Skeena hatchery indicator populations are correlated with Lachmach survivals (Figure 26), with the following relationships:

Toboggan:

$$\log_e s_{Toboggan} = 0.542 + 1.853 \log_e s_{Lachmach} \tag{8}$$

$$\left(n = 8, r^2_{adj.} = 0.66, P < 0.01\right)$$

Fort Babine:

$$\log_e s_{FortBabine} = -0.284 + 1.620 \log_e s_{Lachmach} \tag{9}$$

$$\left(n = 4, r^2_{adj.} = 0.689, P < 0.15\right)$$

The following Table was derived from the probability distributions shown in Figure 27.

| probability of a lower smolt survival at: | Toboggan | Fort Babine |
|---|---|---|
| 1% | 0.004 | 0 |
| 5% | 0.007 | 0.003 |
| 10% | 0.010 | 0.005 |
| 25% | 0.014 | 0.010 |
| 50% | 0.020[11] | 0.015 |

[11] equivalent to approximately 0.09 survival forecast for wild Toboggan smolts.

The survival of wild smolts at Toboggan should be approximately four-times the estimated values shown in the above Table (see Section 4.4). However survivals were poorly predicted in 1997[12], and these forecasts should be treated very cautiously.

The apparent correlation of marine survivals for the two interior indicators and the Lachmach is surprising. Given the long FW migration that smolts from interior systems make it would be reasonable to expect lower survivals for interior stocks relative to a coastal stock like Lachmach (Cederholm and Scarlett 1981; Solazzi et al. 1991). Nevertheless, Toboggan coho appear to survive at least as well as Lachmach coho. The presence of a correlation and the surprising strength of the relationship for the indicator with the longest migration distance could indicate that survival is determined in the ocean, possibly well after ocean entry. Alternatively, the factors determining survival act far up the Skeena River, perhaps in FW and over a large area. Although very localized effects are thought to dominate variability in smolt production (Bradford et al. 1997), the similarity of survival time-series for coho over a broad geography strongly suggests that variation in marine survival is the primary cause of most of the variation in abundance.

## 6. Exploitation rate recommendations

A conventional approach to determining a target exploitation rate ($u$) would involve using the probability distribution of smolt survivals in conjunction with the relationships shown in Figure 21, which describe an optimal fixed escapement strategy. One possible objective in setting $u$ would be to remain "under-the-curve" for one or more of the identified aggregates. Risk is described primarily through the probability distribution of smolt survivals, but considerations of management capability should also be taken into account. Depending on what level of risk we are willing to take (i.e., how poor might survival be?), exploitation rates on the low productivity aggregate represented by Toboggan could be set from 0 to 45%, and on the high productivity aggregate represented by Lachmach from approximately 18% to 77%.

Alternative objectives, including those not focused on production, can be pursued with the following framework. Determining maximum exploitation rates to achieve a target escapement with specified probability requires knowing smolt number, a target escapement floor (i.e., a minimum number of spawners), and the forecast marine survival and its probability distribution. The target exploitation rate can then be determined using the formula

$$u = \max\left(0, \frac{sn_s - E_t}{sn_s}\right) \qquad (10)$$

where

$s$ : smolt survival of stipulated probability,

$n_s$ : smolt number,

[12] Toboggan forecast 1997 survival 0.031, observed: 0.004; Fort Babine forecast 1997 survival 0.021, observed 0.005.

$E_t$ : target escapement.

Smolt number and forecast smolt survival are known only for Lachmach and Toboggan wild coho. Smolt output at Lachmach in 1997 is estimated to have been 17,209. High water at Toboggan in the spring of 1997 presented many difficulties for the trapping operation but smolt production appears to have been similar to the past two years (pers. comm. R. Saimoto, SKR Ltd, Smithers, BC). We assumed a smolt production of 36,560[13]. Probability distributions of smolt survival have been given for Lachmach (Figure 25), Babine and Toboggan (Figure 27).

There are several approaches that may be taken in recommending escapement targets or floors for each population.

1. The escapement target is set to $S_{MSY}$ at the average marine survival rate, and the forecast marine survival is set to the point estimate of the mean. The calculated $u$ is such that fifty percent of the time the escapement is expected to be above $S_{MSY}$. Average survival at Lachmach has been about 9% which corresponds to a $S_{MSY}$ of 808 (Table 5). Average survival for wild Toboggan coho is estimated to be about 11% over the same period, which corresponds to an escapement target of 707 (Table 5). Forecast survivals are 0.091 at Lachmach and 0.085 at Toboggan.
2. The escapement floor is set to the minimum number of spawners required to maintain a genetically viable population size. Waples (1990) has concluded that in Pacific salmon this minimum number of spawners ($N_b$) is approximately 100 animals, but he cautions if the generation time is less than 4 years[14] then genetic change is more rapid and the minimum $N_b$ is larger. For vertebrates, Franklin (1980) recommends that the effective population size ($N_e = gN_b$, where $g$ is the generation time) should be 500. However, more recent studies have suggested that census populations should be at least three-times those levels (B. Riddell, DFO, PBS). At Lachmach the average generation time is estimated to be 3.73 years, making the floor escapement 402. The same target floor escapement was used for Toboggan. Failure to achieve this minimum escapement has severe consequences so we have set the forecast marine survival to the 99$^{th}$ percentile[15]: 0.042 for Lachmach and 0.017 for Toboggan.
3. As escapements decline the smolt output per female increases until the density-dependent mechanisms that underlie the increased survival saturate (Holtby 1988; Holtby and Scrivener 1989). In Carnation Creek saturation appears to occur at an escapement of between 1 and 10 females, or between 0.33 and 3.3 females/km. There is insufficient data, and certainly no experimental data, to which we could refer to determine how far above this saturation point escapements should be set. So, arbitrarily, we set an escapement floor at two-times the upper saturation point for Carnation Creek or 7 females/km. For Lachmach this equates to a floor

[13] wild smolt production estimates were 38137 in 1995 and 34989 in 1996.
[14] The generation time for coho ranges from slightly greater than 3 to slightly less than 4 in the extreme north of BC (Sandercock 1991).
[15] 1% of observed survivals will be less than the value given.

escapement of 112[16]. Toboggan is twice the size of Lachmach and about 71% as productive[17] and so the floor escapement there is 315. For this calculation the marine survival was set to the 95$^{th}$ percentile: 0.056 for Lachmach and 0.030 for Toboggan.

The four methods suggest exploitation rates, ranging from 44% to 67% for Lachmach and from 9% to 77% for Toboggan (Table 6). The wide range in recommended harvest rates is the consequence of different objectives and levels of assumed risk, and is not solely a reflection of uncertainty.

In deciding the exploitation rate to recommend we considered three additional factors. First, both Lachmach and Toboggan appear to be uncharacteristically productive compared to other streams surveyed, judging by observed juvenile densities in the fall of 1995 (Figure 28) and in 1996 (Figure 29). Smolt outputs from other systems, especially in the upper Skeena were probably considerably less than from Toboggan Creek. Second, the survivals experienced by the fish returning in 1997 were well below the forecast survivals (see sect. 5, p. 17). To assume that we have adequately described the probability distribution of survivals is, in our opinion, adding an unknown level of additional risk. And third, the escapement disaster that appears to have occurred in 1997 places the already depressed interior stocks in a perilous state from which, in our opinion, they are unlikely to recover if survival was again poor in 1998. The situation in coastal populations characterized by Lachmach is not as serious, but we caution that another poor survival year would be of concern to future production and would detrimentally affect rebuilding in coastal populations.

## 7. Conclusions

The status of Skeena coho epitomizes the problems faced in attempting to manage the coho salmon of a large and varied geographic region when nearly all of the exploitation is exerted in mixed-stock ocean fisheries. Coho populations in the Skeena above the Kispiox confluence, including the high interior, the Babine, the upper Bulkley (above the Morice confluence) and some tributaries of the Morice, are severely depressed, and have been so for a prolonged period. Consequently, those populations are extremely vulnerable to episodes of poor marine survival. The near-zero ocean survival that appears to have occurred in the 1996 smolt year (1997 returns) has produced a situation in these areas that can only be described as perilous. In mid-Skeena areas, such as the Kispiox, the Lakelse and the Kitsumkalum drainages, there appears to be a wide range of productivities, which results in a wide range in the status of individual populations. Coastal populations, like the Lachmach, are sufficiently productive to withstand variations in marine survival, provided that exploitation is kept at moderate levels. However, even if the majority of populations in the coastal zone can theoretically sustain high rates of exploitation, there are doubtless some less productive populations that cannot. Furthermore, the continued pursuit of maximal levels of production, while

[16] Lachmach is about 8 km long and the sex ratio is 50:50. Toboggan is about 16 km long.
[17] This is based on the ratio of average smolts/spawner.

theoretically feasible, requires correspondingly high levels of investment in monitoring and assessment that have, to date, not been achieved.

The difficulties caused by the mismatch of exploitation rate and productivity are compounded by the large and growing exploitation share of Alaskan fisheries. Alaskan stocks are entirely coastal and are as productive, and in some cases more productive, than Lachmach coho. Like the Lachmach population, southern Alaskan coho production has been stable, even with exploitation rates exceeding 70%.

A classical fixed-escapement strategy (see Section 4.4) applied to the least productive aggregate might be the most appropriate strategy to pursue in managing mixed-stock fisheries in situations where there are wide ranges in productivity. Underutilized production from the more productive stocks could be harvested in a manner that directly targeted those stocks. We appear to have pursued[18] an alternative strategy of tracking the optimal exploitation rate for the most productive aggregate (Figure 21). Depending on the relative differences in productivity of the most and least productive aggregates, this latter approach might allow near-optimal exploitation of the productive aggregate and persistence of the least. Since there is abundant evidence that the lower productivity aggregate has now collapsed, at least in a production sense[19] , we conclude that this latter strategy is probably incompatible with the persistence of upper Skeena coho.

The only encouraging finding in this assessment is that wild-smolt survivals at Toboggan Creek appear to be as much as 4-times higher than hatchery smolts released from the same system. Reconstructed wild smolt production at Toboggan Creek also appears to have been stable for the last 10 years. From this we conclude that the depressed state of interior coho is not due to deteriorating FW habitat, although there are doubtless localized problems. Instead, the now perilous state of upper Skeena coho is due to a chronic mismatch of exploitation rate and productivity.

## 8. Recommendations

1. Given the continuing conservation concerns for upper Skeena coho (principally the Bear-Sustut, Babine, and Bulkley-Morice), the alarming further decline in abundance in 1997, and uncertainty in survival rates for coho returning in 1998, we caution that any exploitation of upper Skeena area coho poses a high risk to the viability of coho populations in that area.

[18] It would probably be more exact to state that exploitation rates exerted in the major mixed-stock fisheries in conjunction fisheries management actions have resulted in a pattern of exploitation that is close to the optimal exploitation rates that would have been calculated for productive coastal coho populations.
[19] And may now be in peril in a conservation sense.

2. Although conservation problems for lower and middle area Skeena coho were not indicated to 1996, because of the precipitous decline in abundance in 1997 and uncertainty in survival rates for coho returning in 1998, we recommend a more conservative approach to the harvest of these coho stocks.
3. Assessment of Skeena coho continues to be affected by limited information, and in particular the lack of effective forecasting tools for Skeena coho and the lack of wild indictor sites where wild smolt production can be measured and their survival determined. Consequently we recommend the development of additional wild indicator sites in the Skeena, with highest priority given to the upper Skeena, as well of the development of more effective forecasting tools for Skeena coho.
4. The juvenile synoptic surveys have proven valuable in allowing us to monitor the status of populations throughout the watershed, and we recommend that they continue at their present scale.

## 9. References


BAILLIE, S. J. 1994. Summary of the 1993 coho salmon smolt trapping operation on the Lachmach River, British Columbia. Can. Data Rep. Fish. Aquat. Sci. 936: 43p.

BILTON, H. T. 1980. Returns of adult coho salmon in relation to mean size and time at release of juveniles to the catch and escapement. Can. Tech. Rep. Fish. Aquat. Sci. 941: all.

BILTON, H. T., R. B. MORLEY, A. S. COBURN, AND J. VAN TYNE. 1984. The influence of time and size at release of juvenile coho salmon (*Oncorhynchus kisutch*) on returns at maturity; results of releases from Quinsam River hatchery, B.C., in 1980. Can. Tech. Rep. Fish. Aquat. Sci. 1306: 98p.

BRADFORD, M. J., G. C. TAYLOR, AND J. A. ALLAN. 1997. Empirical review of coho salmon smolt abundance and the prediction of smolt production at the regional level. Trans. Am. Fish. Soc. 126: 49-64.

CEDERHOLM, C. J., AND W. J. SCARLETT. 1981. Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981, p. 98-110. *In* E. L. Brannon, and E. O. Salo [ed.] Proceedings of the Salmon and Trout Migratory Behavior Symposium, School of Fisheries, University of Washington.

CHAPMAN, D. G. 1951. Some properties of the hypergeometric distribution with applications to zoological sample censuses. Univ. Calif. Publ. Stat. 1: 131-160.

COX-ROGERS, S. 1994. Description of a daily simulation model for the Area 4 (Skeena River commercial fishery. Can. MS Rep. Fish. Aquat. Sci. 2256: 46p.

COX-ROGERS, S., AND L. JANTZ. 1993. Recent trends in the catchability of sockeye salmon in the Skeena River gillnet test fishery, and impacts on escapement estimation. Can. MS Rep. Fish. Aquat. Sci. 2219: 19p.

DAVIES, D. L. W., B. O. FINNEGAN, AND L. B. HOLTBY. 1992. Summary of the 1991 coho salmon smolt trapping operations on the Lachmach River, British Columbia. Can. Data Rep. Fish. Aquat. Sci. 871: 61p.

FINNEGAN, B. 1991. Summary of 1988 coho salmon smolt trapping operations on the Lachmach River and Antigonish Creek, British Columbia. Can. Data Rep. Fish. Aquat. Sci. 844: 29p.

FINNEGAN, B. O., R. L. DUNBRACK, AND K. SIMPSON. 1990. Summary of 1987 coho salmon smolt trapping operations on the Lachmach River, British Columbia. Can. Data Rep. Fish. Aquat. Sci. 812: 27p+iv.

FRANKLIN, I. R. 1980. Evolutionary change in small populations, p. 135-150. *In* M. E. Soule, and B. A. Wilcox [ed.] Conservation biology: an evolutionary-ecological perspective, Sinauer.

GAZEY, W. J., AND K. K. ENGLISH. 1996. Assessment of sockeye and pink salmon stocks in the Northern Boundary area using run reconstruction techniques, 1982-1992. Final report for Fisheries and Oceans Canada. LGL Ltd., Sydney, BC.

GAZEY, W. J., AND M. J. STALEY. 1986. Population estimation from mark-recapture experiments using a sequential Bayes algorithm. Ecology 67: 941-951.

HARTMAN, G. F., AND J. C. SCRIVENER. 1990. Impacts of forestry practices on a coastal stream ecosystem, Carnation Creek, British Columbia. Can. Bull. Fish. Aquat. Sci. 223: 148+viii.

HILBORN, R. 1985. Simplified calculation of optimum spawning stock size from Ricker's stock recruitment curve. Can. J. Fish. Aquat. Sci. 42: 1833-1834.

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

HOLTBY, L. B. 1988. Effects of logging on stream temperatures in Carnation Creek, British Columbia, and associated impacts on the coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 45: 502-515.

HOLTBY, L. B., AND J. C. SCRIVENER. 1989. Observed and simulated effects of climatic variability, clear-cut logging, and fishing on the numbers of chum salmon (*Oncorhynchus keta*) and coho salmon (*O. kisutch*) returning to Carnation Creek, British Columbia, p. 62-81. *In* C. D. Levings, L. B. Holtby, and M. A. Henderson [ed.] Proceedings of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks, Canadian Special Publication of Fisheries and Aquatic Sciences 105.

HOLTBY, L. B., R. KADOWAKI, AND L. JANTZ. 1994. Update of stock status information for early run Skeena River coho salmon (through the 1993 return year). PSARC Working Paper S94-4: 44p.

KADOWAKI, R. K. 1988. Stock assessment of early run Skeena River coho salmon and recommendations for management. Can. Tech. Rep. Fish. Aquat. Sci. 1638: 29 p.

KADOWAKI, R., T. PENDRAY, AND L. JANTZ. 1992. Stock assessment of early run Skeena River coho salmon (through the 1991 return year). PSARC Working Paper S92-3: 13p.

KUHN, B. R., L. LAPI, AND J. M. HAMER. 1988. An introduction to the Canadian database on marked Pacific salmon. Can. Tech. Rep. Fish. Aquat. Sci. 1649: 54p.

LANE, J., AND S. J. BAILLIE. 1994. Summary of the 1992 coho salmon smolt trapping operation on the Lachmach River, British Columbia. Can. Data Rep. Fish. Aquat. Sci. 926: 35p.

LANE, J., AND B. FINNEGAN. 1991. Summary of fall 1988 adult and juvenile coho salmon sampling operation on the Lachmach River, British Columbia. Can. Data Rep. Fish. Aquat. Sci. 824: 61p.

LANE, J., J. A. TAYLOR, AND B. O. FINNEGAN. 1994a. 1991 Adult coho escapement and summary of the 1988-1990 escapement years to the Lachmach River, British Columbia. Can. Data Rep. Fish. Aquat. Sci. 938: 53p.

LANE, J., J. A. TAYLOR, AND B. O. FINNEGAN. 1994b. Summary of adult coho escapement to the Lachmach River, B.C., 1990. Can. Data Rep. Fish. Aquat. Sci. 932: 69p.

SAIMOTO, R. K. 1995. Toboggan Creek coho smolt enumeration 1995. Contractors report to DFO, Stock Assessment Division, July 1995, 68 p.

SANDERCOCK, F. K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*), p. 395-446. *In* C. Groot, and L. Margolis [ed.] Pacific salmon life histories, UBC Press, University of British Columbia.

SCHNUTE, J. 1983. A new approach to estimating populations by the removal method. Can. J. Fish. Aquat. Sci. 40: 2153-2169.

SEBER, G. A. F., AND E. D. LE CREN. 1967. Estimating population parameters from catches large relative to the population. J. Anim. Ecol. 46: 631-643.

SKR CONSULTANTS LTD. 1996. Toboggan Creek coho smolt enumeration 1996. Contractors report to DFO, Stock Assessment Division, August 1996, 53 p.

SOLAZZI, M. F., T. E. NICKELSON, AND S. L. JOHNSON. 1991. Survival, contribution, and return of hatchery coho salmon (*Oncorhynchus kisutch*) released into freshwater, estuarine, and marine environments. Can. J. Fish. Aquat. Sci. 48: 248-253.

STOCKER, M. 1987. Pacific Stock Assessment Review Committee (PSARC) annual report for 1986. Can. MS Rep. Fish. Aquat. Sci. 1951: 97p.

TAYLOR, J. A. 1995. Synoptic surveys of habitat characteristics and fish populations conducted in lakes and streams with the Skeena River watershed, between 15 August and 12 September, 1994. Contractors report by J.A. Taylor and Associates for StAD, DFO. 108 p.

TAYLOR, J. A. 1996. Assessment of juvenile coho population levels in selected lakes and streams within the Skeena River watershed, British Columbia, between 11 and 31 August 1995. Contractors report by J.A. Taylor and Associates for StAD, DFO, 101 p.

TAYLOR, J. A. 1997. Synoptic surveys of juvenile coho populations and associated habitat characteristics in selected lakes and streams within the Skeena River watershed, British Columbia, between 10 August and 10 September 1996. Contractors report by J.A. Taylor and Associates for StAD, DFO, 94 p.

WAPLES, R. S. 1990. Conservation genetics of Pacific salmon. II. Effective population size and the rate of loss of genetic variability. J. Heredity 81: 267-276.

ZIPPIN, C. 1958. The removal method of population estimation. J. Wildl. Manage. 22: 82-90.

**Table 1. Previous management and assessment recommendations.**

| source<br>recommendation | actions taken in response to recommendation |
|---|---|
| Kadowaki 1988 | |
| 1. set an escapement target of 33,000 at river mouth, equivalent to 68 units in the test fishery by Aug. 24$^{th}$ | A conservation plan was developed that included: time and area closures in the troll fishery; reduced fishing times in the gillnet fishery in the approach waters to the Skeena, elimination of the non-tidal sport fishery, and requests to native groups to avoid coho where possible and to reduce coho harvests. The escapement target has been achieved in two years. |
| 2. generate timing & fisheries distributions of hatchery & wild fish to decompose the aggregate into components | Coho produced at Kispiox hatchery, Toboggan Creek hatchery and in net pens on the Babine have been regularly tagged with CWTs. There has been sporadic tagging at some 10 other sites in the watershed. Recovery of the tags in the river mouth fishery has given some information about variations in run timing. |
| 3. tag fish to generate exploitation rates | Exploitation rates and marine survival rates are now obtained for Babine Lake and Toboggan Creek hatchery stocks. Wild smolt survivals have been measured indirectly at Toboggan Creek since 1995. |
| 4. extend test fishery to end of Sept. to estimate relative magnitudes of early and late components | Attempts to extend the test fishery beyond the end of August have been abandoned because of excessive seal predation. |
| Kadowaki, Pendray & Jantz, S92-3 | |
| 1. continue with the escapement target of 33,000 | The conservation plan has continued due to the continued poor performance of Skeena coho indexed by the test-fishery. |
| 2. extend test fishery to first week of Sept. | Implementation of this measure has been abandoned. |
| 3. estimate CWT escapements and in-river harvest for determination of exploitation rates. | In-river creel censuses have been operated opportunistically with Skeena Green Plan funding but have proven expensive. |
| Holtby, Kadowaki & Jantz S94-4 | |
| 1. development of additional exploitation/survival rate indicators | This information is now routinely collected for the Toboggan Creek and Fort Babine hatchery stocks, but there are no wild indicators and there are no coastal indicators. |
| 2. examine the reasons for apparent low hatchery smolt survivals | Wild smolt survivals have been measured indirectly at Toboggan Creek and would seem to indicate that survivals measured on hatchery smolts at that site are 25% of wild survival. No reasons have been identified. |
| 3. critical examination of the assessment program, especially with a view to establishing a drainage wide system of indexed escapements or proxy measures of escapement. | A drainage-wide juvenile synoptic survey program was initiated in 1994, extending the program begun in the Bulkley-Morice. |
| 4. faced with low and fluctuating marine survivals, the need to reduce exploitation rates to sustainable levels was identified | Exploitation rates have been reduced in the northern troll fishery, but those reduction were offset in 1995 and 1996 by greater increases in the net fisheries and by escalating Alaskan exploitation. Further fisheries management actions were undertaken in 1997, which resulted |

| source<br>recommendation | actions taken in response to recommendation |
| --- | --- |
| | in marked reductions in Canadian exploitation rates, but these actions were partially offset by further increases in Alaskan exploitation. |
| 5. development of a pre-season forecasting tool as a prelude to an adaptive management approach was recommended. | Forecasting based on jack returns to the Lachmach River was developed but Lachmach jack returns failed to predict the recruitment failure that seems to have occurred in the Skeena, QCI and sections of the Central Coast. |

Table 2. **Marine survival rates, total exploitation rates and fishery-specific exploitation rates for the three coho indicator stocks. An estimate of the FW sport exploitation rate can be obtained by subtraction.**

| catch year | survival rate | total exploitation rate | fishery-specific exploitation rates | | |
|---|---|---|---|---|---|
| | | | Alaska | northern troll | northern net |
| Lachmach River (wild) | | | | | |
| 1989 | 0.044 | 0.621 | 0.379 | 0.136 | 0.106 |
| 1990 | 0.113 | 0.763 | 0.391 | 0.274 | 0.093 |
| 1991 | 0.121 | 0.726 | 0.338 | 0.291 | 0.091 |
| 1992 | 0.088 | 0.754 | 0.442 | 0.194 | 0.109 |
| 1993 | 0.061 | 0.646 | 0.372 | 0.150 | 0.113 |
| 1994 | 0.174 | 0.706 | 0.460 | 0.178 | 0.064 |
| 1995 | 0.082 | 0.691 | 0.471 | 0.087 | 0.133 |
| 1996 | 0.072 | 0.714 | 0.389 | 0.123 | 0.181 |
| 1997 | 0.055 | 0.553 | 0.484 | 0.021 | 0.047 |
| Toboggan Creek CDP | | | | | |
| 1989 | 0.033 | 0.439 | 0.157 | 0.150 | 0.133 |
| 1990 | 0.034 | 0.685 | 0.248 | 0.260 | 0.178 |
| 1991 | 0.049 | 0.630 | 0.306 | 0.191 | 0.129 |
| 1992 | 0.014 | 0.661 | 0.370 | 0.084 | 0.207 |
| 1993 | 0.014 | 0.558 | 0.294 | 0.074 | 0.190 |
| 1994 | 0.054 | 0.648 | 0.378 | 0.189 | 0.078 |
| 1995 | 0.010 | 0.514 | 0.278 | 0.072 | 0.164 |
| 1996 | 0.027 | 0.730 | 0.320 | 0.142 | 0.201 |
| 1997† | 0.005 | 0.578 | 0.377 | 0.046 | 0.156 |
| Fort Babine CDP | | | | | |
| 1994 | 0.042 | 0.736 | 0.431 | 0.239 | 0.051 |
| 1995 | 0.010 | 0.782 | 0.585 | 0.122 | 0.075 |
| 1996 | 0.019 | 0.574 | 0.342 | 0.130 | 0.055 |
| 1997 | 0.005 | 0.540 | 0.348 | 0.130 | 0.062 |

† excludes FW sport catch for which estimates are not yet available, although the FW catch is thought to have been negligible..

**Table 3. Observed CWT recoveries in Alaskan fisheries by stock, quadrant and gear-type. Gn: drift gillnet, Sn: purse seine, Tr: troll.**

| quadrant | Lachmach | | | Fort Babine | | | Toboggan | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Gn | Sn | Tr | Gn | Sn | Tr | Gn | Sn | Tr | total |
| NW | 0 | 0 | 24 | 0 | 0 | 13 | 0 | 0 | 12 | 49 |
| NE | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 3 |
| SW | 0 | 1 | 6 | 0 | 0 | 2 | 0 | 3 | 7 | 19 |
| SE | 7 | 0 | 4 | 0 | 0 | 1 | 1 | 0 | 10 | 23 |
| total | 7 | 1 | 35 | 0 | 0 | 17 | 1 | 4 | 29 | |

**Table 4. Correlations between the aggregate escapement indicators. $\bar{p}_{max}$ is the proportion of the maximum observed BC-16 by stream averaged over region. The number in brackets is the number of years. Probability values are indicated as *** $P$<0.001; ** $P$<0.01; ns: not significant.**

| index | adjusted test fishery | | Babine fence to Oct. 1st | |
|---|---|---|---|---|
| Babine fence to Oct. 1st | 0.606*** | (41) | — | |
| $\bar{p}_{max}$ (lower Skeena) | 0.685*** | (40) | 0.508*** | (39) |
| $\bar{p}_{max}$ (mid-Skeena) | 0.417** | (41) | 0.141 ns | (40) |
| $\bar{p}_{max}$ (upper Skeena) | 0.476** | (41) | 0.763*** | (40) |
| $\bar{p}_{max}$ (all Skeena) | 0.668*** | (41) | 0.497*** | (40) |

**Table 5. For Toboggan Creek wild and Lachmach River coho, fitted parameters of Ricker stock-recruitment curves for a range of marine survivals.**

| | marine survival rate | $a'$ | $b'$ | $u_{MSY}$ | $S_{MSY}$ | $\frac{recruits}{spawner}$ |
|---|---|---|---|---|---|---|
| Lachmach | 0.25 | 3.18 | 3412 | 0.88 | 946 | 10.1 |
| | 0.20 | 2.96 | 3175 | 0.87 | 929 | 8.12 |
| | 0.14 | 2.61 | 2793 | 0.83 | 887 | 5.68 |
| | 0.12 | 2.45 | 2628 | 0.81 | 863 | 4.87 |
| | 0.10 | 2.27 | 2432 | 0.77 | 830 | 4.06 |
| | 0.08 | 2.05 | 2193 | 0.73 | 782 | 3.25 |
| | 0.06 | 1.76 | 1885 | 0.66 | 710 | 2.44 |
| | 0.04 | 1.35 | 1450 | 0.55 | 588 | 1.62 |
| | 0.02 | 0.66 | 707 | 0.30 | 321 | 0.81 |
| Toboggan | 0.25 | 2.16 | 2817 | 0.75 | 983 | 4.15 |
| | 0.20 | 1.93 | 2525 | 0.71 | 921 | 3.32 |
| | 0.14 | 1.58 | 2059 | 0.61 | 802 | 2.32 |
| | 0.12 | 1.42 | 1857 | 0.57 | 744 | 1.99 |
| | 0.10 | 1.24 | 1619 | 0.51 | 669 | 1.66 |
| | 0.08 | 1.02 | 1327 | 0.44 | 569 | 1.33 |
| | 0.06 | 0.73 | 951 | 0.33 | 427 | 1.00 |
| | 0.04 | 0.32 | 421 | 0.15 | 201 | 0.66 |
| | 0.02 | – | – | – | – | – |

**Table 6. Target exploitation rate calculations for Lachmach and Toboggan wild populations. For Lachmach $n_s$ = 17,209 and for Toboggan $n_s$ = 36560. For each population four methods were used, as discussed in Section 6, p. 20.**

| population/method | $P^{\dagger}$ | $E_t$ | $s$ | $u$ |
|---|---|---|---|---|
| Lachmach | | | | |
| optimal fixed-escapement | 0.1 | – | – | 0.50 |
| $S_{MSY}$ | 0.5 | 808 | 0.091 | 0.48 |
| minimum population size | 0.01 | 402 | 0.042 | 0.44 |
| density-dependence | 0.05 | 315 | 0.056 | 0.67 |
| Toboggan | | | | |
| optimal fixed-escapement | 0.1 | – | – | 0.09 |
| $S_{MSY}$ | 0.5 | 707 | 0.085 | 0.77 |
| minimum population size | 0.01 | 402 | 0.017 | 0.35 |
| density-dependence | 0.05 | 315 | 0.030 | 0.71 |

† $P$ is the probability of observing a smolt survival lower than the one assumed in estimating the escapement target or floor.

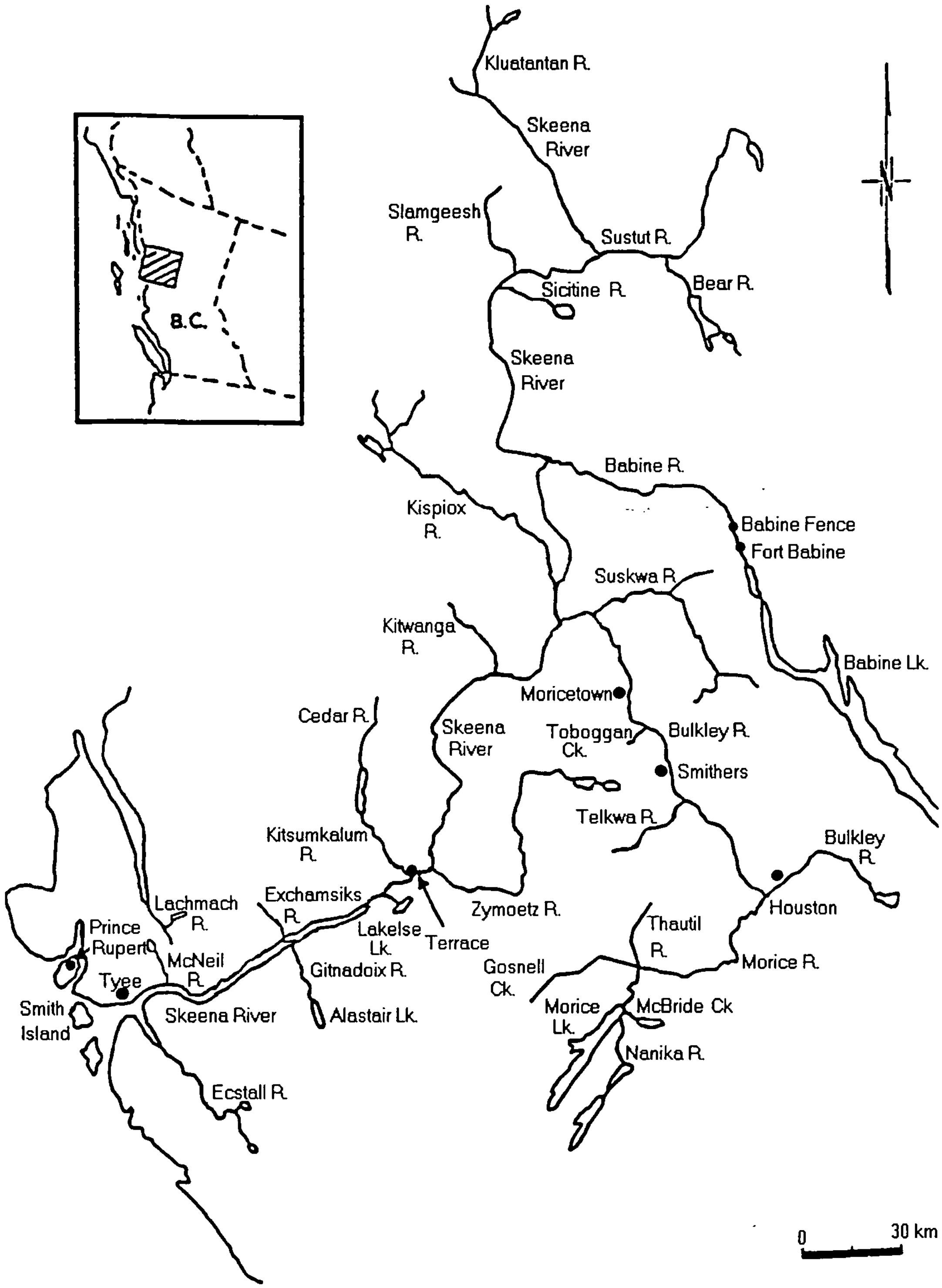


**Figure 1. Area map of the Skeena showing most sites referred to in this Working Paper.**

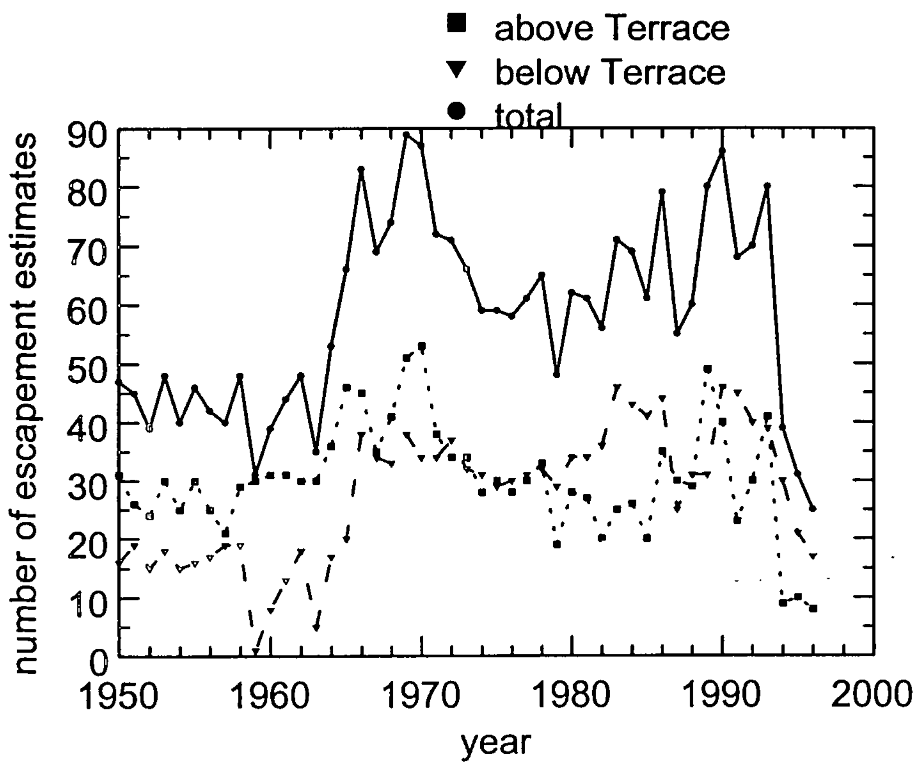


**Figure 2.** **Number of escapement estimates in the BC-16's by year for the entire Skeena and the portions below and above Terrace.**

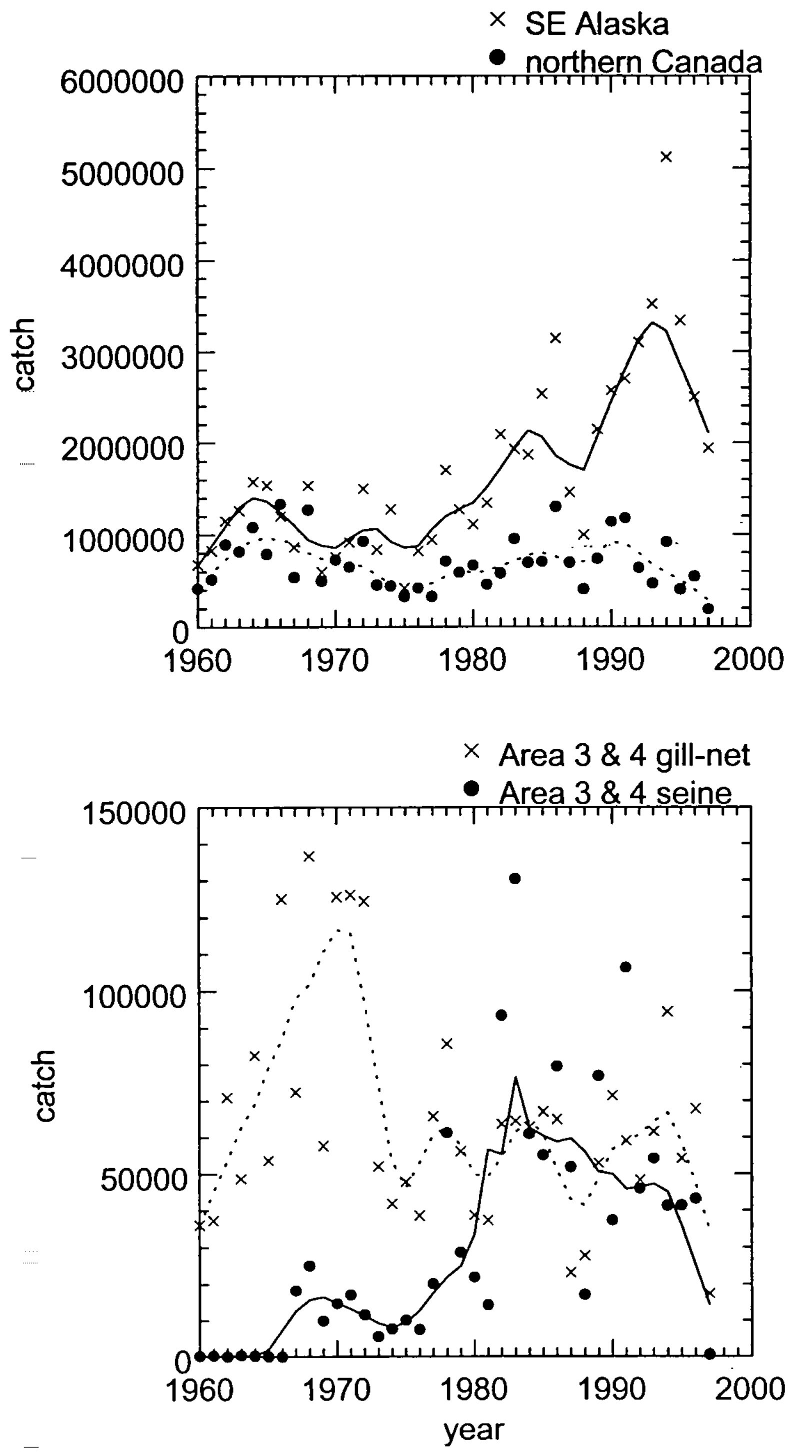


**Figure 3.** **Catch by year for the Area 4 seine and gill-net fisheries, the northern troll and southern Alaska, all fisheries combined.**

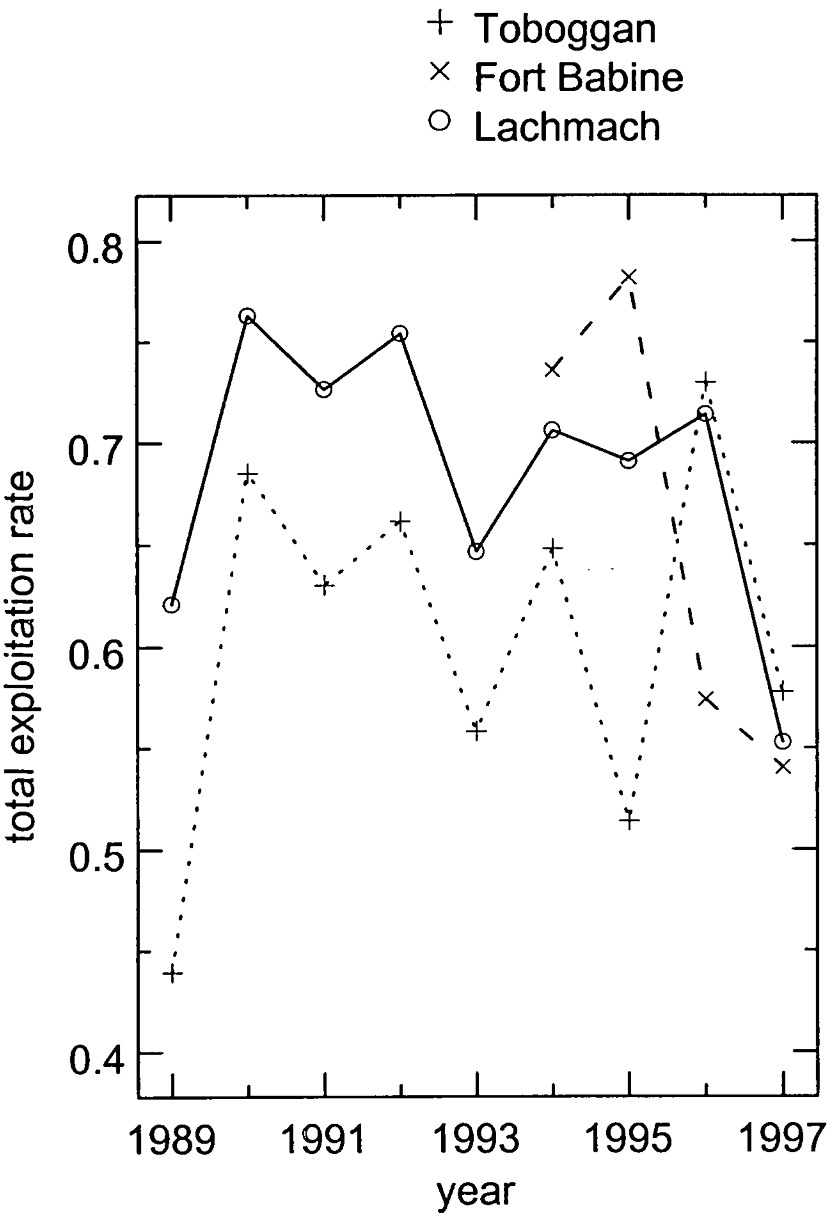


**Figure 4.** **Total exploitation rate on wild Lachmach River coho (Work Channel) and Fort Babine and Toboggan hatchery coho (Skeena)**

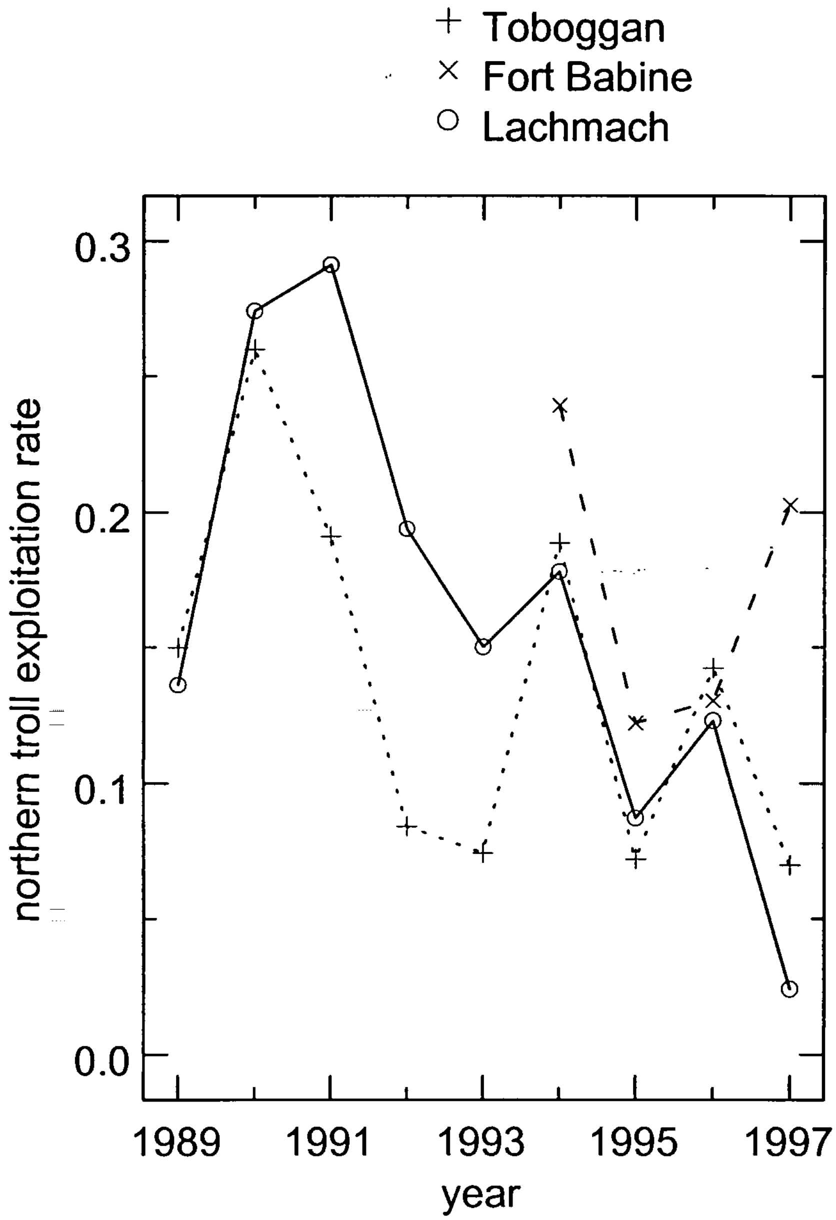


**Figure 5.** **Exploitation rate exerted by Canadian northern troll fishery on wild Lachmach River coho (Work Channel) and Fort Babine and Toboggan hatchery coho (Skeena).**

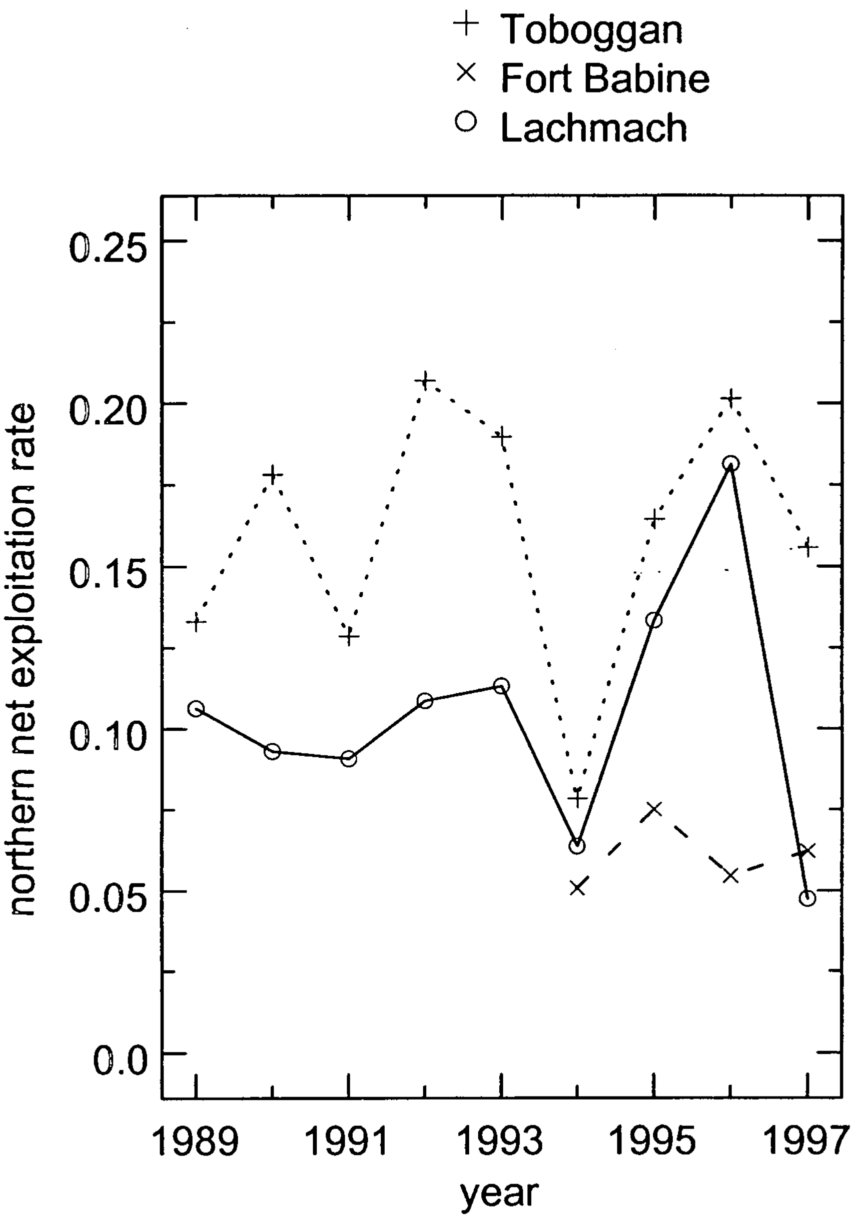


**Figure 6.** **Exploitation rate exerted by Canadian northern net fishery on wild Lachmach River coho (Work Channel and Fort Babine and Toboggan hatchery coho (Skeena). The net catch is made, primarily, by gillnet in Statistical Area 4.**

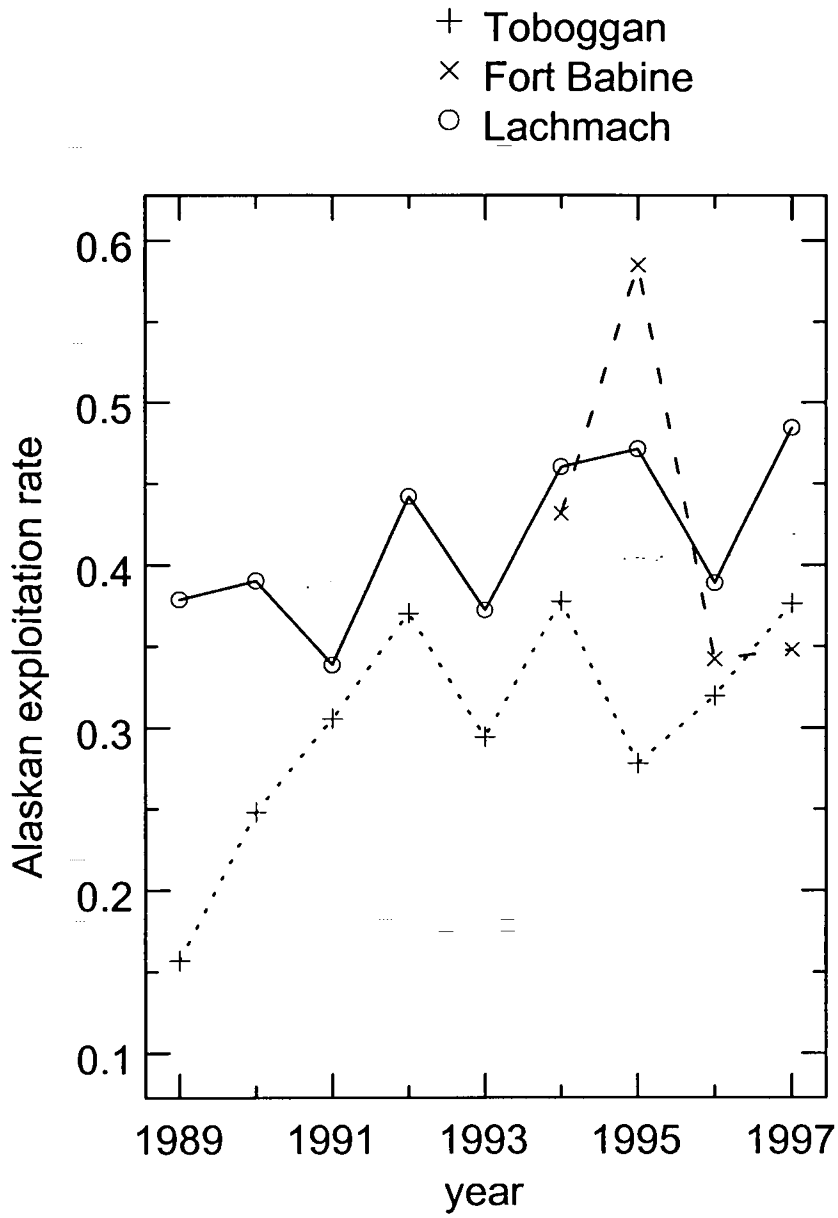


**Figure 7.** **Exploitation rate exerted by Alaskan fisheries on wild Lachmach River coho (Work Channel) and Fort Babine and Toboggan hatchery coho (Skeena).**

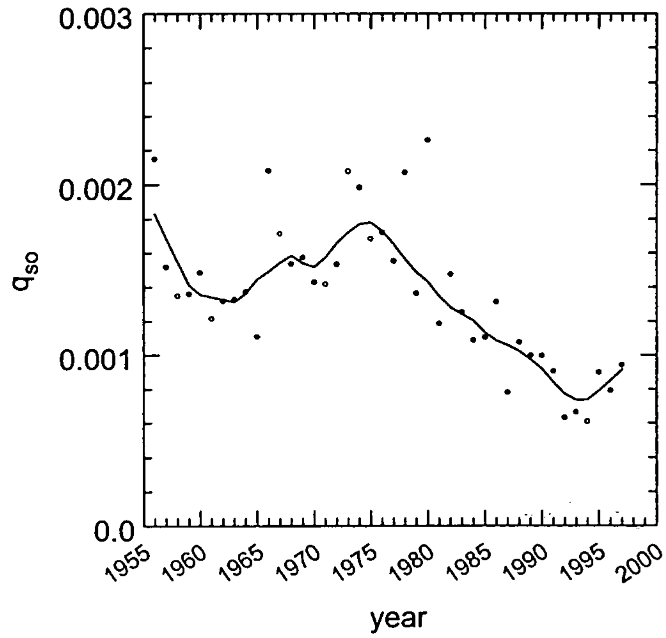


**Figure 8.** **Time series of sockeye catchability ($q_{so}$) with a LOWESS smooth trend line.**

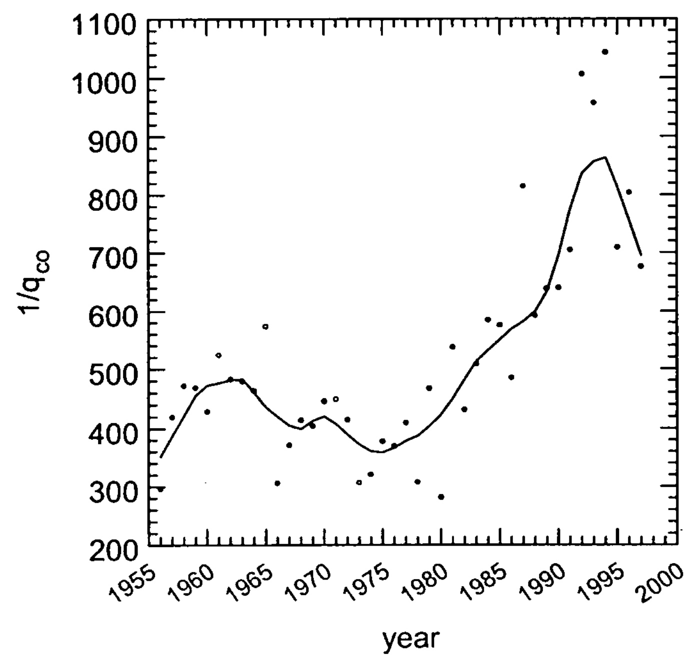


**Figure 9.** **Time series of $1/q_{co}$.**

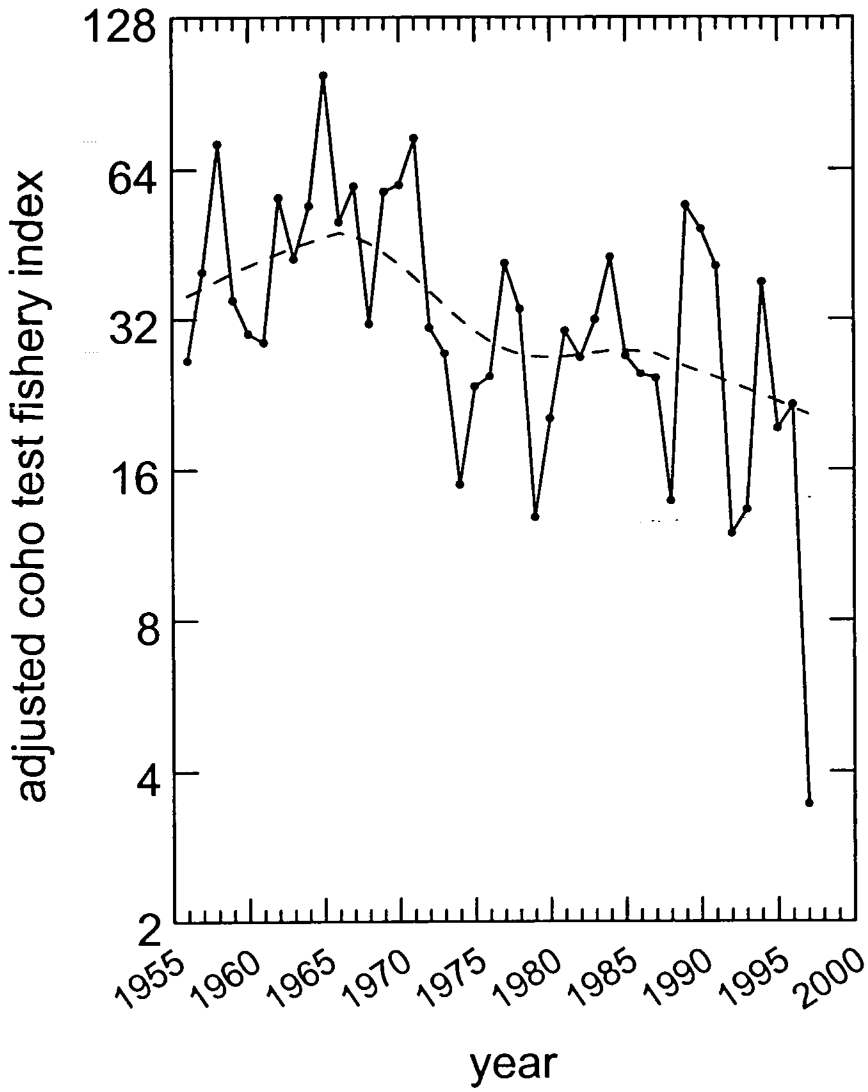


**Figure 10.** **Skeena test fishery index for coho to August 25th, adjusted for sockeye catchability. Line is a LOWESS smooth. Note that the y-axis is a $\log_2$ scale.**

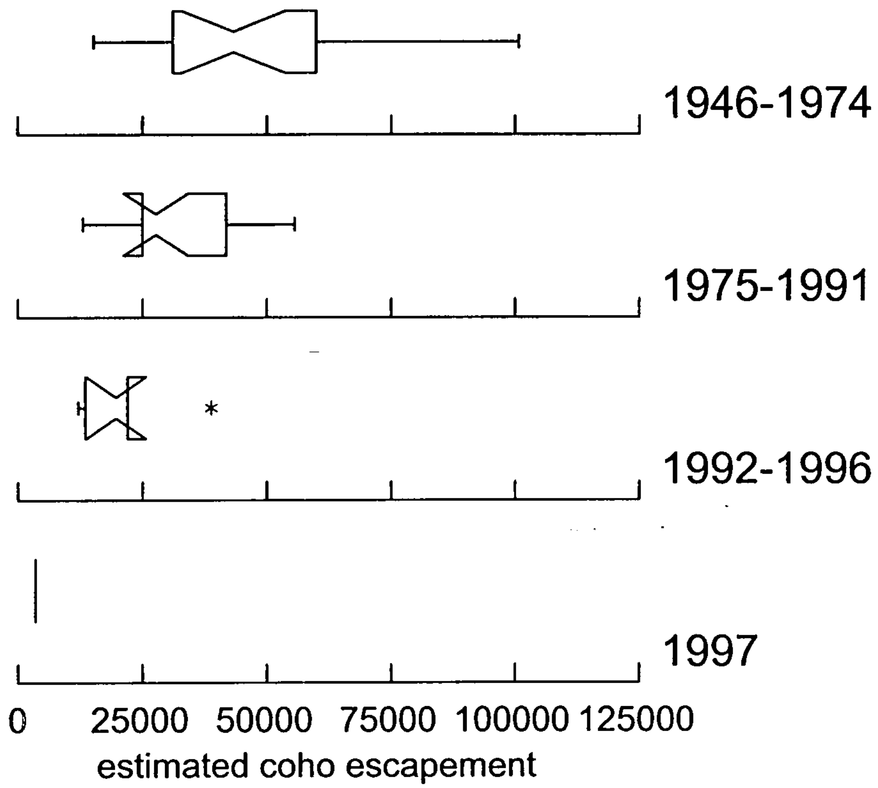


**Figure 11.** **Estimated total escapement to Skeena River aggregate indexed by the test-fishery adjusted for changing efficiency.**

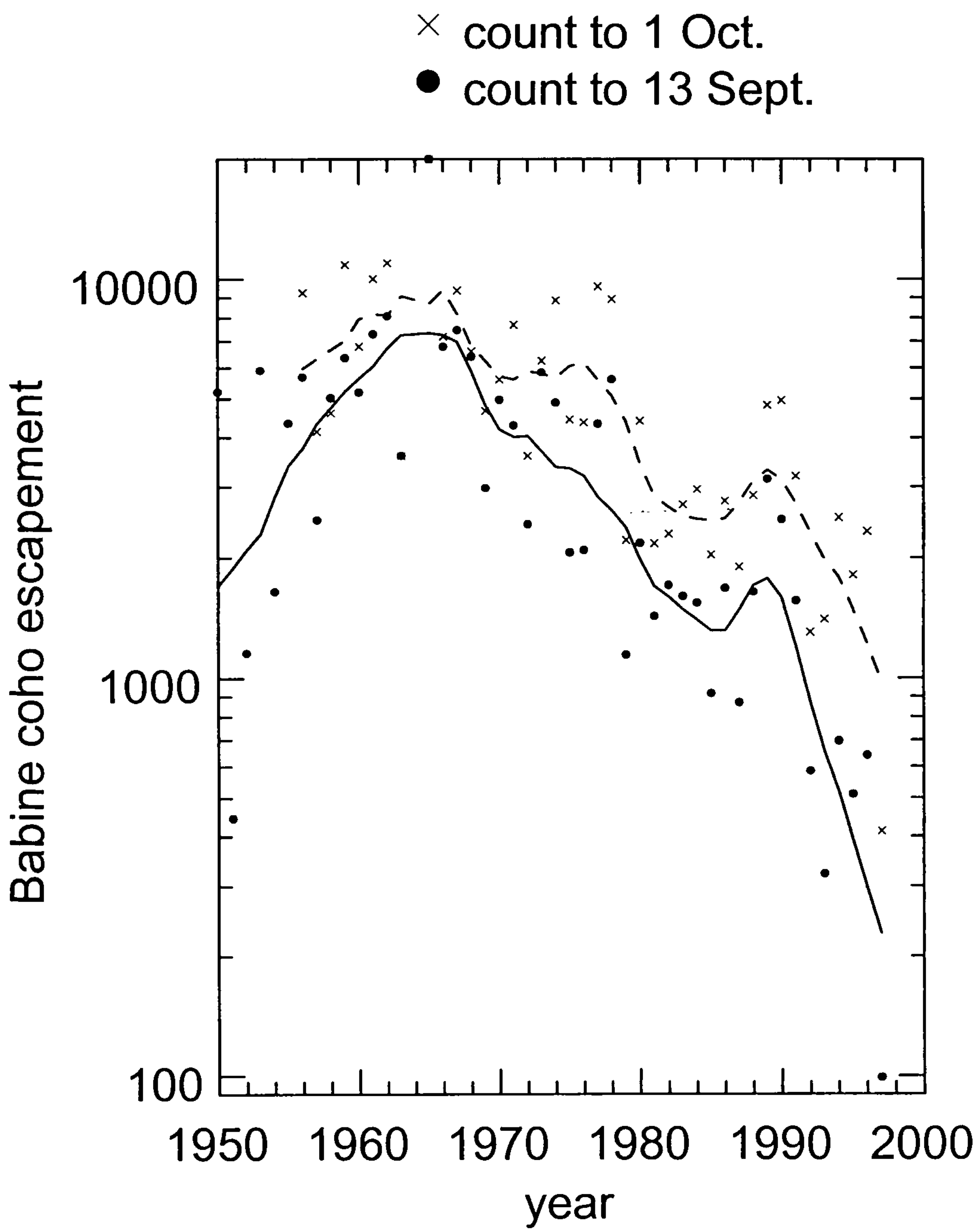


**Figure 12.** Babine fence coho counts to the two index dates. The lines shown are LOWESS smooths.

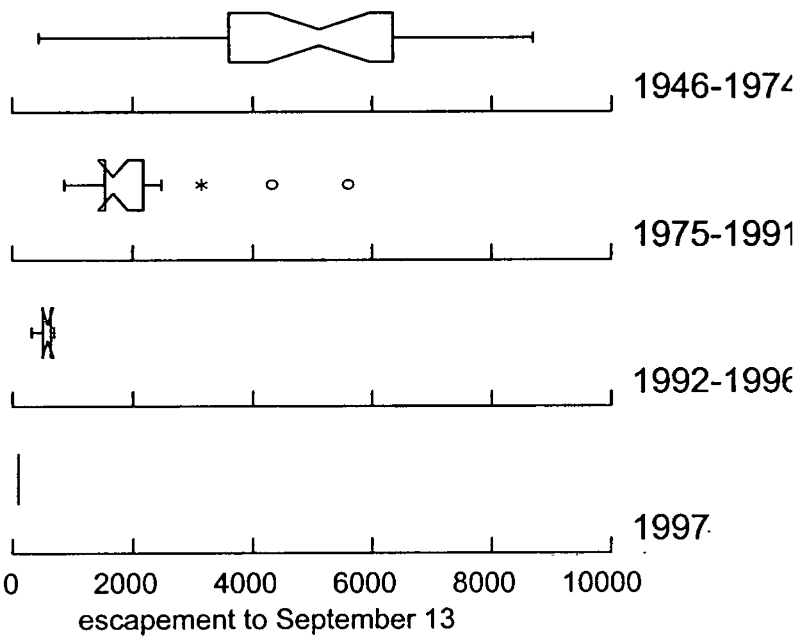


**Figure 13.** **Babine fence escapements to Sept. 13th, grouped into abundance steps apparent in Figure 12.**

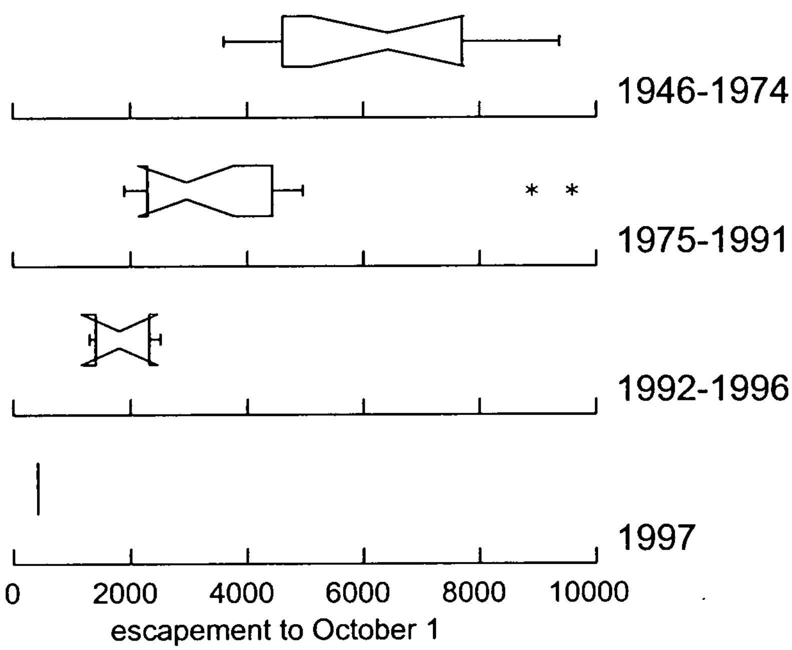


**Figure 14.** **Babine fence escapements to October 1st, grouped into abundance steps apparent in Figure 5.**

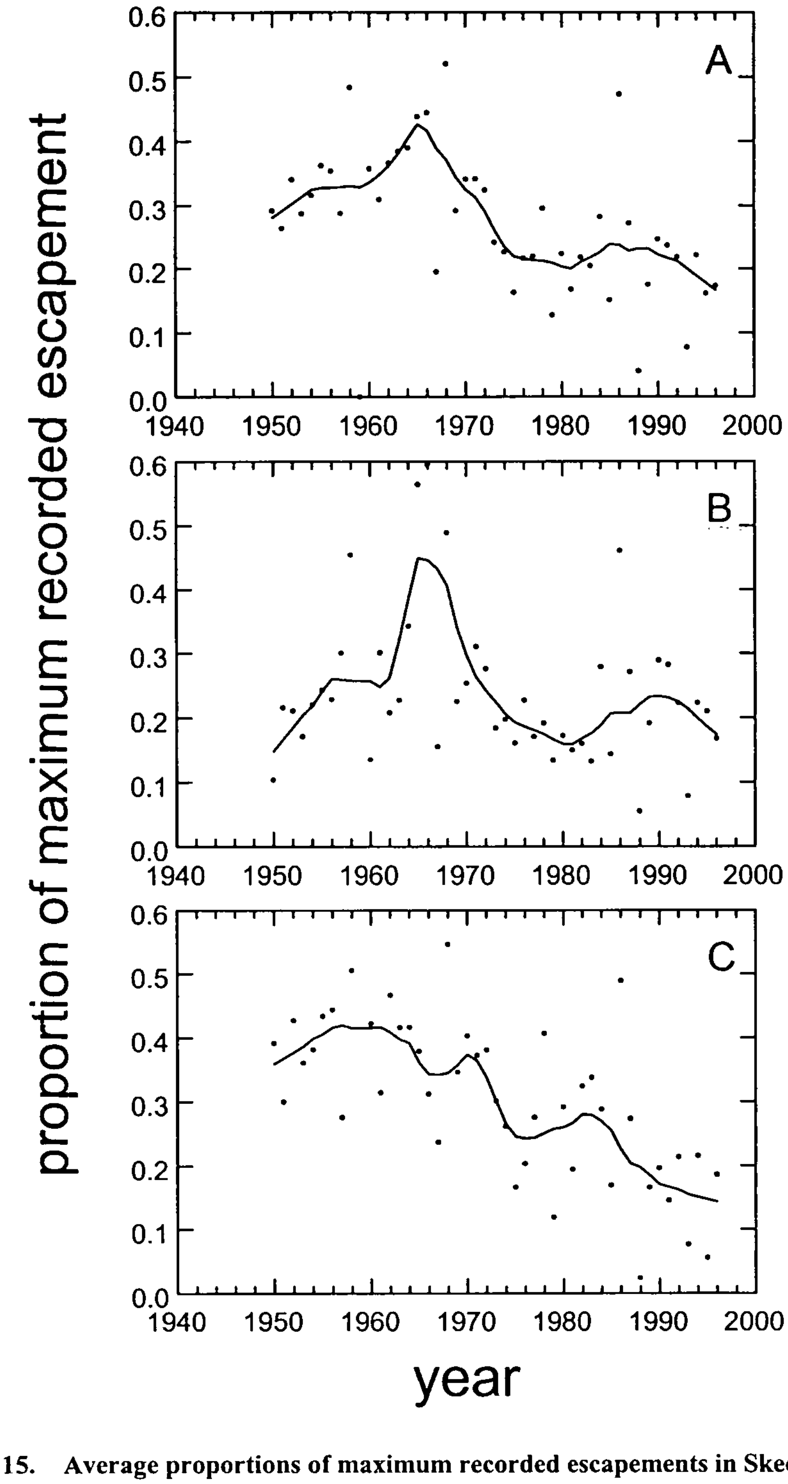


**Figure 15.** **Average proportions of maximum recorded escapements in Skeena streams. A) total Skeena, B) downstream of Terrace including Kispiox, C) upstream of Terrace.**

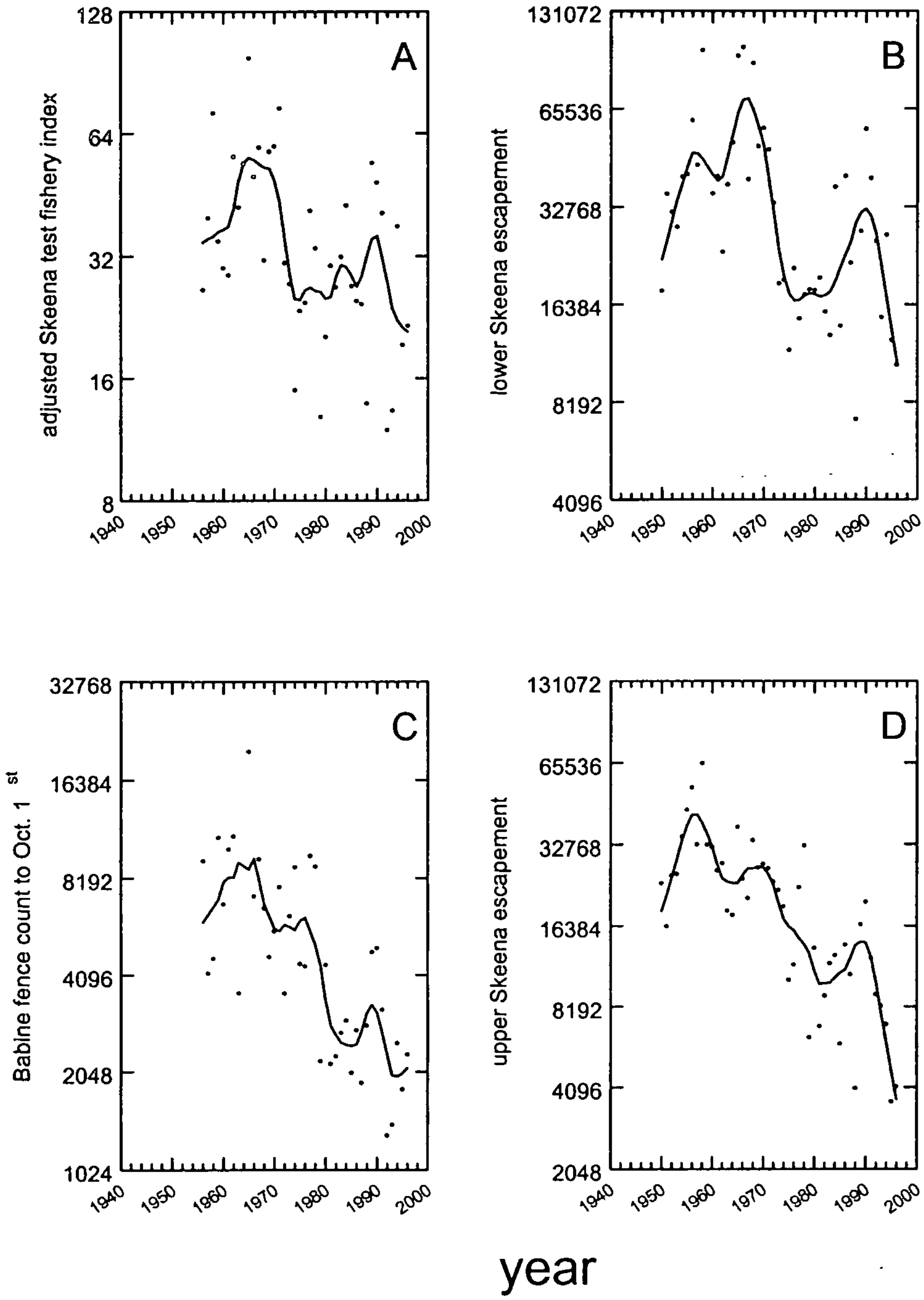


**Figure 16.** **A) Adjusted Skeena test-fishery index. B) Upper Skeena visual coho escapement estimates. C) Babine fence count to Oct. 1st. D) Lower Skeena visual escapement estimates. All trend lines are LOWESS smooths. Note that all y-axis are $\log_2$ scales.**

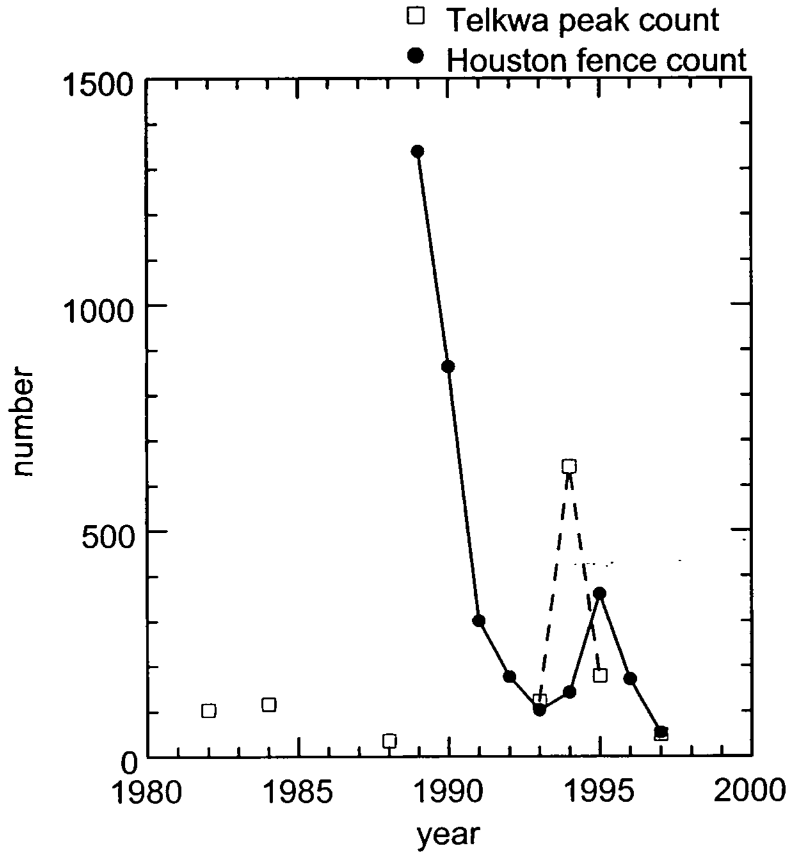


**Figure 17. Additional escapement indicators in the Bulkley/Morice and upper Bulkley regions.**

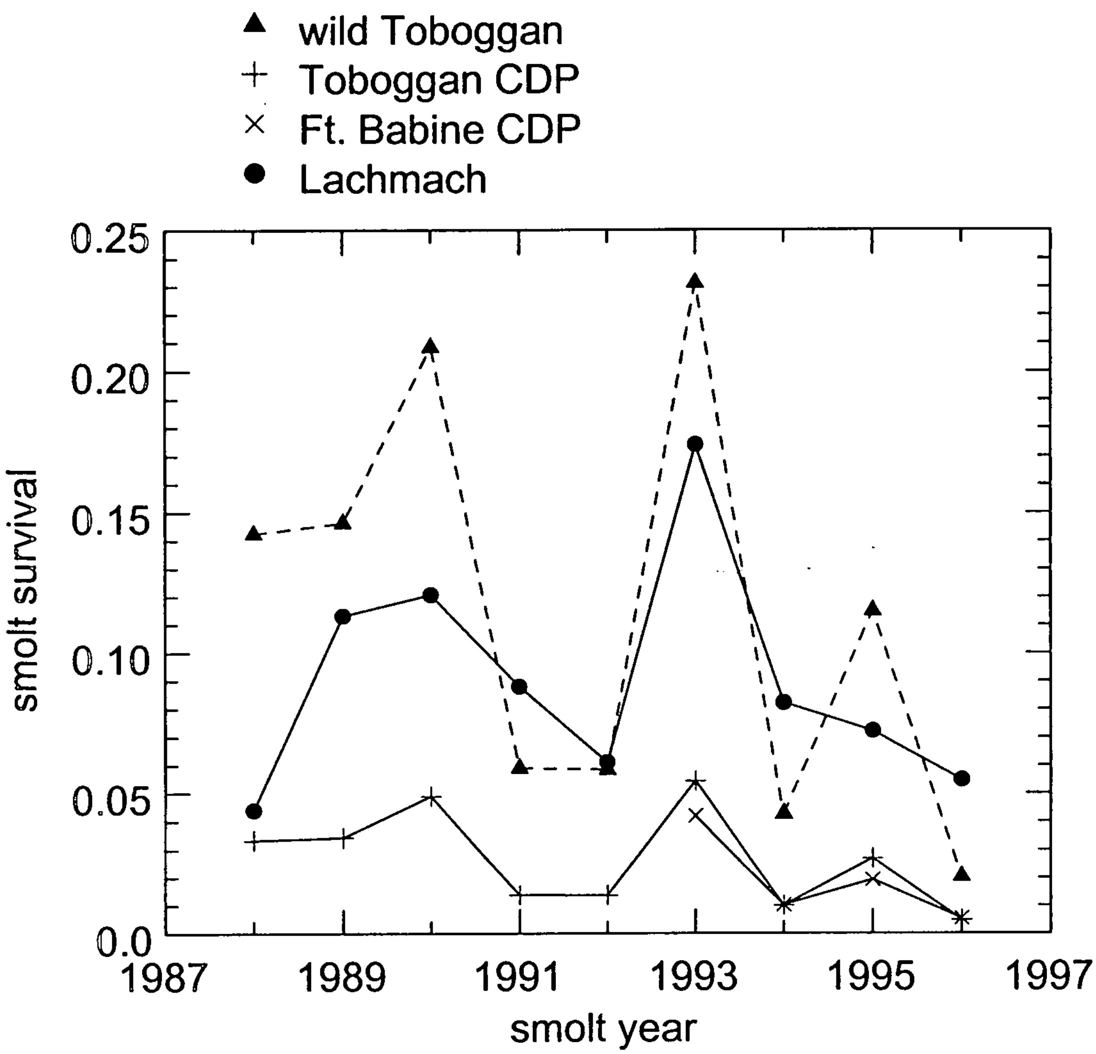


**Figure 18.** **Smolt survivals for the indicator coho stocks, including reconstructed values for the wild Toboggan population.**

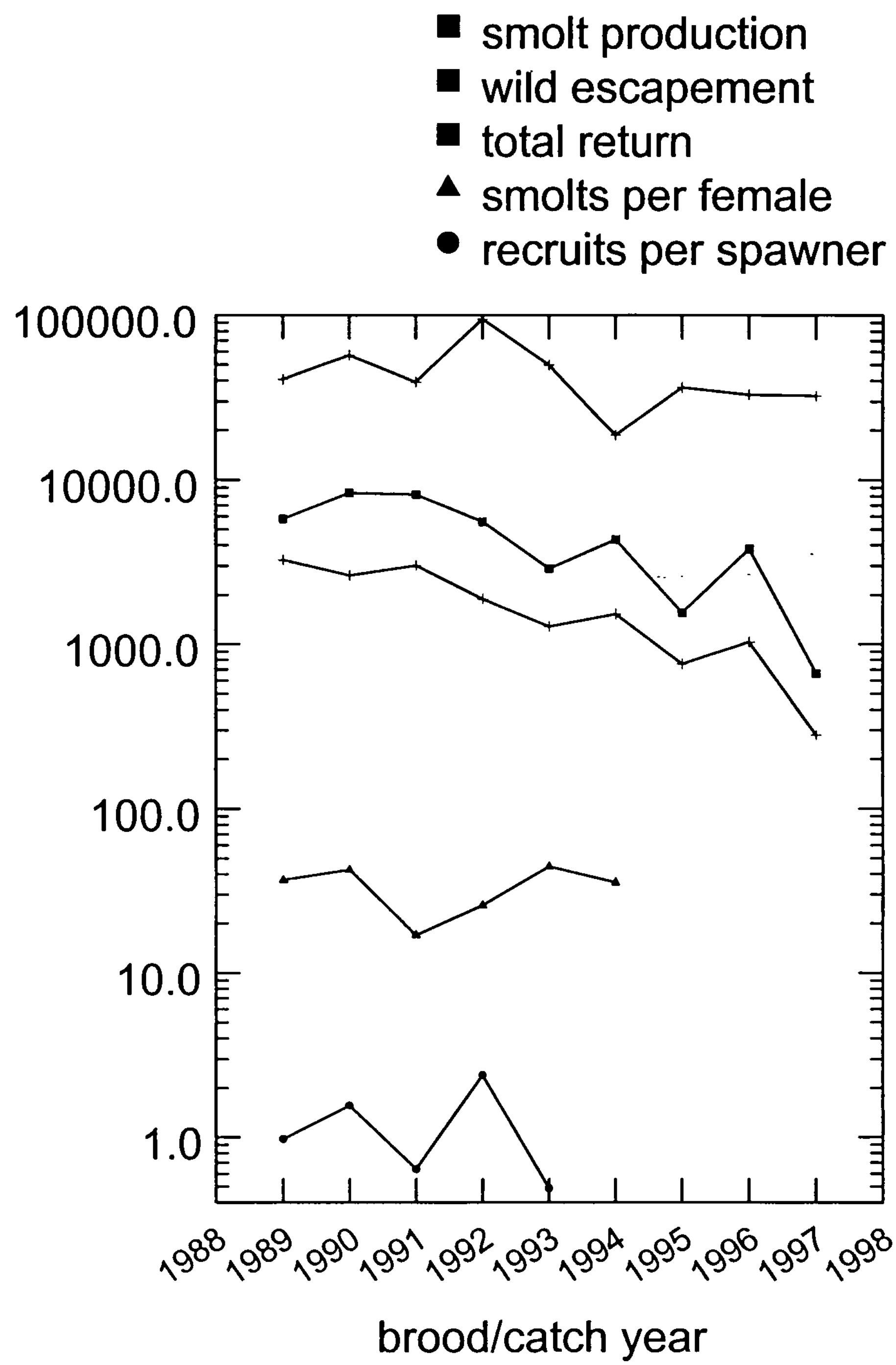


**Figure 19. Production data for wild Toboggan Creek coho.**

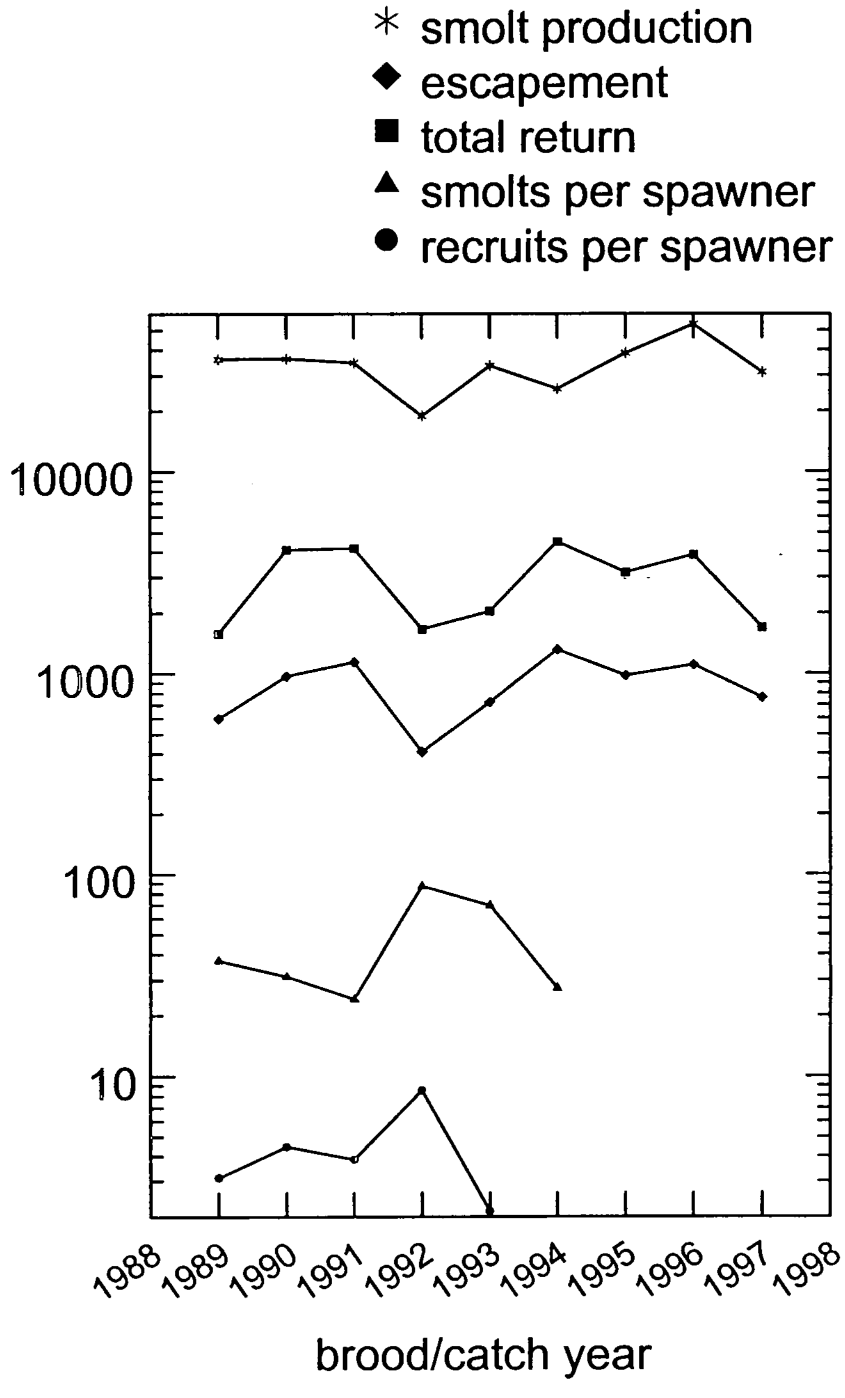


**Figure 20. Production data for Lachmach River wild coho.**

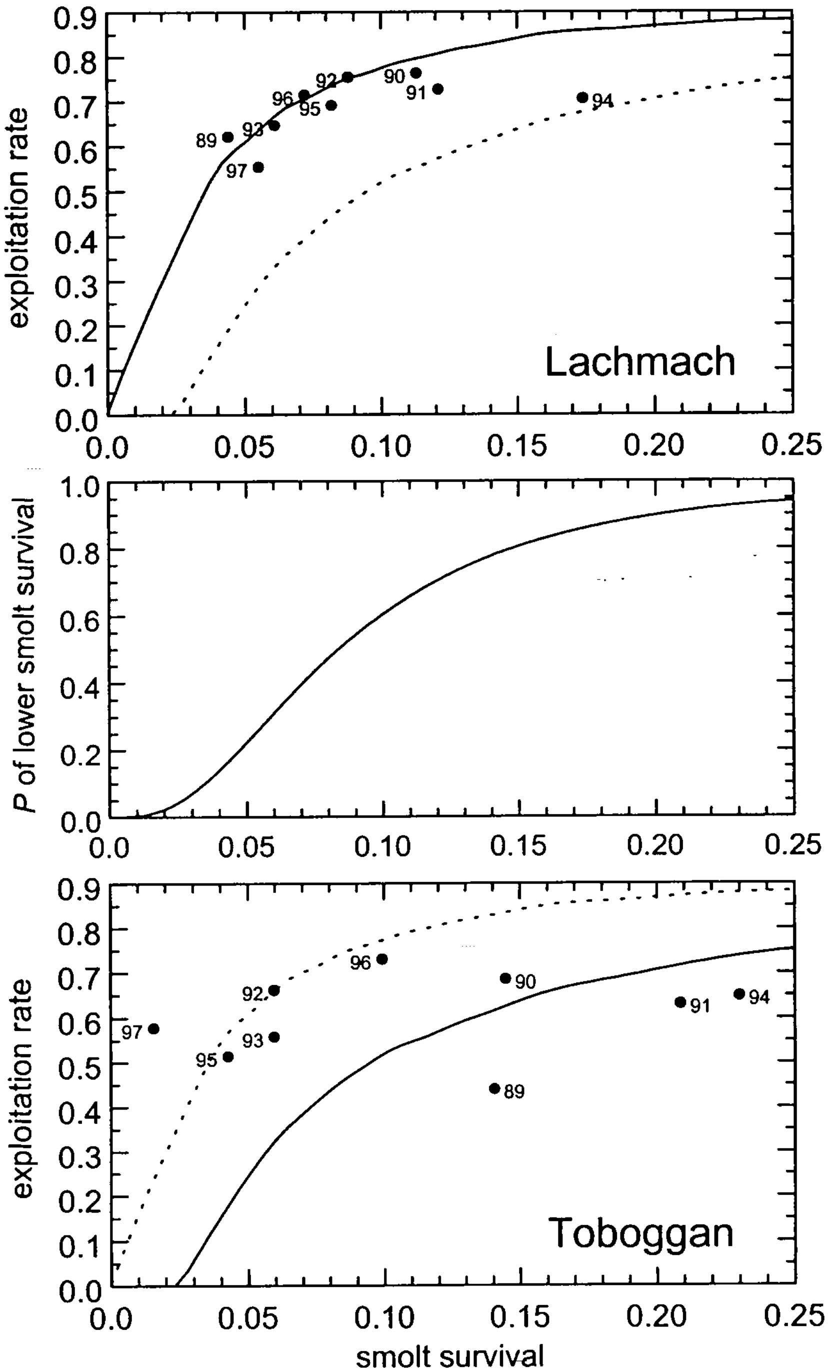


**Figure 21.** **For Lachmach (top) and Toboggan wild coho (bottom) the solid line is the target exploitation rate for optimal production across a range of smolt survivals. FW production is assumed invariant. Applied exploitation rates and observed smolt survivals are shown by year. The middle panel is the cumulative probability distribution of the pooled smolt survivals. In the top and bottom panels the dotted line is the exploitation curve for the other system.**

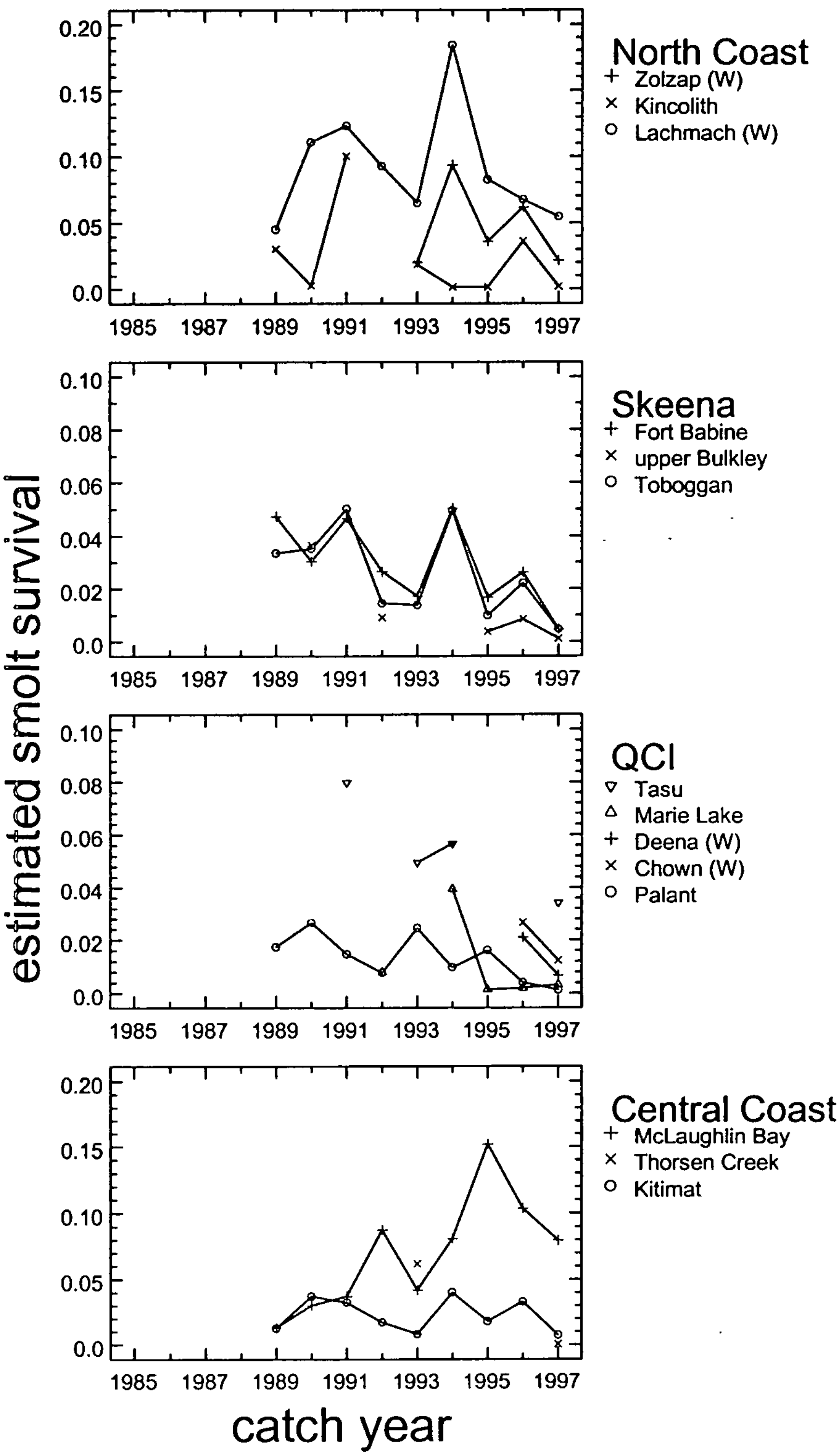


**Figure 22. Estimated smolt survival rates for release sites within four northern regions. Wild stocks are indicated by '(W)'. Note that the y-axis scale is not constant.**

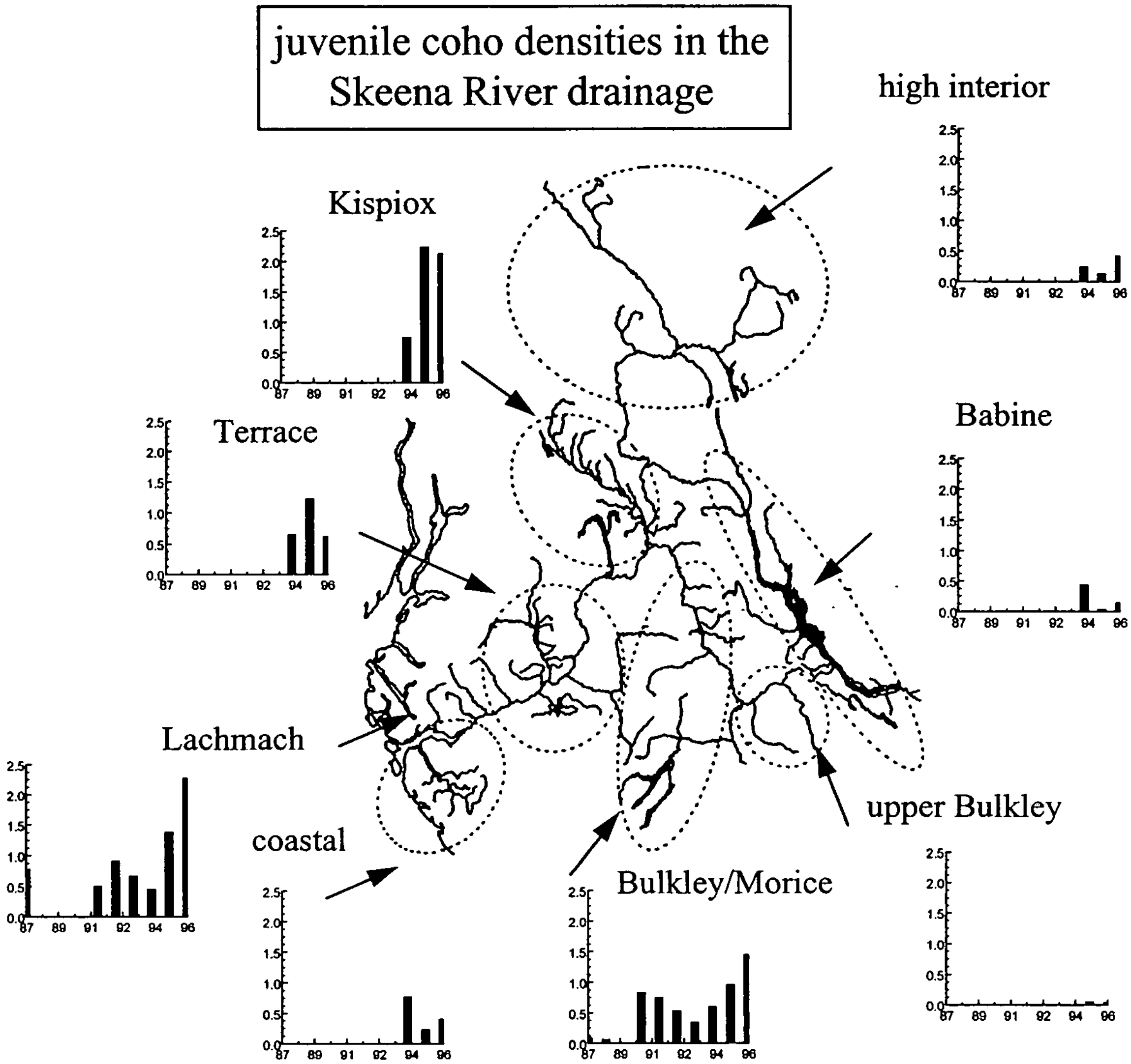


**Figure 23.** **Coho densities (number per square meter) over time are shown for the regions of the Skeena watershed indicated by the dotted lines. The coastal zone includes the Lachmach River, which is located at the head of Work Channel. All of the graphs are drawn to the same vertical scale to emphasize the differences in density between regions.**

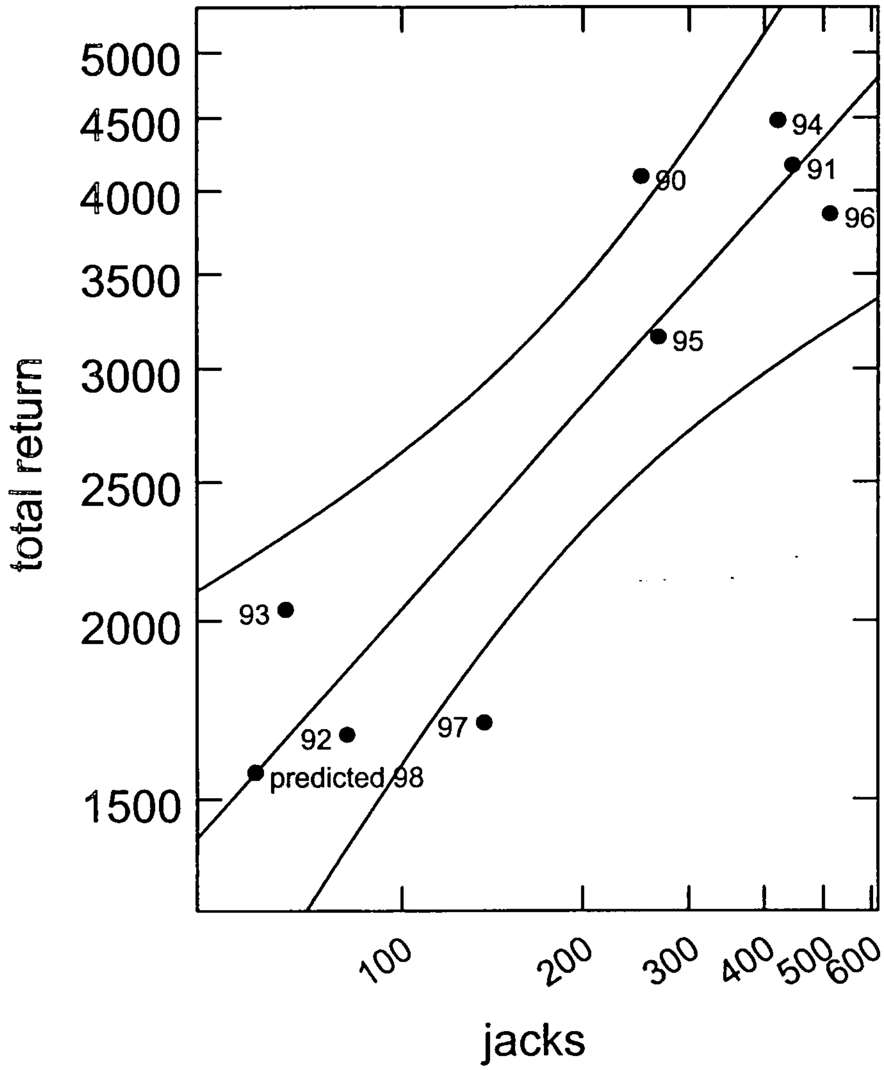


**Figure 24. Sibling relationship for Lachmach River coho with 95% CI around mean prediction. The return year for the age 1.1 and 2.1 fish is indicated.**

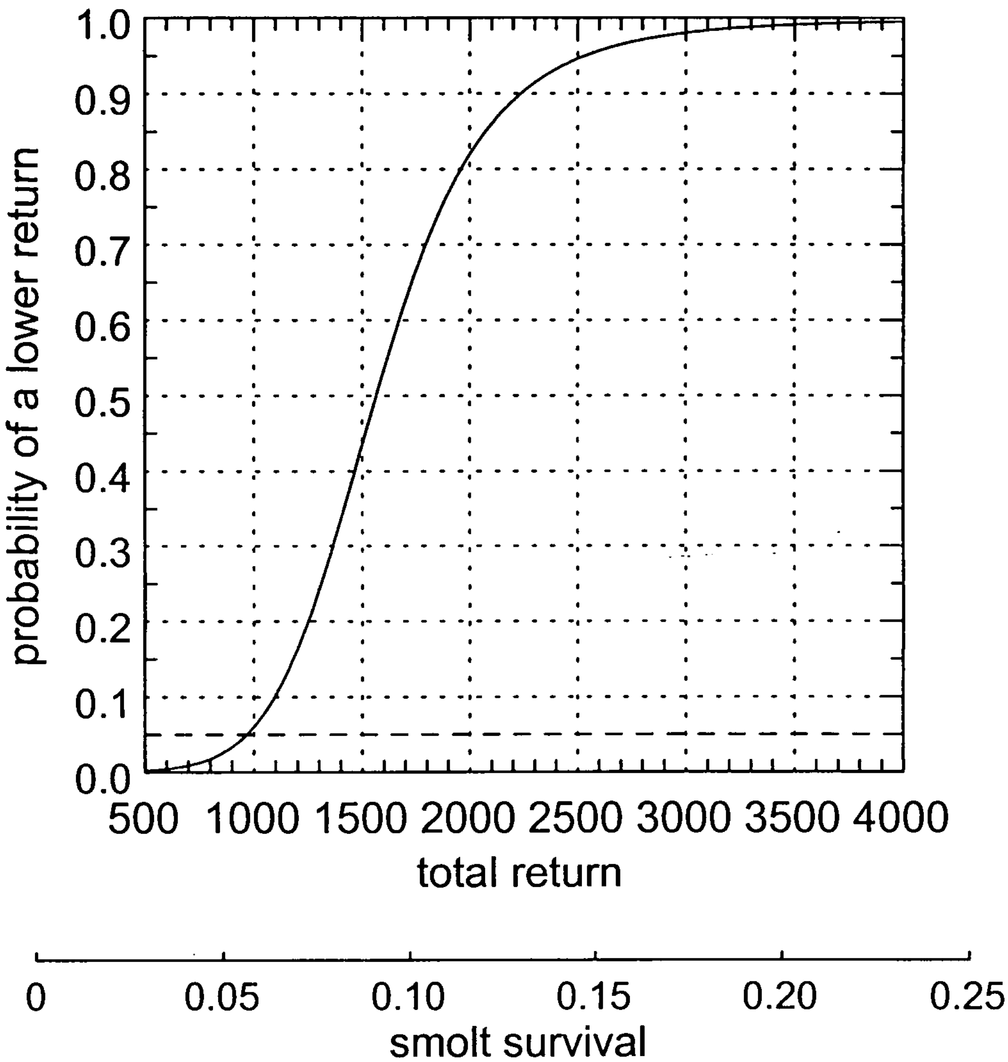


**Figure 25. Probability of a smaller total return or lower smolt survival for 1998 at Lachmach.**

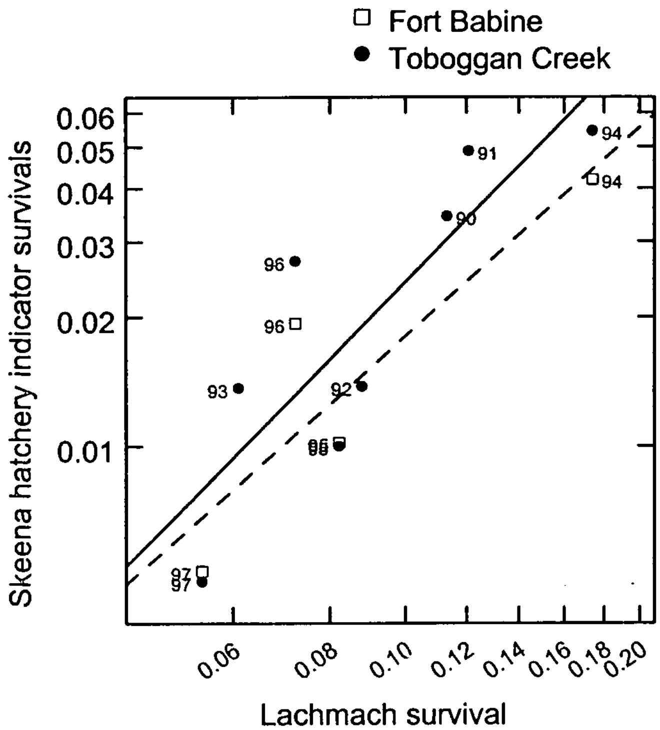


**Figure 26.** **Relationships between marine survivals at the two Skeena hatchery indicator stocks and Lachmach River survival.**

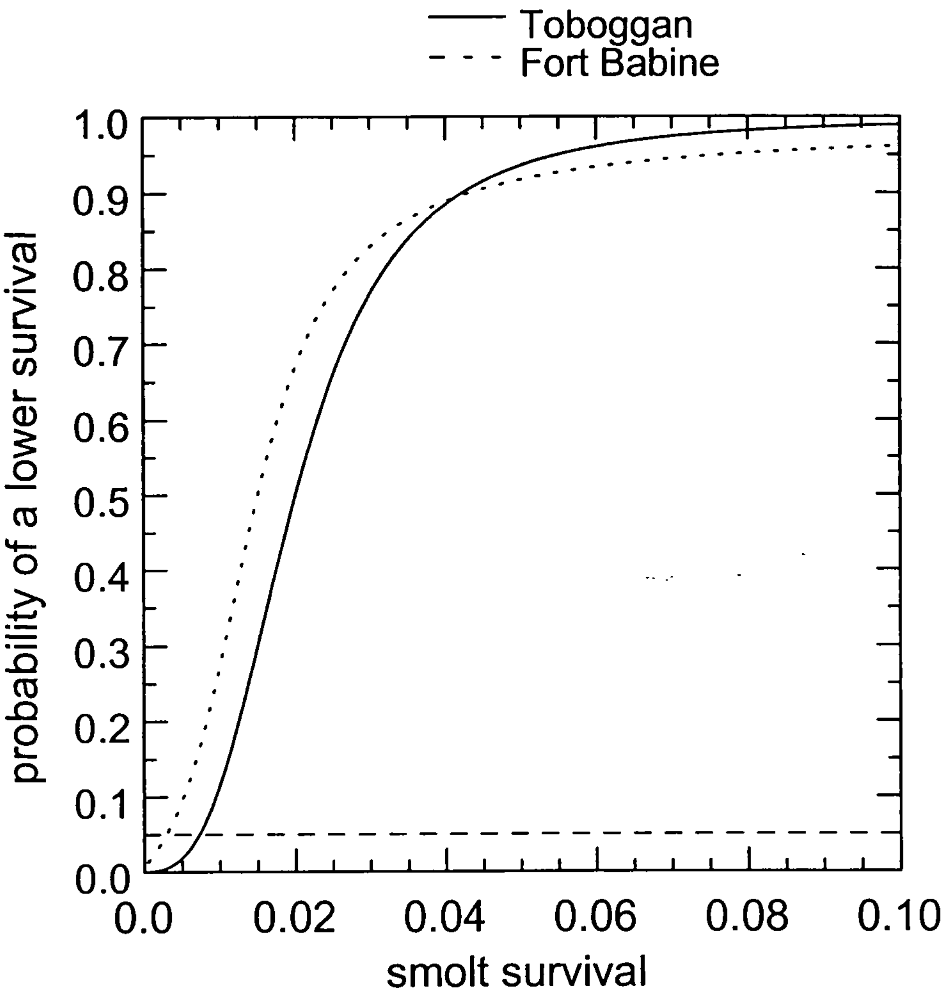


**Figure 27. Probability distributions for predicted smolt survivals at Toboggan and Fort Babine.**

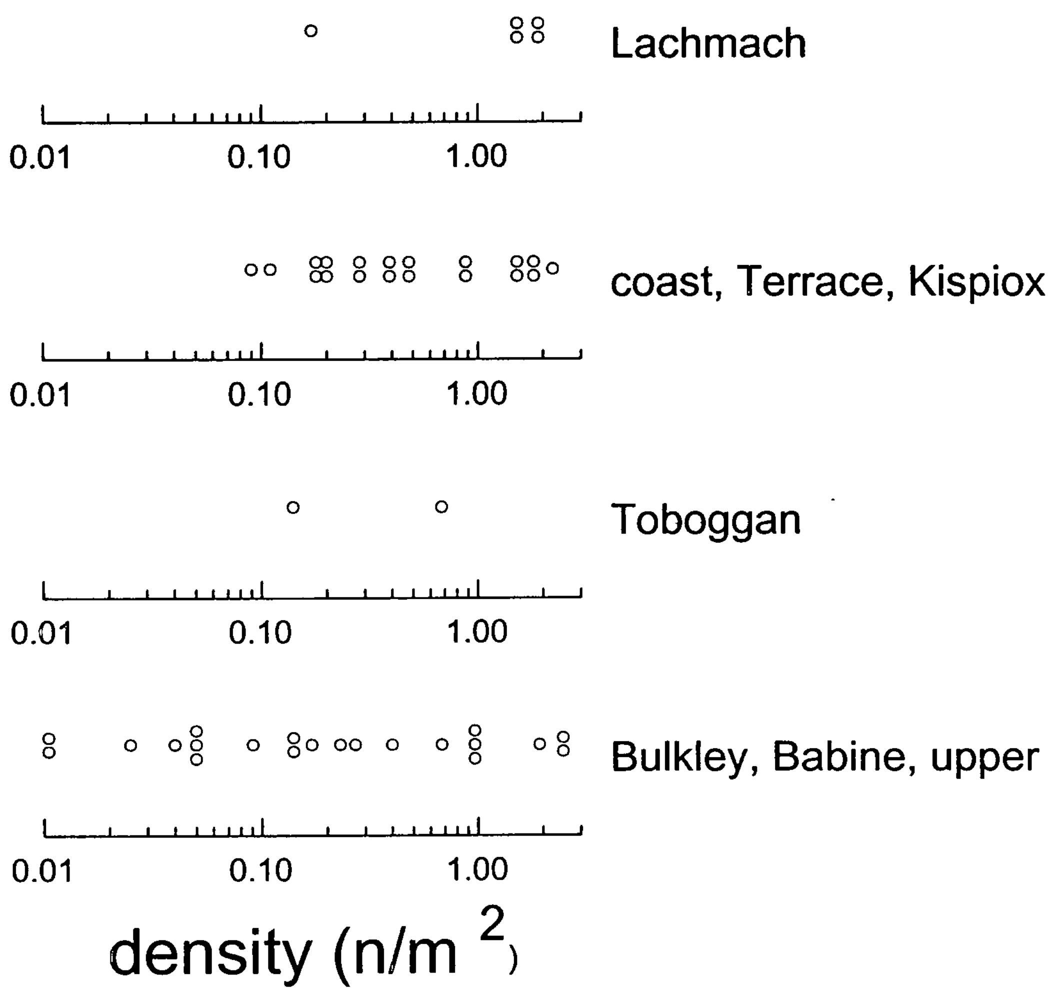


**Figure 28.** **Juvenile densities in the fall of 1995 compared between the Lachmach River, lower and mid-Skeena sites, Toboggan Creek, and interior Skeena sites. Each dot represents a single site. Note that the x-axis has a log scale.**

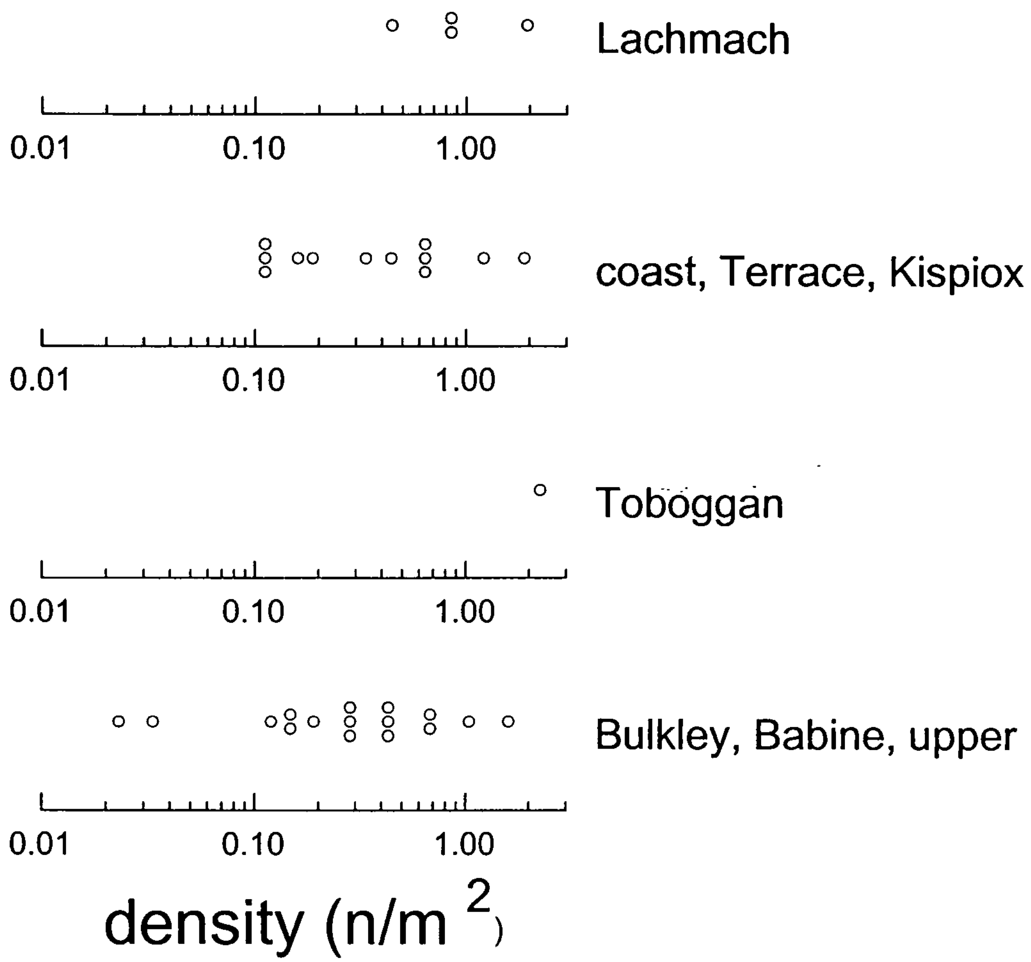


**Figure 29. Juvenile densities in the fall of 1996 compared between the Lachmach River, lower and mid-Skeena sites, Toboggan Creek, and interior Skeena sites. Each dot represents a single site. Note that the x-axis has a log scale.**