PACIFIC FISHERIES RESOURCE CONSERVATION COUNCIL
Conseil pour la conservation des ressources halieutiques du pacifique

STATUS OF PACIFIC SALMON RESOURCES IN SOUTHERN BRITISH COLUMBIA AND THE FRASER RIVER BASIN

JULY 2009

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Labelle, M. 2009. Status of Pacific Salmon Resources in Southern British Columbia and the Fraser River Basin. Vancouver, BC: Pacific Fisheries Resource Conservation Council.

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Printed and bound in Canada

ISBN 1-897110-58-8

Cover photo credit: Fred Seiler

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

1. INTRODUCTION

During 2002, the Pacific Fisheries Resource Conservation Council (PFRCC) published a report on the abundance and diversity of Pacific salmon resources in southern British Columbia (PFRCC 2002). It represented the Council's first step in synthesizing data on the state of these populations, and the available knowledge on the dynamics of this aquatic resource. Other PFRCC reports were published on the state of populations in central and northern British Columbia (BC), up to the Nass River and the Portland Canal (PFRCC 2004) and the trans-boundary rivers of northern BC and the Yukon River (PFRCC 2008). The present report updates the information contained in the 2002 report on southern BC stocks to include recent information provided by field surveys and analyses.

Thousands of streams support Pacific salmon populations in BC and the Yukon. The Council's challenge has been to summarize the available material into informative text that can be used by stakeholders, fisheries managers, interest groups and the public for reference purposes. In developing these reports, the Council has attempted to present a balance of comments and observations that include the details of the resource base, the state of populations today compared to past years, and the management and monitoring of these populations.

Public attention is frequently focused on the activities having negative impacts on the salmon resources. Salmon are indeed threatened by continued economic development, climate change, and human population growth. However, the wild salmon resource still constitutes a diverse, highly dynamic, and resilient group of species. An overly narrow focus on the negative impacts is unlikely to benefit the conservation of salmon or fisheries. An objective review of the salmon resource should consider the full breadth of information and present a long-term perspective on their status while also identifying any immediate problems.

Historical trends in commercial catches of Pacific salmon since 1828 indicate that salmon production was fairly stable from about 1910 to 1990 (Argue and Shepard 2005). Unfortunately, human and environmental impacts have increased in the last 50+ years, with substantial repercussions on the state and prospects of wild salmon populations. The information in this report is largely based on relatively recent records compiled and distributed by Fisheries & Oceans Canada (usually referred to as the Department of Fisheries and Oceans, or DFO from here onwards). The report focuses mainly on trends in salmon spawning levels, as documented in reports reviewed and accepted by the Pacific Scientific Advice Review Committee (PSARC[1]), or published in peer-reviewed journals. The Council expects that this and other stock status reports will be evolving documents that incorporate new information and identify conservation issues as they develop. The Council's website (www.fish.bc.ca) provides the medium for maintaining and updating these reports.

1.1. REPORT STRUCTURE AND DATA SOURCES

While the 2002 PFRCC report on southern BC salmon stocks was published in the Annual Report series, the Council subsequently decided to separate their advisories on salmon resources from those focusing on conservation policy matters. Consequently, annual reports and special advisories are now published independent of one another and as necessary throughout the year. The public is informed of these publications through media releases and by posting all reports on the PFRCC website.

This report covers five salmon populations that occupy streams, rivers and lakes along the southern coast of British Columbia, various tributaries to the Fraser River, and the Okanagan River. The 2002 report was organized by major geographic regions; the Strait of Georgia and Johnstone Strait, the West Coast of Vancouver Island, the Fraser River, and the Okanagan River. In terms of fishery management areas, the region covers the Statistical

[1] www-sci.pac.dfo-mpo.gc.ca/sci/psarc

Areas 11–29, 14–22 on the East and South side Vancouver Island, and Statistical areas 111–121 on the west side of Vancouver Island from Cape Scott to the Juan de Fuca entrance (Fig. 1, below).

The original (2002) report is organized first by major geographic areas, then by species and issues. By contrast, the 2004 report on central and northern areas is organized by first by species, then by geographic areas and issues. While it would be desirable to use the same format for all reports, the present report format conforms largely to the original report format because of the wide range of geo-climatic conditions between areas, the types and levels of impacts from various sources on the stocks and habitats. However, to maintain some consistency between the report formats, the stock status summaries are organized first by species, then by areas and issues. Note that this report layout is similar to that of a recently published report on salmon resources in northern BC and the Yukon trans-boundary rivers (PFRCC 2009).

The basic data used are numbers of spawning salmon from 1952 to 2008. Most of the spawning escapement data can be extracted from the DFO databases, but those for the most recent years are provided by regional management or assessment staff. The vast majority of the spawning escapement data presented was based on visual estimates of the number of spawning salmon as determined by DFO staff. Over time, different people have provided estimates based mostly on visual surveys and in some case, more sophisticated methods. The accuracy of these estimates is unknown unless they have been obtained using well-known quantitative procedures (e.g., counts of salmon at fences, mark-recapture operations). Typically though, the data are treated as reasonable measures of the trend in salmon spawning status through time. The analyses presented in this report use data reported in the spawning records, unless a species was rarely observed in a stream (i.e., ≤5 observations in 50 years). For many major populations, detailed plots of abundance by year are provided for long periods. For less abundant populations, and/or those not monitored regularly, escapements to streams or areas are summarized by decade, and averaged over the most recent years.

It should be emphasized that the absence of an escapement record value for a species in a stream and year does not indicate that no spawning occurred, nor does it imply extinction from a stream. This issue has become increasingly problematic because the number of streams surveyed and survey frequencies by stream declined in recent years. DFO records include survey-based records, but many non-numeric codes are used and cannot be easily used in a trend analysis. For example, a species may be present but a survey record label ‘NO’ indicates that no spawners were detected during the survey. ‘AP’ indicates that adults of a certain species were detected, but no abundance estimate could be generated. ‘NS’ is a database filter label indicating that a given species has not yet been recorded to spawn in a system. ‘UNK’ is another database filter label indicating no evidence that a species has spawned in a system/year. ‘NI’ indicates that a stream was not inspected in a year. Summary cells with no labels (i.e., blank) are generally considered as equivalent to either ‘NI’ or ‘UNK’. Since only numeric entries are used to compute abundance trends, these are not always indicative of total spawner abundance for a certain species in a stream or stream aggregate.

1.2. CANADA’S POLICY FOR THE CONSERVATION OF PACIFIC SALMON

The Fisheries Act allows the Federal Minister of Fisheries to set regulations for the protection and sustainable use of fisheries resources and their habitat, although provincial governments also have important authorities over some species and habitat protection. Canada’s Policy for Conservation of Wild Pacific Salmon (or WSP, Anon. 2005) was formulated in 2005. It stipulates that wild salmon populations will be maintained by identifying and managing “Conservation Units” (CUs). Each of these consists of a group of wild salmon sufficiently isolated from other groups that, if lost, is unlikely to re-colonize naturally within an acceptable period. CUs are defined by genetic criteria and phenotypic traits (e.g., run timing, life history traits, and ocean distribution), so they can,

and often do, include several populations or stocks. The last two terms are used in the following text. The former (populations) refers to all salmon of a given species that use or occupy a watershed. The latter (stocks) is more specific, and refers to a subset of a population that occupies or uses certain rivers, streams, creeks or lakes they originated from within a certain watershed. When a CU contains several populations or stocks, the WSP stipulates that the distribution of salmon within a CU must be determined (Anon. 2005, p.15).

The WSP dictates that benchmarks be set for the extent and type of management actions to be taken in relation to stock status. If a CU is considered to be in the so-called 'Red Zone', the populations in the unit cannot sustain further mortalities due to fishing or further deterioration in freshwater or marine habitats. There are also stipulations for setting and using benchmarks for habitat status. The WSP stipulates that statistically-based and cost-effective monitoring plans must be designed so as to assess the annual abundance of the CU and the distribution of spawners (Anon. 2005, p.19). Integrated strategic plans must be formulated to maintain the genetic diversity of wild salmon, address the causes of any declines, identify the resource management actions needed to remedy these where possible, and restore CUs above their lower benchmarks within an acceptable degree of certainty and within the defined time frame. When monitoring indicates low levels of abundance, or deterioration in the distribution of spawners within a CU, a full range of management actions to reverse the declines will be considered, and an appropriate response implemented.

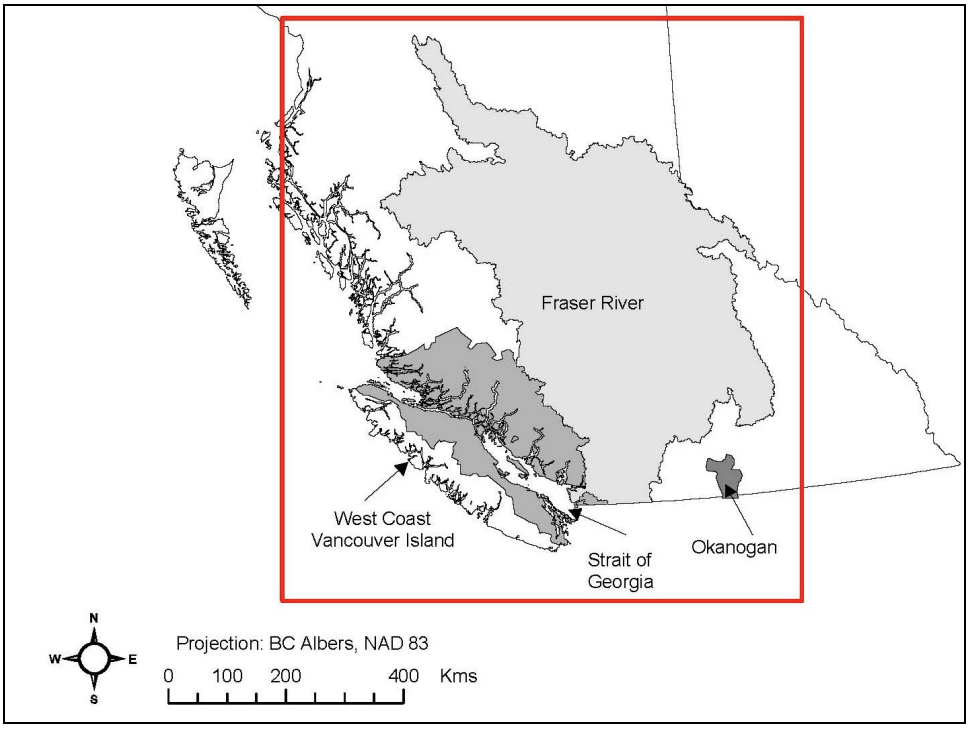
The WSP has far-reaching implications in terms of stock monitoring, fishery management habitat protection and stock restoration activities. The WSP was implemented after publication of the PFRCC 2002 report, which summarized information on stock status using conventionally defined aggregates and reference points. Ideally, this updated review should be based on CU stock-aggregates, with references to the corresponding benchmarks. However, while CUs have been tentatively defined using several criteria[2], the geographical boundaries of some CUs and the operational guidelines used to estimate the benchmarks have not yet been finalized (Anon. 2008, p.19). Consequently, this review was conducted using the same stock-aggregates and reference points as were used in the 2002 PFRCC report. This should not be interpreted as being a major limitation, since many conventional criteria are also being used to establish the CUs and conservation benchmarks.

[2] http://www-comm.pac.dfo-mpo.gc.ca/pages/consultations/wsp/wsp_forum_March_2008_e.htm

1.3. MAPS OF PRINCIPAL REGIONS AND BOUNDARIES

In the following text, attention is draw to certain geographic regions, designated coastal fishery management areas, towns, watersheds, rivers and watersheds. The following maps help geo-locate the major points of interest.

FIGURE 1.1. Maps of British Columbia regions, DFO statistical areas, and points of interest.



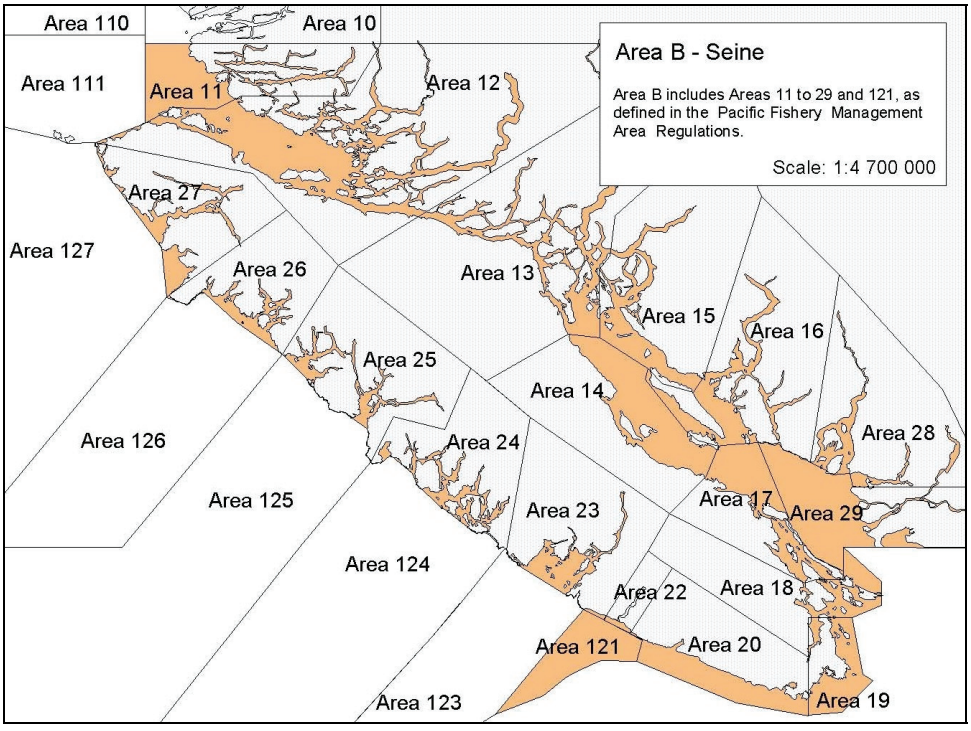
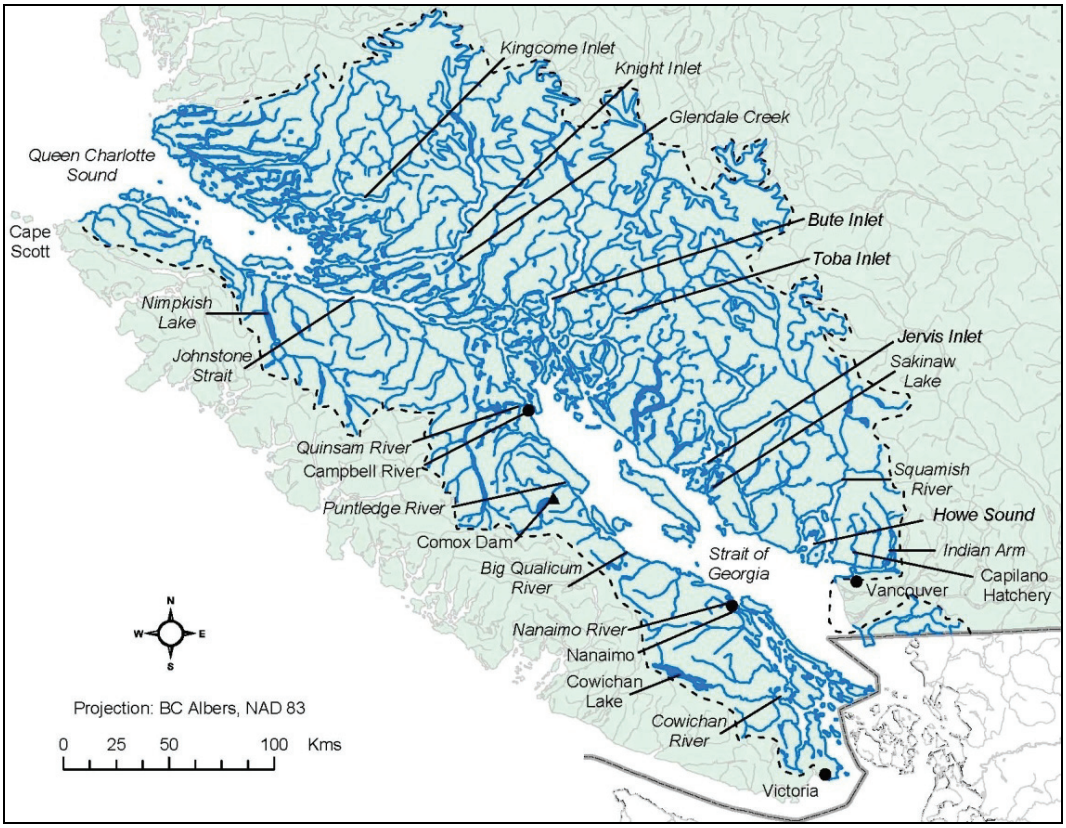


FIGURE 1.2. Main points of reference for GS basin (top) and the WCVI region (bottom).



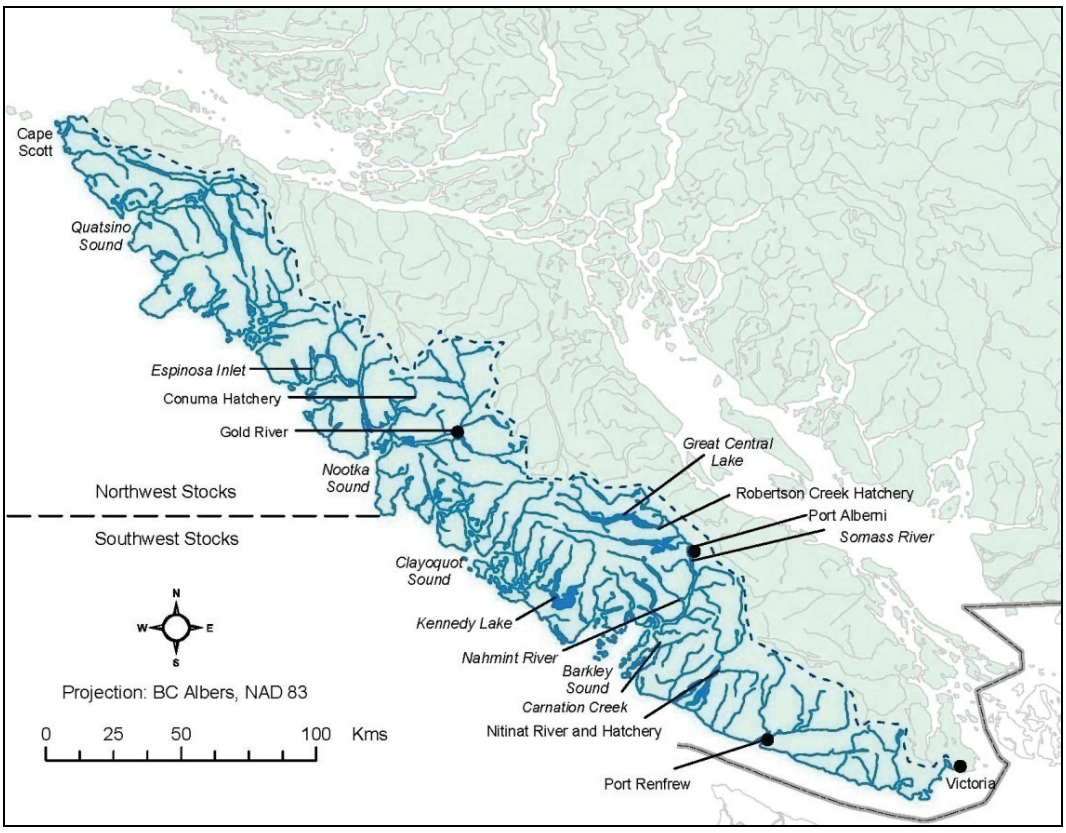
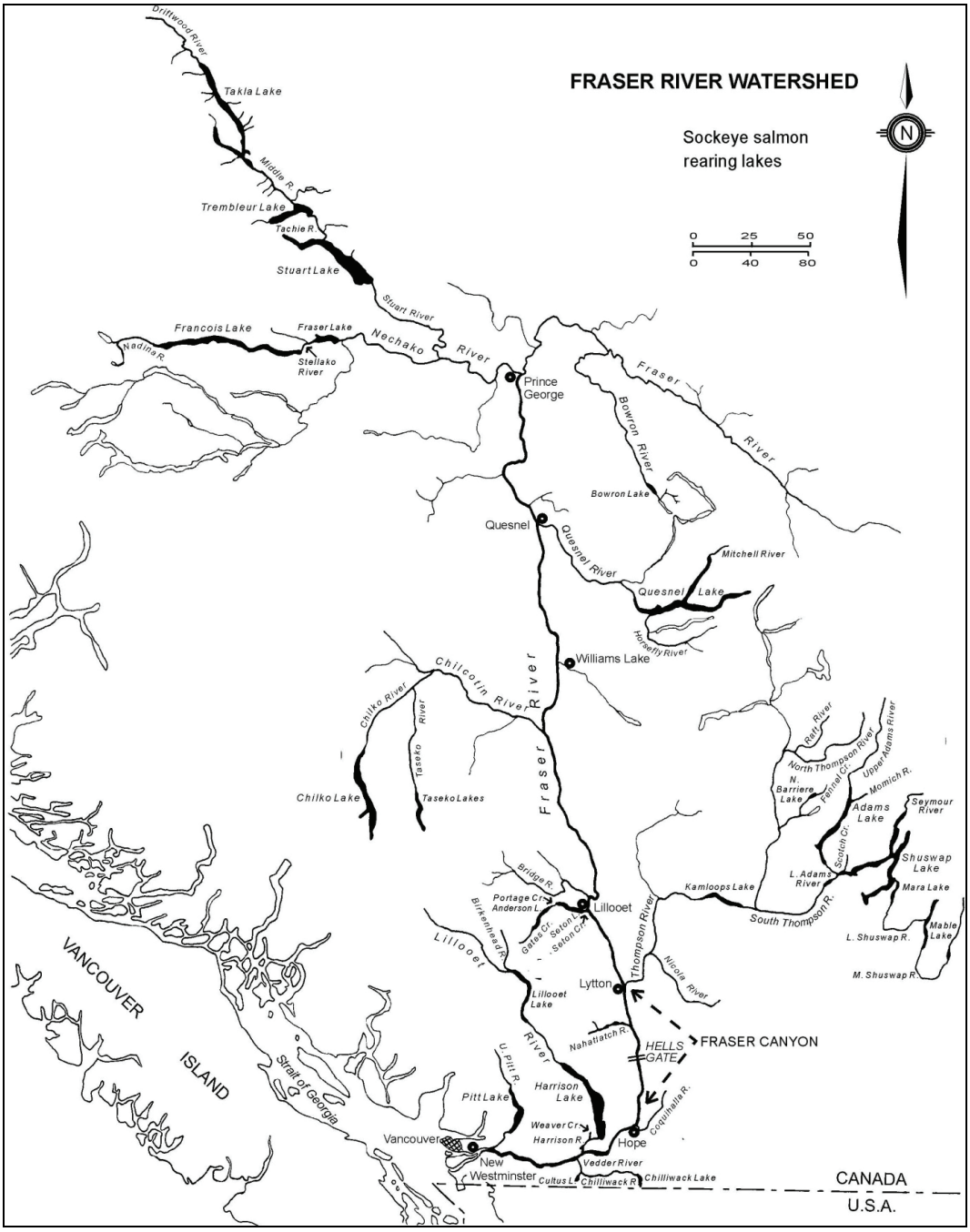


FIGURE 1.3. Map of the Fraser River basin, with principal points of interest referred to in the text.



2. FRASER RIVER

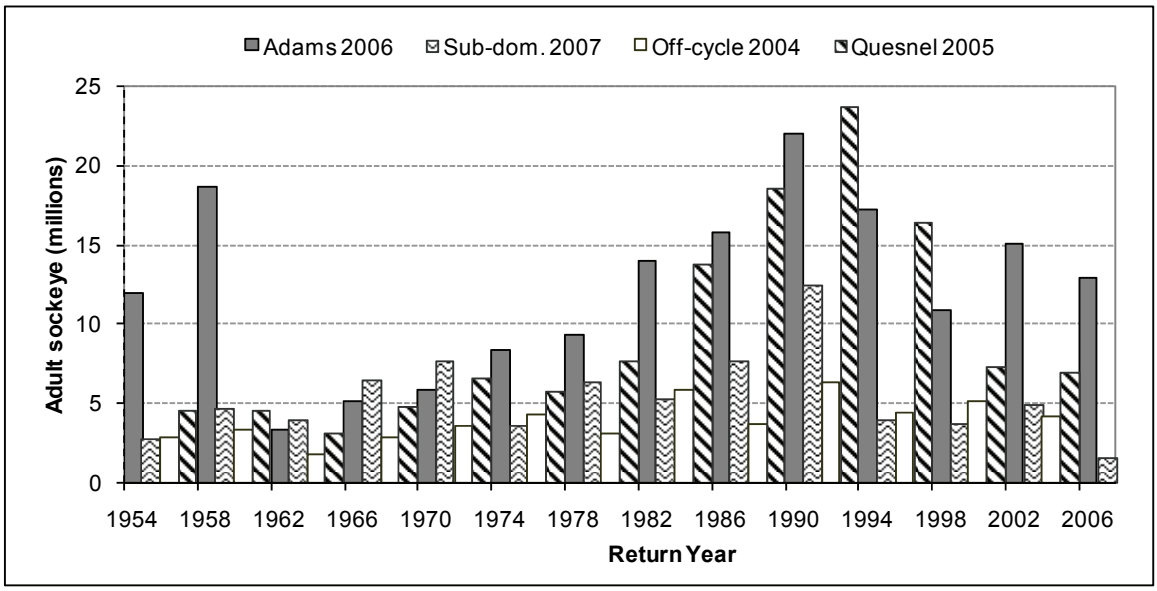
The Fraser River is the largest river and salmon producer in British Columbia (Fig. 1.3). Its watershed is extensively developed for agriculture and other industries, and it contains most of the province's human population. Salmon production is vulnerable to this intensive activity, impact of changes in water quality and quantity, as well as extensive harvesting. The watershed is also the southern limit of major sockeye production and in the southern range for pink and chum salmon. Consequently, environmental changes due to local habitat impacts and global climate effects are likely to affect salmon production in this system.

Overall, returns during 2007 reflected the poor marine survival of the 2005 ocean entry year experienced by many salmon populations in southern British Columbia, Washington and Oregon. Most salmon populations in the Fraser basin are currently at low but sustainable levels. However, there continue to be conservation concerns for some populations. This following section discusses the state of each salmon species using the Fraser River basin, with emphasis on prevailing conservation issues.

2.1. FRASER RIVER SOCKEYE

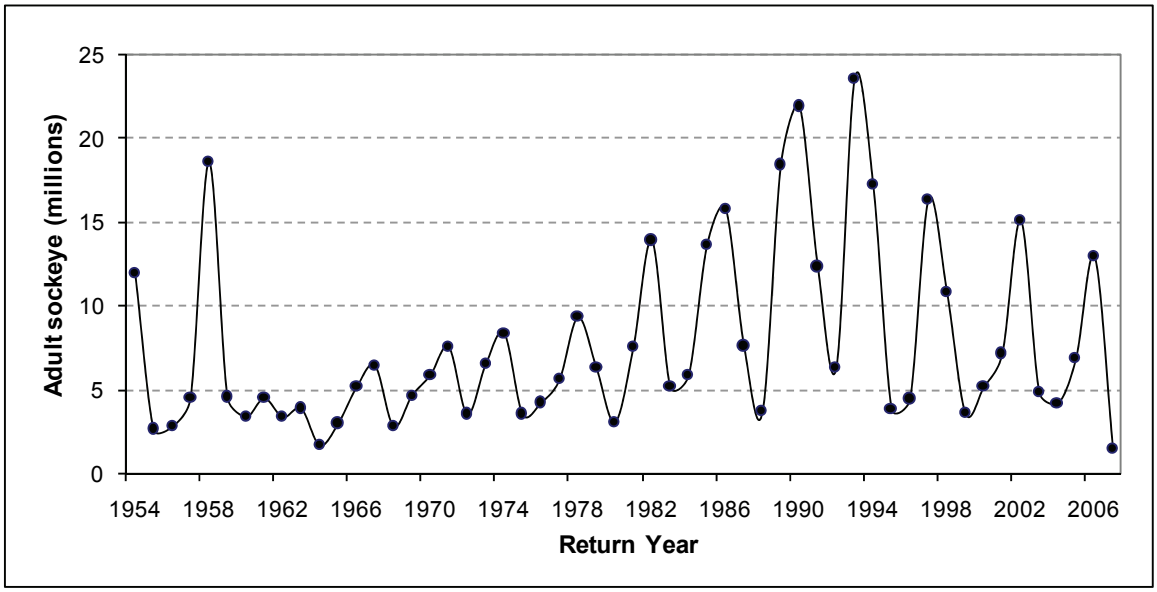
The state of various sockeye stocks cannot be assessed without accounting for the peculiar demographic traits of this entire population using this large system. One major issue concerns an apparent periodic change in production. Historical records indicate that production (or total returns) tends to vary in regular cycles, a pattern which is referred to as cyclic dominance. The biological basis of the cycles is not well understood, but the period of the cycles is four years because most Fraser River sockeye mature at age four (generally 2 years in freshwater, then two years at sea). Several Fraser sockeye stocks show a 4-year cyclic pattern in returns, with one very abundant return year followed by a less abundant year, and then two years of very low abundance. When production is summed over all the stocks returning in a given year, cycles in overall production combined with the numerical dominance of two populations result in a pattern of: a cycle year of strong production when Adam River sockeye have their large returns (1954–2006 Adam cycle); a cycle year of moderate production that follows the Adams cycle (1955–2007, often termed the sub-dominant cycle); a cycle year of low production (1956–2004, often termed the off-cycle); and a cycle year of increasing production (1953–2005) associated with the build-up of the Quesnel River stock (Fig. 2.1).

FIGURE 2.1. Total production of Fraser River sockeye salmon by cycle year (1954–2007).
Data provided by the PSC



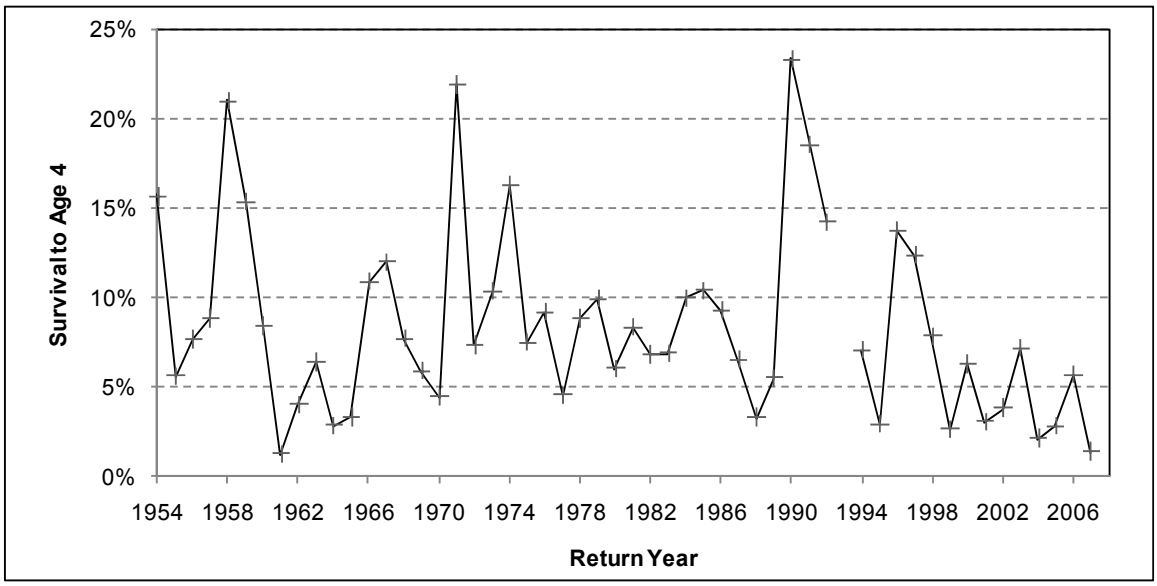
The 4-year production cycles are partly responsible for the overall variation in total annual production observed since 1954 (Fig. 2.2). Following a prolonged period of stock rebuilding, there appears to have been a progressive decline in total abundance since 1993. In 2007, the Fraser sockeye returns were the lowest on the cycle since 1947 and only 28% of the average return on the cycle since 1955. Though the overall abundance was low, returning adults were in good condition and severe restrictions to fisheries resulted in adequate numbers of mature sockeye reaching the spawning grounds (63% of the cycle average escapements since 1955).

FIGURE 2.2. Total returns (catch + spawners) of Fraser River sockeye, 1954–2007.
Variation in returns partially due to 4-year cycles of production in many populations. Data provided by the PSC.



In theory, several factors can cause this including reduced juvenile survival during the fresh water and/or marine rearing stages, insufficient escapement (too few spawners), habitat degradation, etc. The Chilko Lake sockeye population is the only population within the Fraser basin for which smolt-to-adult survival can be directly estimated. Returns of Chilko Lake sockeye in 2007 indicated poor survival compared to past years (Fig. 2.3).

FIGURE 2.3. Survival of sockeye smolts to Age-4 adults from Chilko Lake.
Smolts emigrating from Chilko Lake are estimated past a weir and Age-4 Chilko adults are estimated in catches and on the spawning grounds. Survival expressed as adults/smolts. Data provided by the PSC.



On this basis, it could be hypothesized that declining returns observed since the early 1990's (Fig. 2.2) are due to lower survival rates for all Fraser River sockeye stocks. The trends indicate that all cycle lines have declined since 1990s, but more so for some lines than others (off-cycle relatively stable since the 1950s). This supports the hypothesis that the factors causing lower returns impact certain populations more than others, and mainly during certain cycle years.

There are about 151 sockeye spawning populations (or stocks) in the Fraser River basin. These do not migrate upstream at the same time (Fig. 2.4). Those spawning further north tend to arrive earlier than those spawning further south. Stock assemblages have been established based on their migration period. Schubert (1998) defined the following; The Early Stuart run includes 32 stocks that spawn in the Stuart River system and arrive first. The Early Summer run includes 34 stocks that spawn throughout the Fraser river basin. The Summer run includes 33 stocks that spawn in the Chilko, Quesnel, Stellako, and Stuart systems. The Late run is last and includes 52 stocks that spawn in the lower Fraser, Harrison-Lillooet, Thompson, and Seton-Anderson systems. A comparison of the 2007 returns by run timing group, and the corresponding mean returns over 1954–2007 for all years and by cycle year (every 4 year up to 2007) indicates that the recent returns in each run timing group were < 40% of the historical means of either type (Table 2.1).

FIGURE 2.4. Typical migration periods of Fraser River sockeye stock groupings at the outer Juan de Fuca entrance.
Note the substantial overlap between the Summer and Late-run stock aggregates Data provided by the PSC

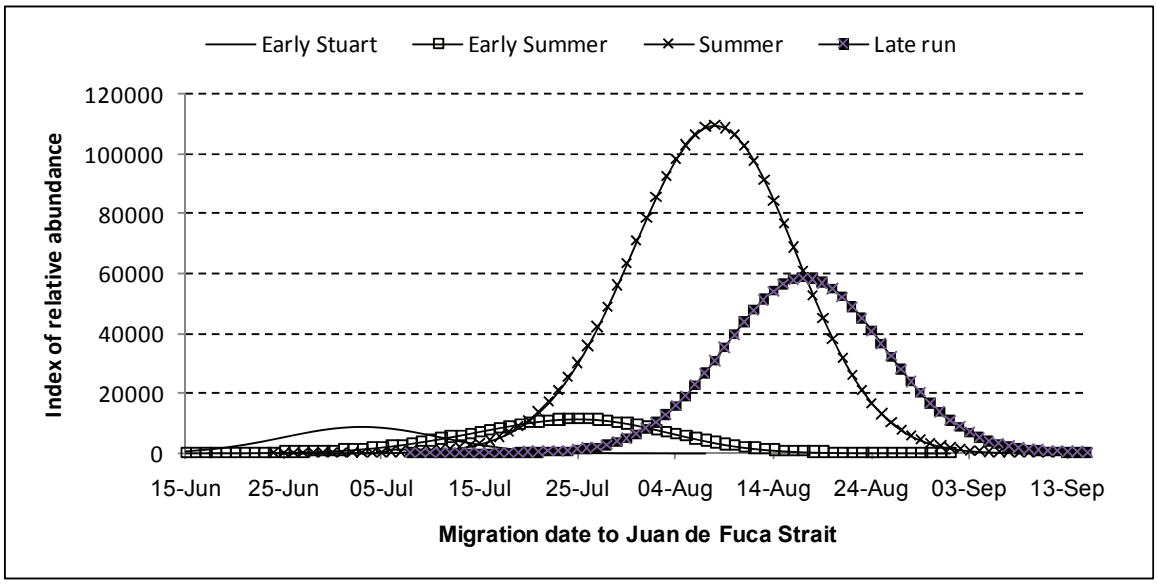


TABLE 2.1. Observed return of Fraser River sockeye salmon in 2007 by run timing groups compared to historical means for the stock aggregates.
Data provided by the PSC.

Run timing groups stocks included	Mean run size All cycle years	Mean run size 2007 cycle year	Actual 2007 returns	Proportion of mean All cycle years	Proportion of mean 2007 cycle year
Early Stuart	330,000	192,000	12,731	0.039	0.066
Early Summer	508,000	579,000	194,804	0.383	0.336
Bowron	44,000	89,000			
Fennell	24,000	32,000			
Gates	58,000	25,000			
Nadina	87,000	127,000			
Pittg	71,000	82,000			
Raft	31,000	20,000			
Scotch	62,000	20,000			
Seymour	131,000	184,000			
Summer	3,782,000	2,401,000	635,101	0.168	0.265
Chilko	1,373,000	1,574,000			
Late Stuart	579,000	92,000			
Quesnel	1,349,000	103,000			
Stellako	481,000	632,000			
Late	2,936,000	2,166,000	665,121	0.227	0.307
Cultus	41,000	93,000			
Harrison	41,000	66,000			
Late Shuswap	2,081,000	1,482,000			
Portage	39,000	24,000			
Weaver	375,000	173,000			
Birkenhead	359,000	328,000			
TOTAL	7,556,000	5,338,000	1,507,757	0.200	0.282

The 2007 returns for the Early Stuart group were the most depressed relative to the average. The second worst relative to the average were the Summer-run stocks. Based on recent run timing patterns, the Birkenhead stock is akin a late Summer-run but is considered to be in that grouping for management purposes (see Anon. 2008, p. 60). And on this basis, the second most depressed group would be the Late-run. This also includes the Cultus Lake stock, which is very depressed and recently re-classified as being subject to conservation concern.

The Council has not conducted a full assessment of each major stock through 2007, but trends for thirty of these are updated by the PSC staff (Appendix A). These indicate that some stocks in each run timing group fared better than other. Their current state, relative to the full time series of data available, indicates increasing production in ten stocks, no long-term change in seven, decreasing production in seven, and unknown trend status for six. Long-term production trends for eight major stocks are illustrated in Appendix B.

Trends in total production within aggregates (either a cycle year or a run-timing group) are informative, but do not provide crucial information on the nature of the factors responsible for the depressed state of some stocks. Each season, efforts are made to determine the strength of various runs and manage fisheries to ensure there are sufficient escapements to meet the conservation levels. However, once mature salmon move up the Fraser River, there is little that can be done to ensure they reach the spawning grounds and successfully reproduce. And within each aggregate, the distribution of spawners can vary substantially from year to year. DFO keeps track of spawning levels in numerous systems, and when total production decreases to low levels, significant conservation measures are usually implemented to restrict fishing and maintain escapements during periods of low returns.

Since the mid 1990s, monitoring activities indicated that many Late-run sockeye died in-river before spawning. Final escapement estimates for 2008 released by DFO at the time of this writing indicated that the 2004 cycle return year suffered the lowest spawning success in fifty years in 2008 (65%) for all stocks combined. The low spawning success coupled with a lower than average return on the cycle will necessitate future conservation actions to rebuild this cycle.

It is beyond the scope of this report to describe all investigations aimed at identifying the nature of the factors responsible for in-river sockeye losses. However, there is mounting evidence that detrimental freshwater conditions are contributing to declining returns. These include high water discharge levels and warm temperatures caused by large snow melts and heavy rains that affect early runs (like Early Stuart, e.g., in 1997). Draughts and relatively hot weather can also affect the migration of stocks arriving late (Summer-run and Late-run, e.g., in 1998 and 2004).

Late-run sockeye are unusual in that they tend to aggregate near the mouth of the Fraser River and hold for 3–6 weeks before moving upstream. The factors inducing this holding behaviour have not been identified with certainty, but some biologists speculate it evolved to ensure sockeye can survive in fresh water long enough to reach the spawning grounds when conditions are most suitable. But beginning in 1995, and continuing through 2008, the average holding period was ≤ 5 d in all years since 2000 except during 2002 (22 days). This caused earlier than normal upstream migrations. In 2000 and 2001, some stocks moved upstream 4–6 weeks earlier than normal. In some years when Late-runs were large (in 2002 and 2006), the holding periods were greater, but even in these years, the upstream migration began earlier than historically observed. The pattern of early migration appears to be occurring in all Late-run populations including Cultus sockeye, which previously had a consistent migration pattern since the 1940's (based on fence counts). This recent shift in migration behaviour led almost all Late-run stocks to move upstream prior to the historical median upstream date since 1995. Interestingly, early migration times have also been observed in Fraser River pink, chum and white-fleshed chinook salmon. For Fraser River pink salmon, the change to earlier migration occurred coincident with the change in sockeye, and has been associated with decreased delay in approach waters within the Strait of Georgia (Lapointe, 2009).

Stocks entering the Fraser River earlier than normal spend longer periods in fresh water before spawning. This extended period of fresh water residency is thought to be one factor causing two types of mortalities; (i) 'en route' mortality where fish die during their upstream migration before reaching the spawning grounds, and (ii) pre-spawn mortality where females die on the spawning grounds with their eggs intact. The two sources of mortality are incremental, and both increased substantially since 1995 (Fig. 2.5, 2.6). Temporal patterns in intra-annual mortality have been documented through tagging programs in a number of years. These investigations revealed that earlier migrants suffer the highest en-route and pre-spawn mortality, with most of those entering before mid-August dying before, en route or just before spawning (Cooke *et al.* 2004, Lapointe 2009). In years of very early entry (2000, 2001), total mortality due to both exceeded 90%, compared to about 10% in years of normal migration behaviour prior to 1995.

FIGURE 2.5. Pre-spawning mortality estimates for the Lower Adams River late-run stock.
Mortality rates based on differences between spawning times and estimated escapements at Mission. Only early migration years labelled. Data provided by the PSC.

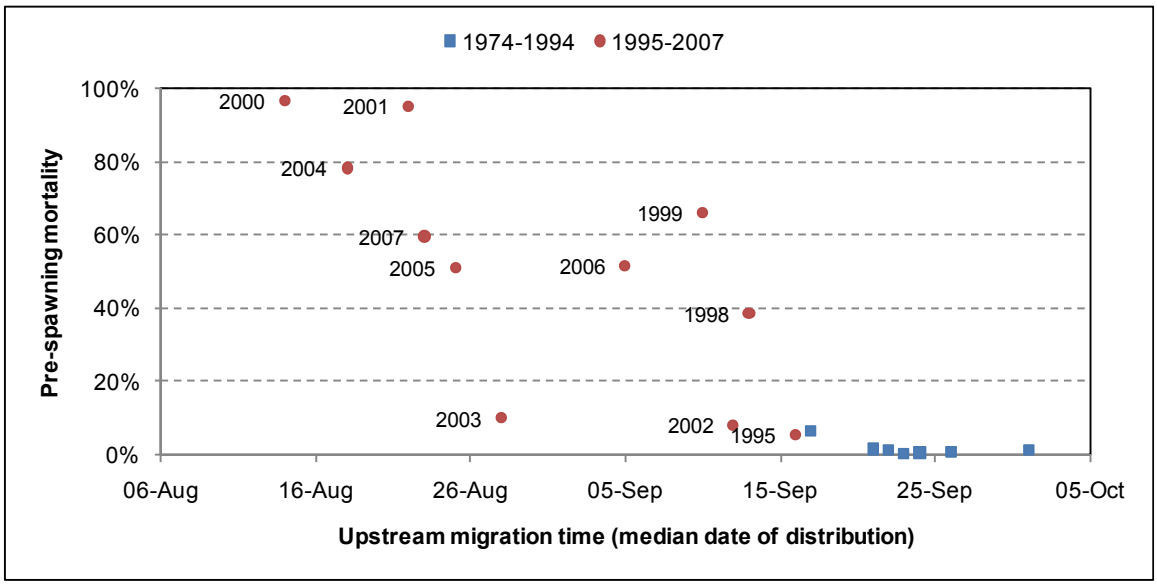
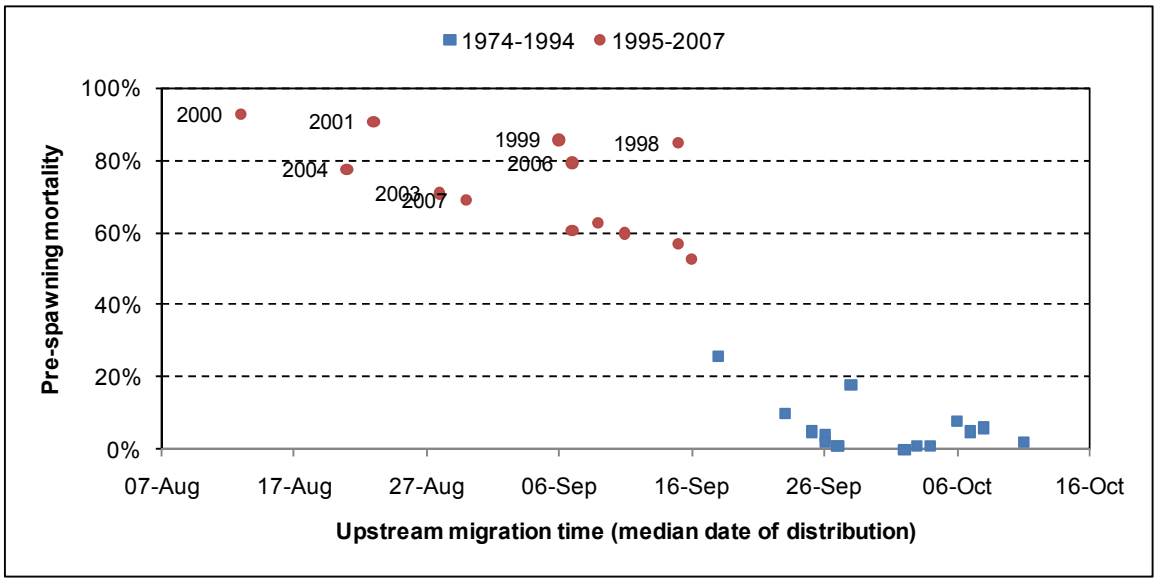


FIGURE 2.6. Pre-spawning mortality estimates for the Weaver Creek late-run stock.
Mortality rates based on differences between spawning times and estimated escapements at Mission. Only early migration years labelled. Data provided by the PSC.



Following a 2002 Council recommendation to allocate further resources to investigate this problem, a five-year National Research and Engineering Research Council Grant (NSERC) was awarded to Dr. Scott Hinch of University British Columbia (UBC). Some of the results obtained so far have been published in the scientific literature (for citations see PSC website at http://www.psc.org/pubs/LateRun/PeerReviewedPapers.pdf), and were presented at a UBC workshop held in June 2008.

Losses caused by the early upstream migration can translate into long term losses in productivity. Because of this, allowable harvests were reduced in recent years to compensate for in-river losses. Beginning in 2001, exploitation rates have generally been limited to ≤20%, except for the large Adams return years (2006 cycle) that do not seem to hold as long. Harvest restrictions reduced the decline in the rate of escapement, but had less effect on the numbers of effective spawners on most cycles. Allowable exploitation rates on the Cultus Lake population were further reduced to 10–12% following an assessment by COSEWIC that the population was 'endangered'. Efforts are being made to rebuild it via predator removals in Cultus Lake, habitat improvements, hatchery supplementation and a captive brood program. Some activities have been reported to be successful but the state of this population has not improved substantially. A notable exception to declining escapements of Late-run populations is the Harrison Lake stock, which has had unprecedented large escapement in recent years, despite migrating upstream earlier than most Late-run populations. The reason is not known with certainty, but may be linked to the life history of this population. Unlike most Fraser River sockeye, Harrison sockeye fry do not rear in lakes, but migrate soon after emergence to rear in the Fraser River estuary.

Conservation measures to protect Late-run populations via harvest controls can have substantial economic repercussions because their run timing periods overlap to some extent with those of stock aggregates in other run timing categories (Fig. 2.4). Efforts to reduce fishing mortality on Late-run stocks will likely reduce the harvest opportunities on the more plentiful Summer-run stocks. Determining fishery exploitation patterns that meet optimal harvest and escapement requirements is a complex task, and even more so when there are risks of substantial in-river and pre-spawning mortalities. Pre-season forecasts of adult returns are conducted using several analytical methods based on historical productivity levels and survival rates over some base period (see

Cass *et al.* 2006). Forecasts are uncertain and generally presented as a range of return values based on the expected return and observed deviations from past forecasts. These figures serve to determine the probability that the actual return will exceed a given forecast value. This exercise is conducted mainly for pre-season planning purposes, with the forecasts updated in-season using ancillary data such as fishery-specific catches, test fishing results, hydro-acoustic indices of daily escapements, stock-composition estimates from analyses of bio-samples, etc. There are indications that ocean conditions may be improving, and the most recent forecast indicates there is a 50% chance of getting a total return of 11 million sockeye to the Fraser River in 2009. While this may be sufficient to ensure that escapement objectives are met, considerable monitoring effort should focus on pre-spawning losses and spawning success.

Recently, the Fraser River Sockeye Spawning Initiative (FRSSI) was created to identify the fishery management strategies that can help meet user group requirements and target escapements (see Pestall *et al.* 2008). A simulation model is used to project future abundance levels based on the demographic traits of some populations, but not those of individual life stages. No assumptions are made about future conditions and detrimental impacts, but to increase the likelihood meeting the spawning targets, the model allows for management adjustments to be made in-season with the effects based on losses observed under some conditions in recent years. At this stage, the approach has not yet been evaluated in terms of identifying cost-effective protection measures in the face of uncertainty to allow depressed stocks to rebuild. In the meantime, DFO fishery management plans will continue to rely on fishery closures by time and area to limit direct impacts on depressed runs during periods of peak passage though those fisheries.

In 2002, the PFRCC wrote to the Minister of Fisheries & Oceans on two occasions to emphasize its concern about the Late-run Fraser River sockeye and to call for dedicated research efforts and stock management solutions. Since then, significant resources have been used to determine how best to deal with these issues, including scientific studies to identify the major determinants of pre-spawning mortality. DFO and various user groups have also agreed to reduce exploitation rates on some stocks.

Unfortunately, the sockeye stock-status situation has not improved much since then, and there are still concerns about the depressed state of early Stuart and Cultus Lake stocks. Given this state of affairs, additional measures may be required to reverse the decline in overall productivity and maintain diversity. Detrimental conditions during the early stages of marine life are not easily predicted, and at best, can be counterbalanced to some extent by adjusting fishing plans based on in-season estimates of run strength. However, further efforts can be made to increase productivity and survival during other stages. For example, the enhancement and predator control activities being conducted in Cultus Lake may prove to be successful in the long run, but returning adults may also require more protection than has been provided so far. This may require a re-evaluation of traditional management objectives. One of these is attempting to meet the requirements of various user groups while protecting and rebuilding depressed stocks. This can amount to conflicting objectives, and some trade-offs are required to minimize risks to severely depressed stocks.

Fishery management scenarios that allow depressed stocks to rebuild may allow escapements of healthy stocks to exceed their target spawning levels. Fishery managers consider this to be an important 'issue' (Anon. 2008, p. 67–68), but it remains to be shown that management does not weight too heavily the short term harvest demands against the need to ensure maximum protection to depressed stocks. Council-sponsored investigations revealed no evidence that 'over-escapement' can cause salmon stock collapses (Walters *et al.* 2004), or detrimental delayed-density impacts on other stocks, although the possibility remains that it can induce lower productivity of some stocks due to certain limiting factors (insufficient forage, increased predation, etc.). But over-escapements can also potentially increase diversity, in the long run, under some conditions, and the productivity of entire watersheds via the transport of marine nutrients (Schindler *et al.* 2005). In light of such

facts, the Council has recommended that when faced with considerable uncertainty and trade-off decisions, DFO should take measures to minimize fishery impacts on depressed stocks even if this causes the escapement of healthy stocks to exceed escapement targets. DFO is at liberty to allow Excess Salmon to Spawning Requirements (ESSR) fisheries to limit the access of mature fish to the spawning grounds. These can provide economic opportunities to First Nations who rely on special harvest and marketing methods to derive maximum benefits from these up-river fisheries.

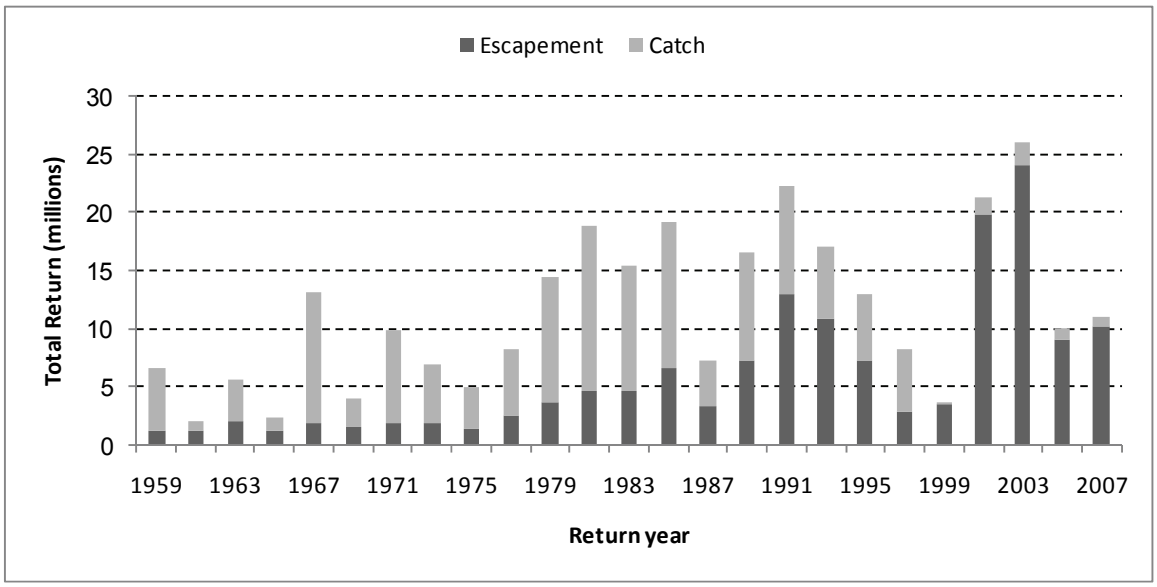
2.2. FRASER RIVER PINK

Pink salmon have the shortest life cycle of all Pacific salmon species and they always mature as two-year-olds. In the Fraser River, this two-year life cycle results in pink salmon returning mainly in the odd-years. Very low returns (<1000) have been reported recently on some even years, although the early commercial catch records indicate that thousands were landed in even years during 1900–1928 (Argue and Shepard, 2005). Spawning tends to be concentrated in the Fraser River tributaries below Hope, but significant spawning also occurs in the Thompson River. There is currently no explanation about why pink production in the even-years is absent. Pink salmon spawn in the early autumn and juveniles migrate to the sea soon after emergence from the gravel in the following spring.

The 2003 return of Fraser pink salmon was the largest on record, but subsequent returns declined to historical averages (Fig. 2.7). Spawning ground assessments of Fraser River pink salmon have not been conducted since 2001 due to funding limitations. Estimates of the total return for 2003–2008 are characterized by considerable uncertainty since they are based on expanded cumulative catches from marine purse seine test fisheries conducted by the Pacific Salmon Commission. And since 2003, spawning escapements are estimated as total returns less catches and are not considered as reliable as spawning ground survey estimates. Furthermore, the distribution of pink salmon spawners among tributaries within the watershed cannot be quantified for recent years. The lack of spawning ground estimates has not precluded the forecasting of pink salmon returns since these are based on fry abundance estimates obtained from fry trapping operations conducted in the spring of even-years near Mission, BC. This trapping program also provides indices of abundance for juvenile chinook, coho and chum that have also been used by DFO scientists for assessment purposes in recent years.

Until 1999, catches often exceeded the escapements. But since then, exploitation rates on Fraser river pink salmon have decreased substantially, averaging only 8% of the total return. Although processor demand and pink salmon prices have decreased in some recent year, harvest reductions have resulted primarily from mixed-stock constraints related to conservation actions taken to protect late-run sockeye and interior Fraser River coho salmon populations.

FIGURE 2.7. Total production of Fraser River pink salmon, 1959–2007.
Catch and escapement estimates provided by the PSC.



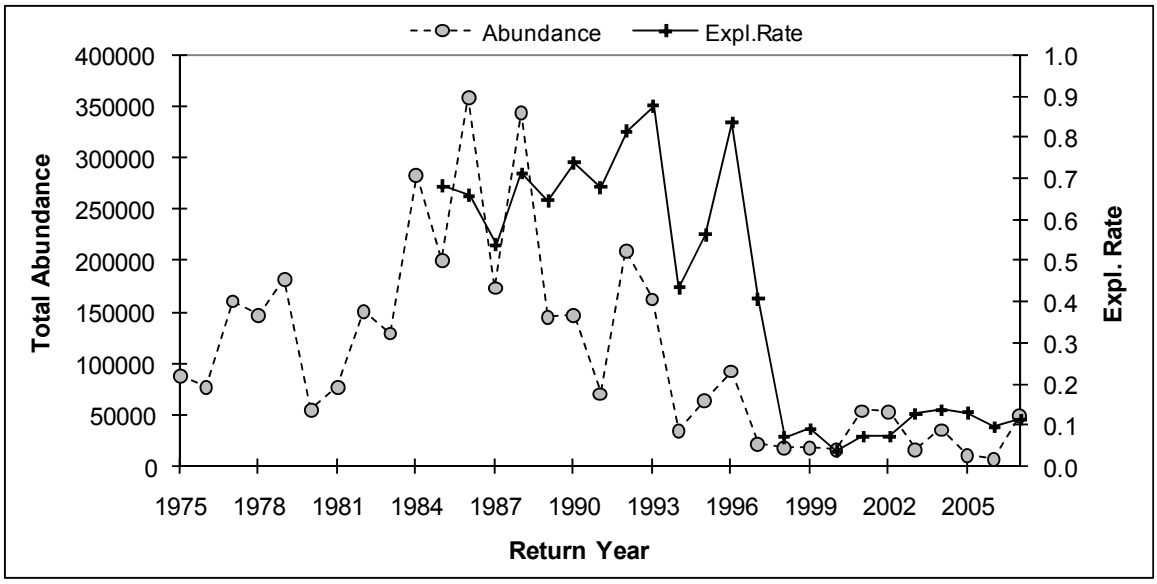
A previous analysis indicated that survival of Fraser pink salmon was less than two adult returns per spawner during 1991–1999, and was thought to account for most of the decline in pink salmon returns. Harvest rates were reduced to compensate for the poor survival, and spawning goals were met, with the exceptions of 1997 and 1999. For 2007, the escapement objective of six million pink salmon was met. No objectives for directed fishery catches or escapements were set for 2008, being an even year with no expected returns.

The large returns of 2001–2003 show that the productive capacity of Fraser River pink stocks is considerable and merits further attention. Given the concurrent changes in monitoring and exploitation since 2001, coupled with possible interactions with other salmon species, it is doubtful that the nature of the factors responsible for peak production can be identified with certainty at this stage. The Council has recommended that DFO conduct an investigation to determine if the 'new' and 'old' escapement indices are similar, so as to determine if recent trends are due to changes in estimation procedures. And since the high returns were associated with periods of low exploitation, low harvest rates should be maintained to ensure that pink salmon populations increase to levels that make maximum use of available habitats. The potential for the pink fry monitoring program to provide useful data on juvenile abundance for other salmon species should be evaluated.

2.3. FRASER RIVER COHO

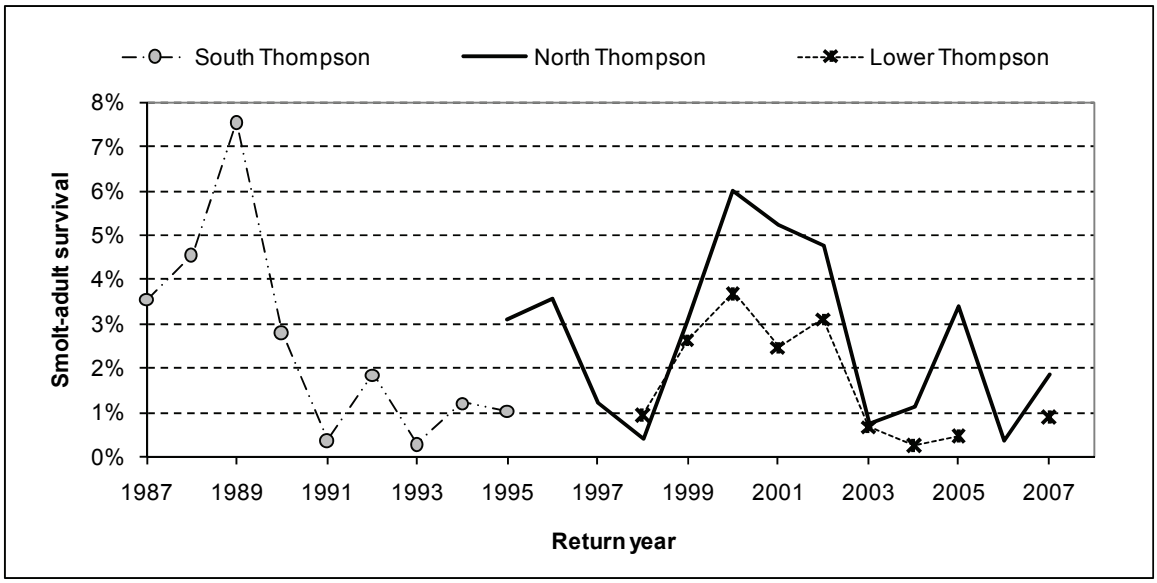
Two major groups of coho salmon are assessed in the Fraser River. One occupies coastal and lower Fraser tributaries (Simpson *et al.* 2001), while the other is an interior population aggregate that uses tributaries above Hope (Irvine *et al.* 2001). The major losses in production for both groups during the past decade have catalyzed the imposition of strict conservation measures in southern BC fisheries in 1998. Irvine *et al.* (2001) noted that these "appear to have stopped the declining trend for interior Fraser coho populations". Recent exploitation rates in BC fisheries on Thompson River stocks have been <20% (<2 out of 10 mature coho harvested), with productivity levels (in recruits-per-spawner) new exceeding replacement levels (Fig. 2.8).

FIGURE 2.8. Estimates of total returns (catch+escapement) and annual exploitation rates of Thompson River coho. *See Irvine et al. 2001 for details on methods.*



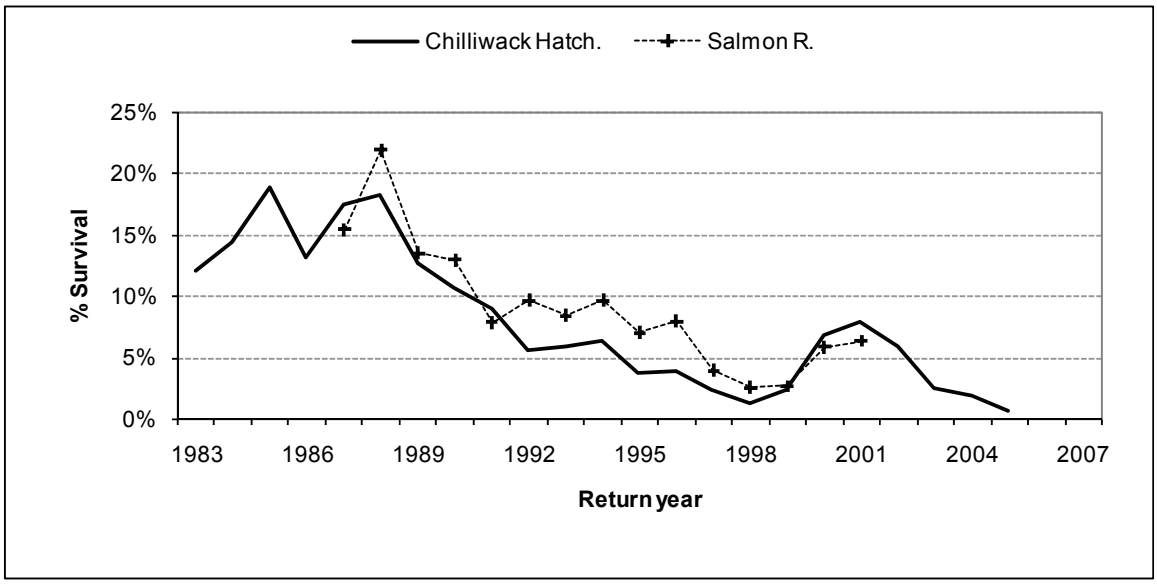
Returns of non-Thompson coho to the interior Fraser have been recorded since 1998, and varied substantially during 1998–2007, ranging from a low of 1512 in 2006, to a high of 16,191 in 2007 (mean ≈ 8600/yr). Estimates of smolt-to-adult survival since 1998 are mainly based on those of tagged smolts released in the north Thompson River (Fig. 2.9).These vary considerably as well, and have been relatively low in recent years. Increased survival for the 2002 brood year (2005 return year) is thought to be a biased estimate due to high hatchery contribution to one of the three streams used by the population aggregate (M. Chamberlain, DFO, pers. comm.).

FIGURE 2.9. Survival of Interior Fraser tagged coho smolts form the Thompson River tributaries since the 1984 spawning year (adults return 3 years later).
Survival rate is tag return (catch + escap.) divided by tagged smolts released. Releases from the Eagle River are too low to estimate recent survival rates for South Thompson coho.



Survival estimates of lower Fraser river coho are not as complete nor as reliable as those of the Thompson River. Coho in this region utilise many habitats subject to greater urban and agricultural impacts, and spawn later in the fall when water conditions are not good for visual assessments. Furthermore, the returns to natural streams are frequently a mix of naturally-produced and hatchery-produced coho. Assessments of lower Fraser coho are largely based on a standardized escapement assessment in the upper Pitt River, monitoring of smolts and adults via a counting weir on the Salmon River, and coded-wire tagging of smolts in the Chilliwack and the Salmon River hatcheries. Survival estimates increased in 2001 for the Thompson River populations, but have dropped to negligible levels since then (Fig. 2.10). Funding cutbacks led to the elimination of coded-wire tagging operations at the Salmon River hatchery in the late 1990s, so that system is no longer used as an indicator stock.

FIGURE 2.10. Survival rates for two the lower Fraser indicator stocks from the Chilliwack and Salmon rivers.
Survival rate is tag return (catch + escap.) divided by tagged smolts released.



The Interior Fraser River coho became the first Pacific salmon stock to be listed as endangered by the Committee on the Status of Wildlife in Canada (COSEWIC, website:www.cosewic.gc.ca). Endangered status indicates that this stock is considered to be at risk of extirpation or extinction. That Committee concluded that the poor state of this population was largely caused by "substantial declines due to changes in freshwater and marine habitats and over-fishing".

The Council acknowledges that DFO and several user groups have co-operated to conserve coho in the Fraser River during the recent period of low marine survival. Unfortunately, these populations do not seem to be rebuilding as fast as anticipated. Consequently, the Council has emphasized the need to continue applying the precautionary approach to fishery management, and maintain restrictions on fishing opportunities until there are clear signs that these populations have recovered to levels that can sustain some exploitation.

2.4. FRASER RIVER CHINOOK

Chinook production in the Fraser River is the largest in Canada and involves numerous life history types. Populations are grouped on the basis of their upstream migration period, spawning location, life history type, and marine catch distributions. DFO is currently examining the definitions of chinook groups[3] but the present report uses five groups described by the Chinook Technical Committee of the Pacific Salmon Commission[4] :

1. Upper Fraser spring-run, which rear one year in freshwater and three years at sea (also includes Birkenhead River stock (age index 1.3);
2. Mainstem Thompson River spring-run, which rear one year in freshwater then two years at sea (age index 1.2);
3. Fraser River (mostly mid-mainstem Fraser) summer-run, which typically rear one year in freshwater then three years at sea (age index 1.3);
4. Thompson River summer-run, which rear less than six months in freshwater, then three years at sea (age index 0.3);
5. Fall-runs consisting mainly of white-flesh chinook[5] using the Harrison River, which rear less than two months in freshwater, then two to three years at sea (age index 0.3).

Fraser River chinook have benefited from major reductions in ocean fisheries under the Pacific Salmon Treaty (1985, 1999), and protection measures for interior Fraser coho and west coast of Vancouver Island chinook stocks. Unfortunately, there are no long-term indicator stocks in the mid-upper Fraser River chinook populations, so exploitation rates are not routinely monitored. This problem was highlighted in the past, but was not fixed due to PST budget reductions in 2002. Consequently, escapement trends are still used as crude indicators of stock status. These indicate that after 10–30 years of stable or improved escapements, some stock aggregates decreased to very low levels similar to those of the 1970s (Fig. 2.11, 2.12). The Fraser River spring runs are harvested mainly in-river, but the summer-runs can be subject to fishing impacts in marine and fresh waters. It is hypothesized that these runs are subject to relatively low exploitation rates. If so, the recent drop in escapement could likely be attributed to lower survival rates in fresh water and/or the marine environment. Increased escapements of Age 0.3 chinook supports the notion that those emigrating as fry may encounter more suitable conditions (greater forage, less predation, etc.) than those emigrating as yearlings, perhaps induced by medium-long term environmental changes.

[3] see Pacific Science Advisory Review Committee Proc. Series 2002/005

[4] see Pacific Salmon Commission Report TCCHINOOK (02)-1. Feb. 8, 2002.

[5] see Pacific Science Advisory Review Committee Proc. Series 2001/030.

FIGURE 2.11. Escapements trends of Fraser River spring-run stocks (groups 1–2), 1975–2007.

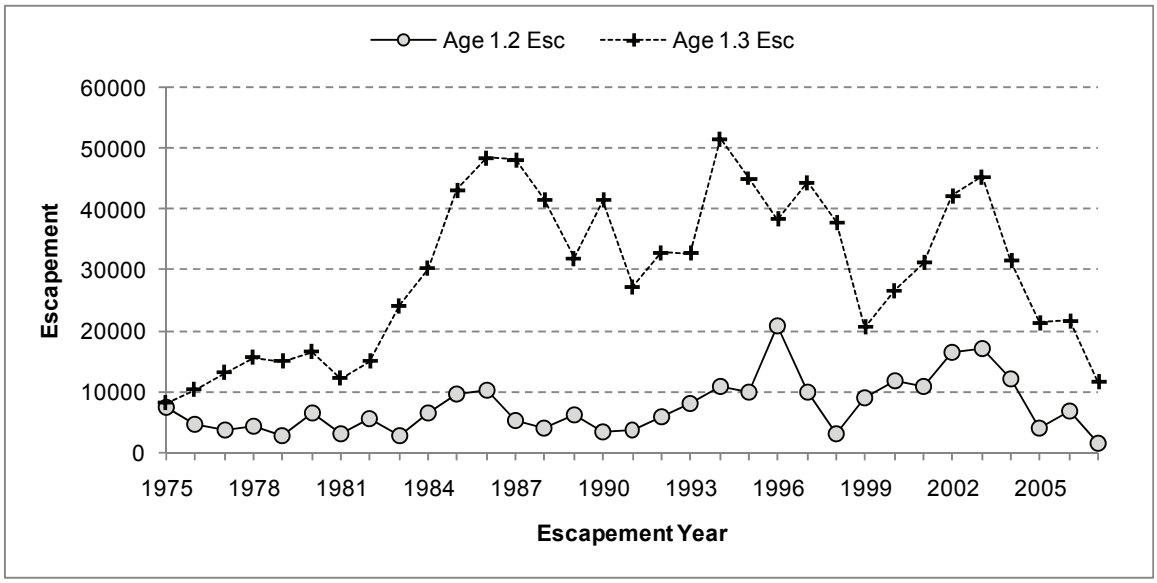
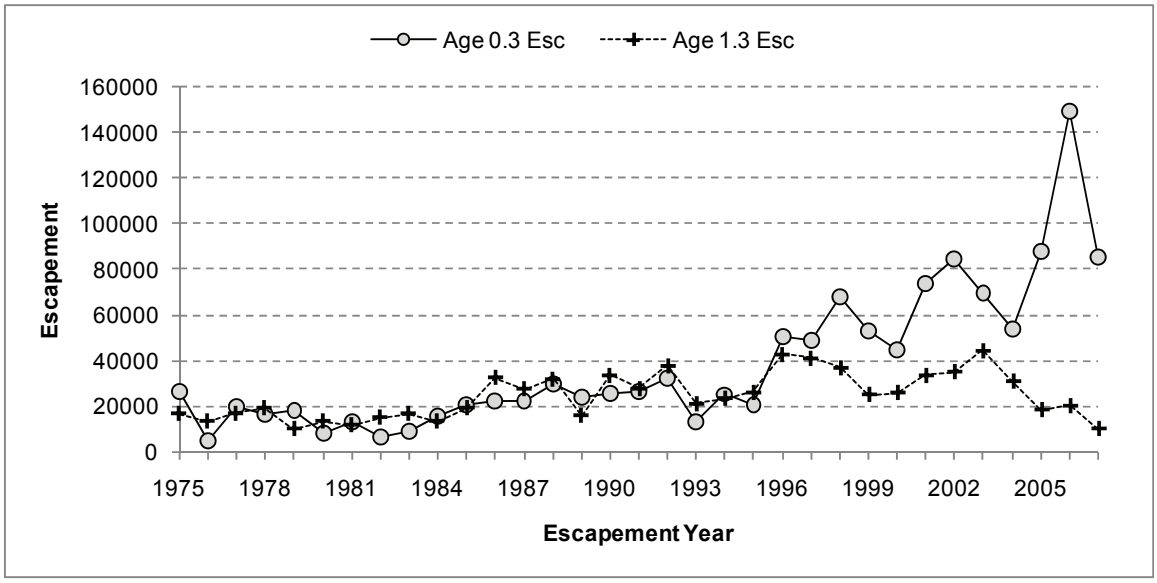


FIGURE 2.12. Escapement trends of Fraser River summer-run stocks (groups 3–4), 1975–2007.

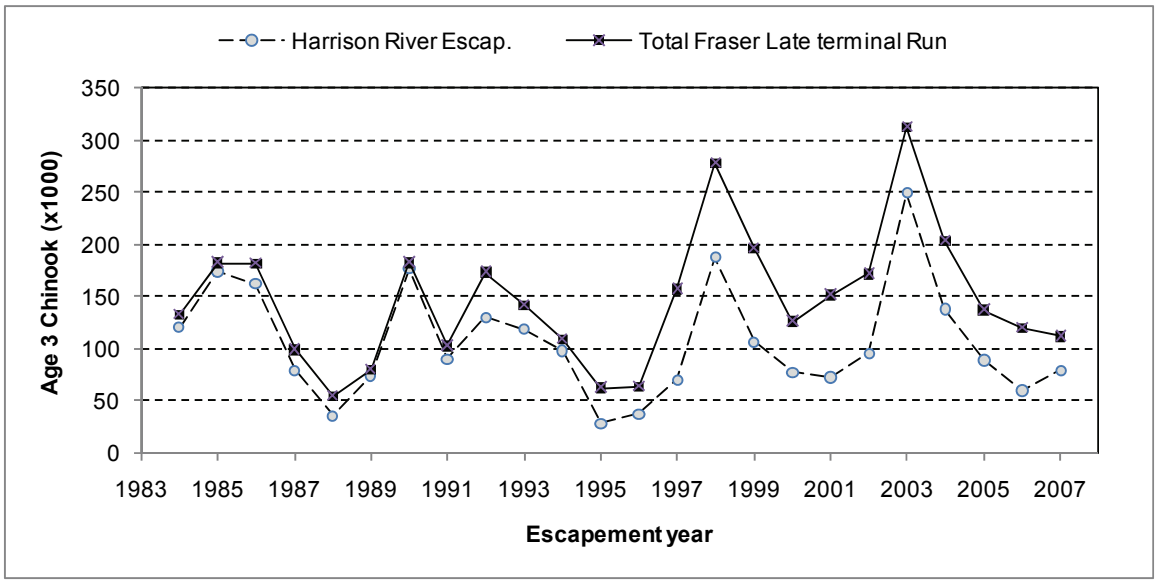


The major Fall-run chinook populations are those returning to the Harrison River, and the Chilliwack River which joins the Fraser about 16 km further downstream. In 1981, eggs and sperm from Harrison River white chinook spawners were used to supply new hatcheries on the Chilliwack River and the Chehalis River (a tributary to the Harrisson River). The Chilliwack hatchery used Harrison broodstock during 1981–1984, but the hatchery has used returns to the hatchery for production purposes since then. These two enhancement projects have influenced the stock monitoring and assessment procedures used in this region since 1984, given the increased contributions of hatchery returns. In the past, natural escapements were estimated via aerial surveys, but since 1984, mark-recapture operations have been relied on. Coded-wire tagging of hatchery releases has been conducted to provide information on harvest and survival patterns, but not all tagged fish return to the

hatcheries, and tagged proportions in the natural spawning populations surveyed are too low to provide reliable figures of total tag escapements. As a result, estimates of survival rates, exploitation rates, stock productivity and hatchery contributions still rely heavily on ancillary observations and several assumptions.

Until recently, most of the Fall-run chinook returned to the Harrison River, but returns to the Chilliwack River have been comparable in some recent years. Fall-run chinook abundance trends do not match those of spring and summer-runs even for the age 0.3 group (Fig. 2.13).

FIGURE 2.13. Total returns of fall-run white chinook to the Harrison and Chilliwack rivers.
Harrisson escapements include only spawners, while totals include escapements to both rivers plus terminal catches. Average harvest rates in fisheries within the Fraser River (terminal catches) were <5% during these years.

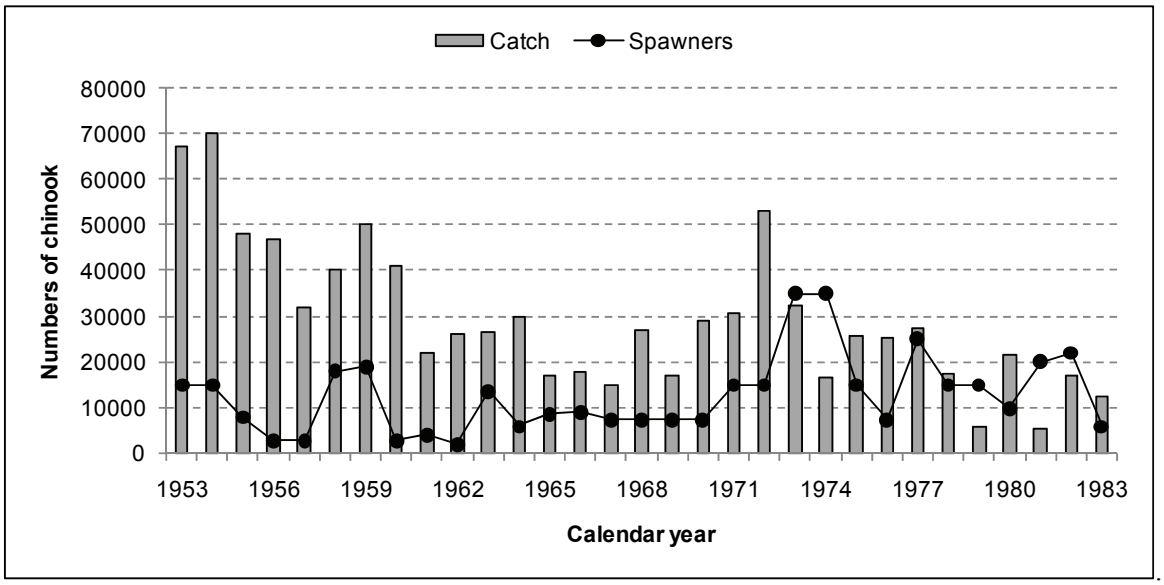


Differences in abundance trends may be influenced by hatchery production, or indicate there is an 'optimal' fry size or migration period, since those naturally in this system are the only ones known to migrate directly to sea after emergence (Starr and Schubert 1990). And in a recent assessment, it was also noted that brood survival of the Harrison population varied more than a hundred-fold up to 2001, and was very low during the 1991–1993 spawning years (progeny per parent of ~0.5:1)[6]. This assessment set a conservative escapement goal for Harrison River white chinook of about 75,000 spawners, and exploitation rates at MSY of about 0.61. These targets are based on data from monitoring activities conducted since the hatcheries were built (early 1980s). It has been hypothesized that production was substantially greater before then. It is difficult to compare estimates based on the shorter and longer data series since earlier escapements were based on visual counts (likely under-estimates), and historical catch records for white chinook are not very reliable. Omitting such uncertainties, DFO records indicate that historical returns of white chinook to the Harrison River were relatively large (Fig. 2.14).

Given the prevailing assumption that overall exploitation on Harrison River chinook in all waters occupied likely exceeded 50% before the 1980s, total returns from a single spawning may very well have been over 200,000 fish. This would exceed the average annual returns over 1984–2007 (≈147,000) comprised of natural and enhanced production.

[6] www.dfo-mpo.gc.ca/csas/csas/Proceedings/2001/Pro2001_030e.pdf.

FIGURE 2.14. Fraser River net fishery catches of white chinook, and spawning levels, 1953–1983.
Based on DFO records



Even if a conservative expansion factor is used to adjust the visual escapement survey figures (x 4–8, from Starr and Schubert 1990), and the maximum harvest rates in Fraser River net fisheries are assumed to be 30%, the terminal runs in the early 1950s may have exceeded 100,000 fish. And this figure does not account for the troll and sport fishery catches in the Strait of Georgia and the WCVI, and those in more distant U.S. and Canadian net fisheries. These harvests in ocean fisheries would have been reduced after the 1985 Pacific Salmon Treaty.

It is likely that production of fall white chinook was greater in past years, so the escapement goals set by the DFO for the Harrison River account for the uncertainty by favouring larger escapements when possible to help determine the maximum productive capacity of this major population. While overall abundance has not been increasing steadily since the 1980s, the population is not considered to be at risk given the recent return levels.

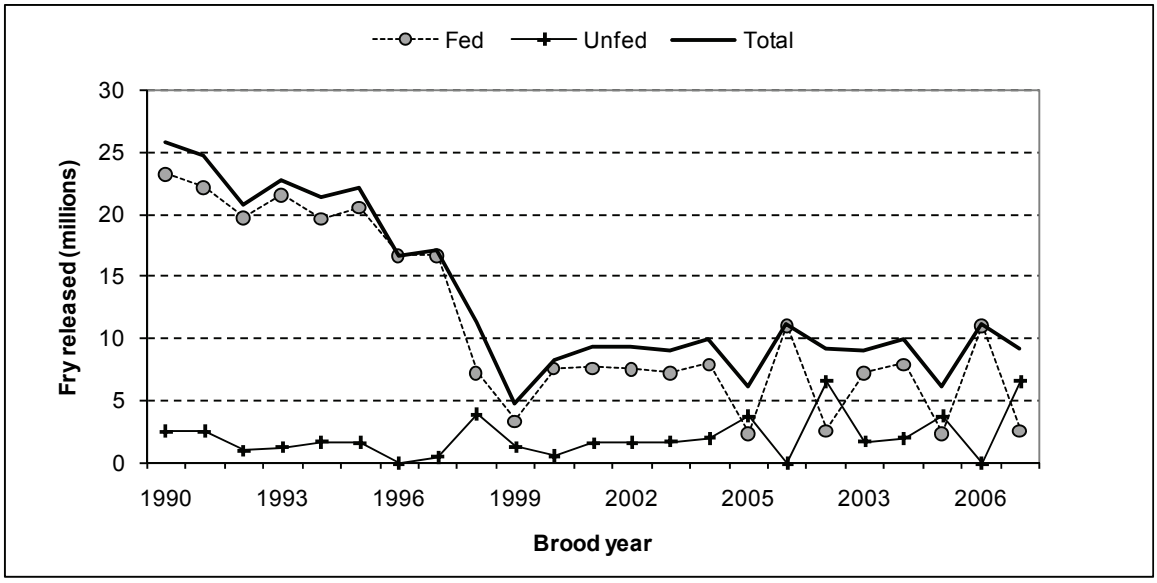
The PFRCC has noted that the absence of any long-term chinook indicator stocks in the upper Fraser River is a serious limitation to assessment and management of this salmon species. The Council is also aware that DFO started to address this limitation through funds to implement the 1999 Pacific Salmon Treaty. A useful step would be the establishment and maintenance of a core assessment framework for upper Fraser River chinook salmon, including tagged stocks to assess marine survivals and changes in fishery exploitation rates. As for the Harrison River natural population, the Council supports the suggestion that higher escapements should be allowed whenever possible to assess the hypothesis that maximum production may be greater than estimated based on short time series. Furthermore, production of Harrison River white chinook is largely determined by environmental conditions in freshwater and the ocean. In light of such facts, monitoring programs that track changes in survival and exploitation rates should be maintained to identify the main factors responsible for changes in escapement patterns. This would likely require increasing coded-wire tagging operations, and improving escapement monitoring procedures.

2.5. FRASER RIVER CHUM

Chum salmon been reported to spawn in at least 120 streams in the lower Fraser River (Farwell *et al.* 1987; Ryall *et al.* 1999), and use streams mainly below Hope, a town located about 150 km upstream of the Fraser River mouth. The number of spawning locations likely varies annually as a function of access and abundance, but the most recent WSP definitions account for 94 distinct chum spawning sites, grouped into two CUs (Fraser River canyon and Lower Fraser River, with most spawning sites being in the later. Most of the Fraser chum production (>90%) comes from about 10 streams, that have natural spawning populations, and in some cases, major hatchery production facilities. The most important ones are the Harrison, Chehalis, Chilliwack and Stave rivers. Smaller populations also subject to enhancement activities and long term escapement and include those in Inch Creek and Weaver Creek (a Harrison River tributary).

Enhancement of Fraser River chum contributed substantially to the Fraser River production. Initial enhancement activities in the 70's were small compared to those that began in the 80's with the opening of major production facilities on the Chilliwack and Chehalis rivers. Hatchery production releases consisted of unfed fry and fed fry, and initial assessments showed that the survival rate of fed fry was almost double that of the unfed fry (Anon. 1996). With additional production from large hatcheries in the early 1980s, the total number of fry released during 1991–1998 was about 21 million/year, of which 95% were fed fry. Hatchery releases of fed fry decreased substantially after 1998, and total annual production has averaged about 9 million per year since the (Fig. 2.15).

FIGURE 2.15. Hatchery releases of chum fry in the lower Fraser River for 1990–2007 brood years.
Year of ocean entry is brood year + 1.

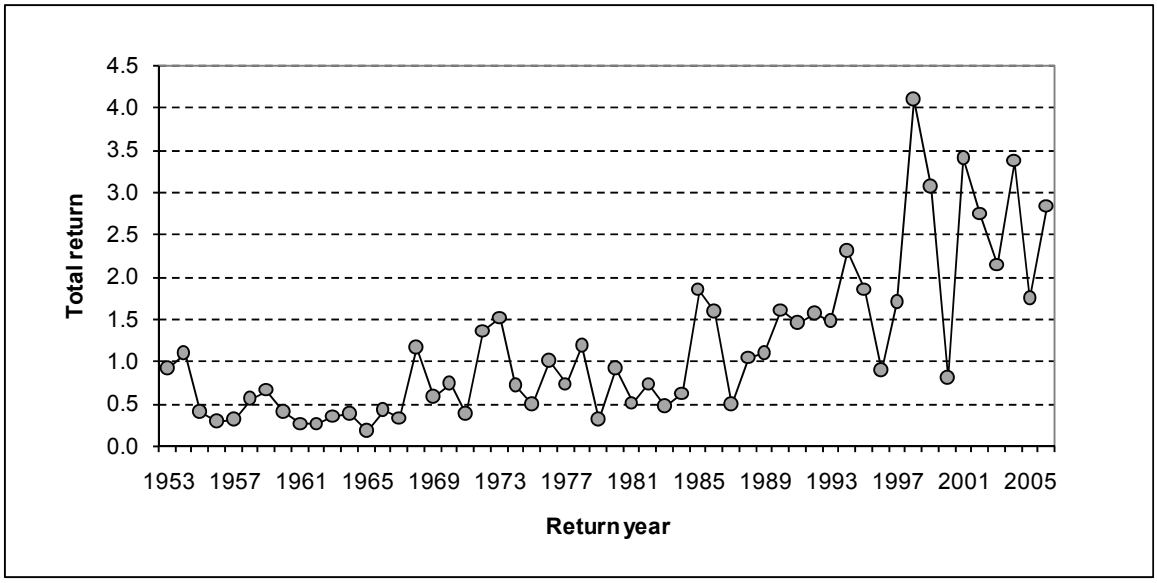


Chum escapements have been recorded since the 1950s (see Farwell *et al.* 1987), and were historically based on inconsistent visual survey procedures. Raw survey data can serve to track general escapement trends, but these typically under-represent actual escapements unless adjusted for the average time spent by spawners on the survey grounds (Cousens *et al.* 1982; Farwell *et al.* 1987; Irvine and Nelson 1995; Grant *et al.* 2007). In recent years, mark-recapture methods have been used to estimate escapement to important systems (e.g., Harrison River). This likely improved the reliability of escapement estimates, but the accuracy and precision of escapement estimates has varied substantially since 1953.

Escapement trends do not always account for the combined effects of enhancement, survival and exploitation. Trends in total returns are somewhat more informative, but these require catch estimates. When stock specific markers are unavailable, crude catch estimates are generated using 'run-reconstruction' methods (Schubert 1982) that rebuilds initial run sizes backwards from escapements and possible prior catches that rely largely on assumptions about movement patterns through various fisheries. This assessment procedure is somewhat dated, overly simplistic and may not yield reliable estimates in cases involving multiple stocks intercepted by multiple fisheries over large areas.

Chum fry generally migrate to the sea soon after emergence, and few fry are hatchery reared to sizes large enough to be coded-wire tagged before release. In recent years, thermal marks have been applied to the otoliths (small bones in the ear) of some hatchery releases to identify them, but this is not routinely done for assessment purposes. However, biological markers (e.g., protein or DNA markers) are increasingly being used to determine the stock composition of commercial catches, including those of lower Fraser River chum stocks. Trends in total returns are increasing (Fig. 2.16), and in spite of reduced hatchery production since the late 1990s. Since hatchery production levels have been relatively stable in recent years, increased returns are likely caused by lower exploitation rates or increased survival rates, mainly since 1998. Historically, Fraser River chum were harvest in mixed stock fisheries occurring in Johnstone Strait, Georgia Strait, Juan de Fuca Strait, and in US fisheries south of the Canadian border. Significant harvests also took place in the lower Fraser River.

FIGURE 2.16. Total return of Fraser River chum, 1953–2006.
Returns consist of catch + escapements of adults.



Over the years, harvest rates were reduced via the implementation of the "Clockwork" strategy in 1983 (Hilborn and Luedke 1987), the Fraser River management plan in 1987 (Gould *et al.* 1991), a modified "Clockwork" strategy in 2002 to stabilise fishing schedules, the recent adoption of an alternative fixed harvest rate strategy (~20%, PSC 2008), and further restrictions on terminal fisheries to protect co-migrating steelhead and coho stocks which indirectly reduced impacts on chum stocks. Since the mid-90's, the Johnstone Strait fisheries accounted for ≈50% of the Fraser River chum catch, while the Fraser River fisheries (combined terminal and in-river) accounted for ≈30%.

Fraser River chum are included in a geographically bounded population aggregate referred to as the Inner South Coast (ISC). It includes stocks using tributaries to mainland inlets, Johnstone strait, the Strait of Georgia, the Juan de Fuca Strait and the Fraser River (Ryall *et al*. 1999). The ISC aggregate includes an Inner Study Area (ISA) aggregate (or the Clockwork grouping) that comprises the lower Fraser River stocks (Ryall *et al*. 1999). The ISA aggregate is one of the largest producers of chum salmon in BC. Since the mid-90's, Fraser River chum accounted for about 70% of the total escapement and 60% of total returns to the ISA (PSC 2008; Joe Tadey, DFO, pers. comm.).

3. OKANAGAN RIVER SOCKEYE AND CHINOOK

The Okanagan is not a renowned salmon-bearing region, but some sockeye occupy the lower Okanagan River and Osoyoos Lake. Six anadromous salmon species are reported to have returned in substantial numbers to the Canadian section of the Okanagan River. Currently, only sockeye have been observed to spawn and rear (to smolts) in that section. Steelhead and chinook salmon status remains uncertain due to low numbers of returning adults, that may be part of a larger population distributed on both sides of the border. The depressed state of anadromous salmon runs in the Okanagan River has lead to it being declared BC's most endangered river (Outdoor Recreation Council of BC, March, 2002) and amongst Canada's four most endangered ecosystems (Hon. David Anderson, July 31, 2002).

Okanagan sockeye must migrate through the Columbia River hydro-system and pass nine dams, both as emigrating juveniles and returning adults. Obviously some manage to survive the complicated migration through this trans-boundary system, and apparently, in increasing numbers during the past decade. Conserving and restoring salmon populations in this basin is a difficult challenge, but one that has been accepted by many regional organizations. As early as 1994, the Okanagan Nation Alliance (ONA) declared an intention to rebuild the local salmon stocks. This catalyzed a decade of collaborative work involving several government agencies and power utilities. An ecosystem-based approach for the restoration of fish and associated habitats in the Okanagan Basin was proposed[7], and has begun to show some results.

Sockeye spawn in the Okanagan River below the McIntyre Dam (downstream of Vaseux Lake) and rear in the northern basin of Osoyoos Lake. Development, human population growth, and flood control features have extensively degraded their habitat. In the lower Okanagan River, more than 90% of the natural stream channel has been lost, including most of the stream-side riparian habitat. Hayatt and Rankin (1999) conducted the most recent and thorough assessment of Okanagan sockeye status. The authors recommended minimum spawning levels (58,730 Wells Dam count "units" or 29,365 peak visual counts on the spawning ground). They also noted that habitat conditions did not appear to limit sockeye population size to current levels, and identified various data needs to assist with future assessment work. Adult sockeye returns in the fall of 2008 (165,334 counted past Wells Dam, and an AUC estimate of 128,584 spawners near the town of Oliver is the largest on record, and indicates that the population may be rebuilding.

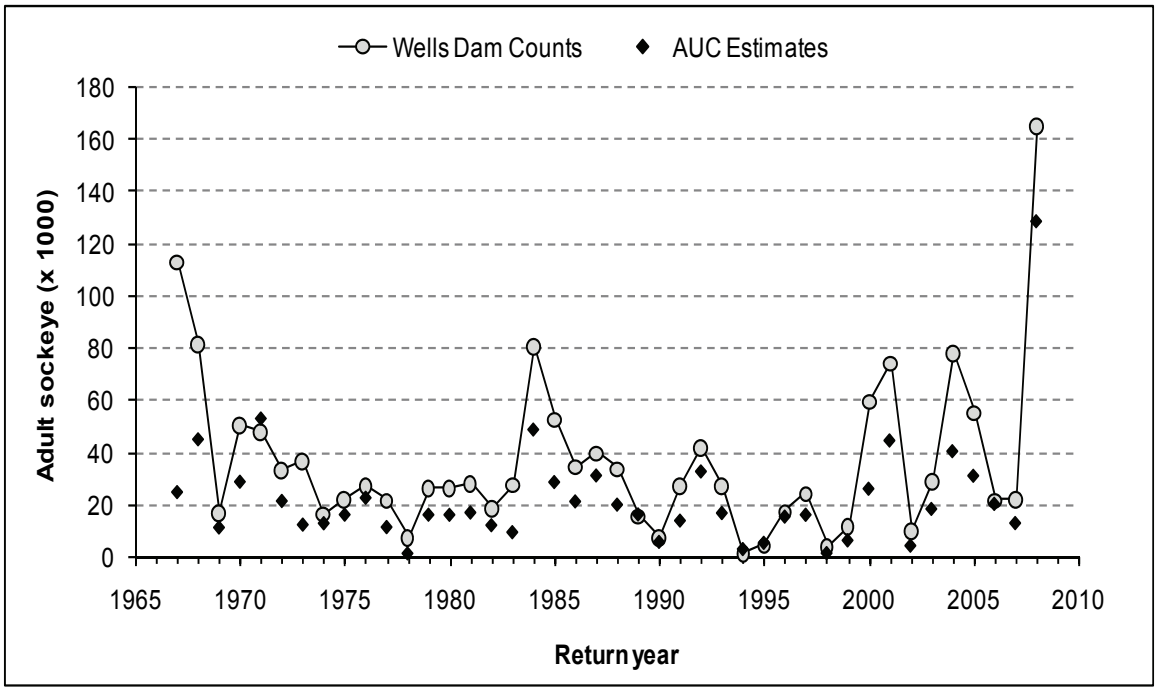
The distinction between the Wells Dam counts and spawning survey estimates is important for assessment and management purposes. Wells Dam is the last Columbia River facility that adult sockeye must pass through before reaching the spawning grounds. It is located about 180 km from the Okanagan River in a low velocity and warm water section. The prevailing and relatively arid climate of this region can potentially induce substantial pre-spawning mortality. Spawning ground survey estimates can be used to determine the extent of pre-spawning mortality. However, the Wells Dam counting method is designed to provide estimates to ±5% of the true value, which exceeds the accuracy typically provided by AUC spawning surveys, which also tend to under-estimate abundance levels. This problem precludes the reliable estimation of pre-spawning mortality, and is the subject on ongoing investigations.

Past sockeye returns to the Okanagan River were highly erratic due to variation in productivity, survival and fishery removals. Okanagan sockeye used to be subject to relatively large harvest rates in the lower Columbia fisheries (≈70–80%). However, these were progressively reduced to protect several weak salmon stocks in the Columbia River basin, and have been <10% since 2001 (Fryer and Kelsey 2002, H. Wright-ONA, pers. comm.), which likely contributed to the recent increase in escapements. Since the Wells Dam was completed in 1967,

[7] Toward Ecosystem-Based Management: Breaking Down the Barriers in the Columbia River Basin and Beyond. Spokane, WA April 27-May 1, 2002. Sponsored by the American Fisheries Society and the Sustainable Fisheries Foundation.

peak counts of more than 60,000 sockeye were obtained in some years, but the peak historical level were only exceeded recently (Fig. 3.1). However, over the 32 years for which comparisons are possible, the spawning ground survey estimates accounted on average for about 68% of the Wells Dam counts. The proportion of this discrepancy that can be explained by survey deficiencies and pre-spawning mortalities has not yet been determined with confidence.

FIGURE 3.1. Okanagan River adult sockeye returns based on fishway counts at Wells Dam, and the AUC estimates from spawning ground surveys, 1967–2008.



Annual Okanagan sockeye production depends on successful spawning in the river and the rearing capacity of Osoyoos Lake. The latter is not considered to be a limiting factor, because sockeye leaving the lake are amongst the largest known. But Rankin[8] noted that lake rearing is limited by 17ºC temperatures and dissolved oxygen concentrations of 4 mg/l, since fry do not tolerate higher temperatures or lower [O_2] levels. If so, only the northern basin of Osoyoos Lake currently offers suitable summer rearing conditions.

A final issue concerns the magnitude of restoration efforts required in the Okanagan River with the involvement of many stakeholders. The PFRCC has supported the efforts of various government and non-government organizations with a common objective of rebuilding the Okanagan River salmon stocks. The general consensus that is that the goals can only be achieved if priority is given to resolving the organizational and process issues, as opposed to having closure on various scientific and technical debates. Communities and organizations have expressed the desire to be involved and assist with this complex task, with the initial focus being on sockeye, then on other species. Over the past decade, the ONA has emerged as a lead entity with ongoing support from DFO, other ministries and several project sponsors in both Canada and the US. Its continued involvement with the restoration of the sockeye population using one of Canada's most disturbed ecosystems is challenging but crucial.

[8] Rankin, P. 2002. pers. comm. Presentation at conference referenced in previous footnote.

Chinook salmon have also been recorded on the Canadian side of the Okanagan River, but the absence of reliable figures for recent years precludes the tracking of trends in abundance. Following a 2006 COSEWIC assessment, this population was given the 'threatened' status.

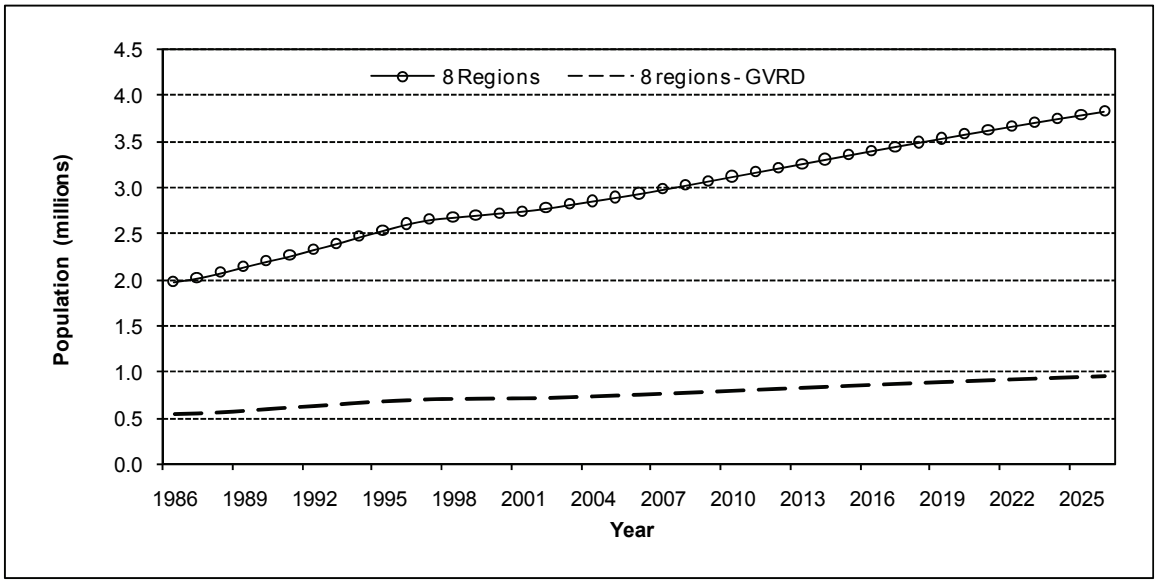
The PFRCC has supported the allocation of more sufficient resources for the various monitoring and research activities focusing on identifying the factors limiting the production of sockeye at each life history stage, both in the Okanagan basin and their broader ecosystem outside the basin. The results should be used to determine realistic and cost-effective rebuilding targets based on various user group inputs, as well as considerations of logistic, scientific and financial constraints.

It has been reported that Canadian contributions (financial, scientific, etc.) have helped to justify and secure continued support from the US hydropower industry to help mitigate environmental problems caused by past development practices. In light of the tangible signs of success, such contributions should be maintained or even increased in the future. Rebuilding Okanagan salmon populations and restoring their ecosystems may involve many social/cultural trade-offs. It is beyond the Council's mandate to intervene on such issues but, irrespective of the trade-offs to be made, the Council has remained focused on the rebuilding of salmon populations in this region to levels equal to or greater than those supported by historical records.

4. STRAIT OF GEORGIA (INCLUDING JOHNSTONE STRAIT)

The Strait of Georgia region is defined here as the area between the east and south-east coasts of Vancouver Island and the North American continent (Fig. 1.2). There are dozens of inlets and river mouths in this area, many of which are used by salmon produced by artificial enhancement and rearing facilities. This region is also the population centre of the province, with two-thirds of the provincial population located in the eight Regional Districts adjacent to the Strait of Georgia (GS), Juan de Fuca Strait (JF), and Johnstone Strait (JS). The districts include Comox-Strathcona, Capital Region, Cowichan Valley, Greater Vancouver, Mount Waddington, Nanaimo, Powell River, and the Sunshine Coast. The population in this assemblage is projected to expand by about 40% over the next fifteen years. Population projections indicate steady growth with a possible doubling of the population during 1986–2026, which could potentially have important impacts water use and quality, aquatic and riparian habitats, and fishing activities.

FIGURE 4.1. Projected population increase in eight Regional Districts adjacent to the Strait of Georgia as defined above.
Projections from the BC Ministry of Management Services (see BC Stats Population Projections, June 2001).Greater Vancouver Regional District labelled as GVRD.



The detrimental impacts of past population growth and development on salmon and steelhead resources in this region are well documented, and many have been chronicled in recent Council background papers on habitat.

4.1. STRAIT OF GEORGIA SOCKEYE

Sockeye salmon in the region are known to use many small coastal lakes, large rivers in mainland inlets and Nimpkish River system, but they are not present in some of the larger lakes on the east coast of Vancouver Island. Where sockeye have been present, their status is highly variable and in many cases uncertain for lack of surveys. It is believed that sockeye abundance has been significantly reduced through habitat impacts and mixed-stock fisheries for Fraser sockeye and pink salmon over the years.

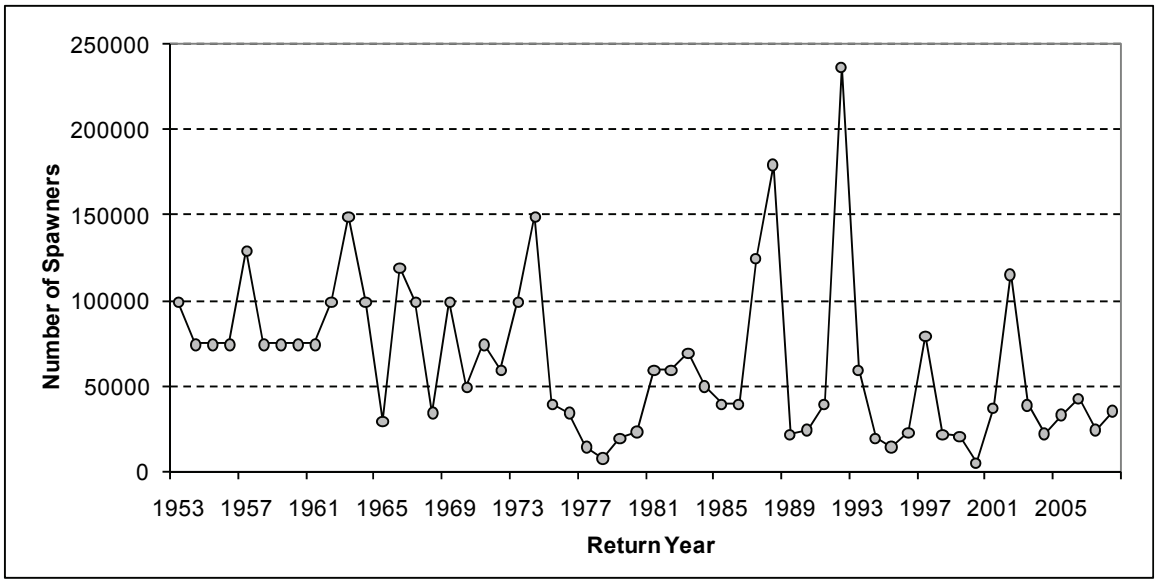
Along the east coast of Vancouver Island (ECVI), sockeye have a limited distribution. Few sockeye are known to have used the Cowichan Lake system, although kokanee have been observed in Cowichan Lake (Neave 1949). Sockeye are infrequently recorded in the Nanaimo River system (four small lakes) and those are considered likely to be strays from other systems. Sockeye may have utilized Comox Lake and the Puntledge River, but limited survey records before the Comox Dam in 1913 do not identify the species as being present.

Morris *et al.* (1979, p.80) noted that "only the lower 13 km of the Puntledge are presently accessible to spawning salmonids, as upstream migration is limited by the Comox Dam. The upper Puntledge River, the Cruikshank River, and all the tributaries of the rivers and Comox Lake once supported large salmonid populations".

There are also records indicating that sockeye were introduced in Comox Lake, but with very little success. Remnant numbers of sockeye are still observed in this system although their origins are not known. Sockeye are recorded in the Campbell River system, but sockeye are not endemic to the upper lakes due to Elk Falls located only five kilometres up the Campbell River (Bell and Thompson 1977).

The Nimpkish watershed is the largest non-Fraser River producer of sockeye in the Strait of Georgia region. Most investigators agree that the historical population sizes in this watershed were much larger than the recorded spawning escapements (Fig. 4.2). The escapements appear to alternate between fixed populations levels, apparently an artefact of the methods used to record spawning abundance levels (letter categories used to designate level ranges). This procedure tended to weigh more heavily lower escapements, with nine of ten allowable categories used to designate escapements <100,000 salmon, but only one for greater than this level (see Weinstein 1991 for details).

FIGURE 4.2. Recorded sockeye spawning escapements for the Nimpkish River basin, 1953–2008.
Returns to the two run-timing components are not distinguished in this figure.



Sockeye returns to the Nimpkish consist of two run-timing groups: an early run (mid-May to mid-June) to Vernon Lake in the upper Nimpkish River, and a mid-summer run (mid-June to August) returning to the main spawning grounds of Woss Lake and upper Nimpkish Lake. In the mid-1970s, the spawning escapement of Nimpkish sockeye was very depressed, which lead DFO staff to review how sockeye fisheries in Johnstone Strait were being conducted and their impacts on this population. This lead to significant changes in allowable fishing patterns (time, area, and day open to fishing). The Salmon Enhancement Program (SEP) initiated a small-scale hatchery

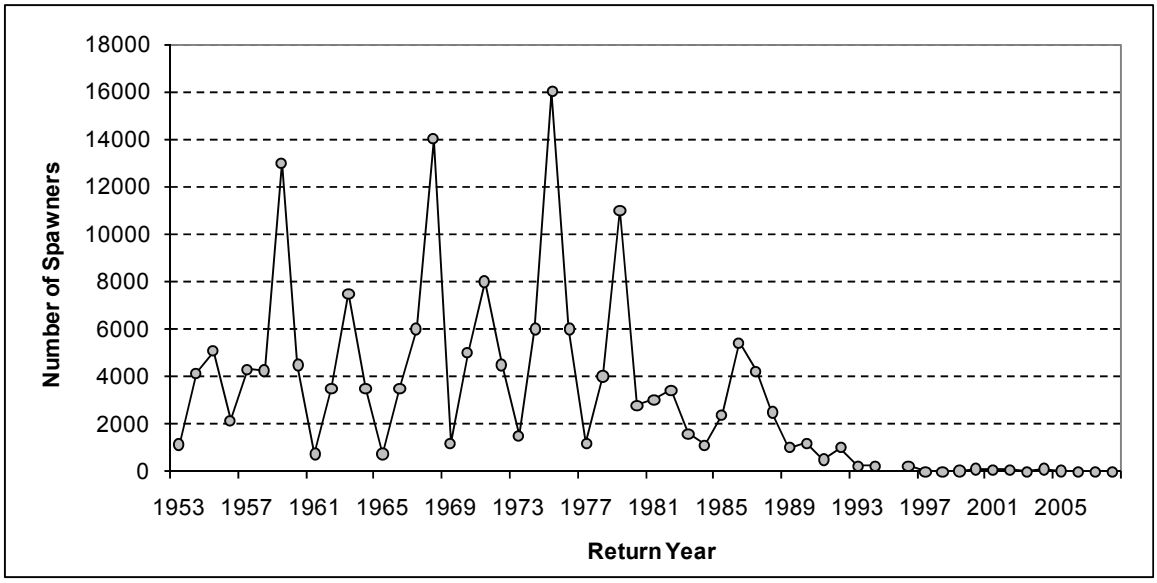
production operation and a Nimpkish Lake enrichment program during the mid-1980s, all of which may have assisted in rebuilding of this stock. The old hatchery was replaced with a new facility in 1997, and has been operated since then by the Namgiss First Nation.

Recent escapements to this system have been less than the hypothesized maximum capacities, with the lowest returns observed in 2000. Returns improved substantially in 2001 and again in 2002 throughout the entire watershed. Other sockeye systems in the region include Nahwitti Lake and the Shushartie River (the latter not surveyed frequently). Sockeye returning to the Nahwitti River have an early run-timing and seem to have fared better than other small lake systems, although coverage is sporadic and inconsistent over time. Returns were historically a few thousand per year, but recent levels were approximately one thousand sockeye.

Along the mainland side of the Strait region, sockeye use the large river systems in lower Queen Charlotte Sound and Johnston Strait (Kakweiken R, Klinaklini R., and Devereux Cr.), in Knight inlet (Ahnuhati R.) and in Kingcome Inlet (Kingcome R.). The remoteness and glacial nature of these systems creates numerous assessment difficulties. Their status is uncertain, but increased returns have been reported recently for some of them.

On the islands and along the mainland shores, there are numerous small coastal lakes that support or once supported sockeye populations (Appendix C, Table C.1). Under the federal government's proposed Wild Salmon Policy each of these may be considered as distinct Conservation Units (CUs), although it remains to be determined if they will be actively managed as CU aggregates (W. Luedke, DFO, pers. comm.). Even within this geographically small region, individual populations can often be genetically distinguished from adjacent ones, and can exhibit differences in demographic traits suited to particular spawning habitats and rearing lake conditions. If conservation of diversity remains a top WSP priority, stock-specific conservation measures will be needed. An assessment of the state of sockeye populations in this region was presented in the May 2002 PSARC meeting focusing on Sakinaw Lake sockeye (Ruby Creek spawning area, Murray and Wood 2002). Spawning escapements of this population have declined dramatically during the 1990s (Fig. 4.3).

FIGURE 4.3. Estimates of total spawners near Sakinaw Lake (Ruby Creek).
Based on DFO records.



Many populations had >1,000 spawners, but their numbers have declined drastically to only a single spawner in 2006 and none in 2007–08. Severely depressed populations (<50 spawners) located in proximity to highly developed areas (e.g., Strait of Georgia) are at considerable risk of extinction. The Sakinaw Lake sockeye population has been classified as 'Endangered' by the COSEWIC, but at the time of this writing, the BC Minister of Environment, in consultation with the Federal Minister of Fisheries & Oceans, had not yet listed this population on Schedule I of SARA. Should this be done, the federal government would be required to develop a recovery plan to protect and rebuild it. Such plans could involve costly initiatives, in terms of restoration of habitat, alterations to fishing practices, and restrictions on development.

Current DFO plans are to stop the decline and re-establish a self-sustaining, naturally spawning population. For this purpose, a captive broodstock program was initiated in 2001 to maintain genetic diversity. It is also hypothesized that returning adults (if any, nowadays) tend to reach approach waters throughout July, so DFO has agreed to delay some interception fisheries until July 25 and reduce recreational takes (see Anon. 2009, p.25–26 for details). It has yet to be proven that such measures are sufficient to rebuild this population, and if not, additional measures would be required, including listing this population under SARA.

Sockeye in the Strait of Georgia are quite diverse, although the basis for assessment is relatively weak. Returns to most streams are depressed from past levels. This situation has a serious potential effect under the Wild Salmon Policy and the Species at Risk legislation. Individual sockeye populations are likely to be identified as single conservation units and require specific conservation plans if they are judged to be at risk. The PFRCC has suggested that the stock status of these small populations be more carefully examined, and a framework for quantitative assessments be specified.

4.2 STRAIT OF GEORGIA PINK

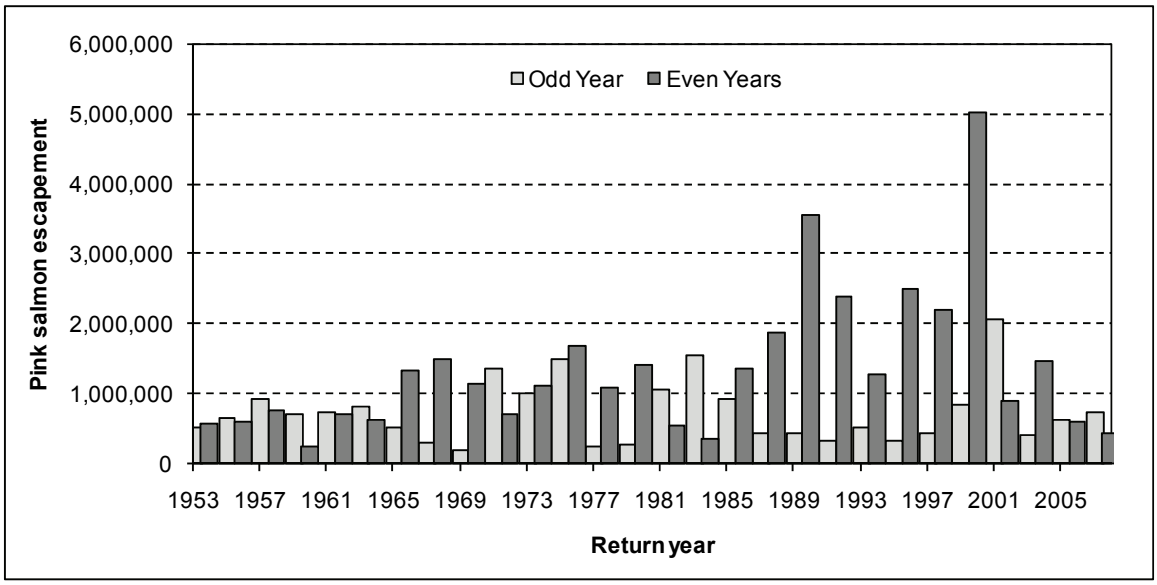
Outside the Fraser River basin, pink salmon have been recorded to spawn in 115 streams from Statistical Area 12 (lower Queen Charlotte Sound) through to Area 20 (southern Vancouver Island around to Port Renfrew). Unlike the Fraser River pink populations, those surrounding the Strait of Georgia (including Broughton Archipelago) can spawn in even and odd years. Most if not all non-Fraser spawning populations are assessed using visual survey procedures. Catches cannot be assigned to individual stocks regularly using various markers, although large-scale tagging and tag-recovery programs were conducted by the PSC in 1959 and 1961 to collect baseline information. Since then, it is simply assumed they are caught in large mixed-stock fisheries with Fraser River populations mostly in odd-years. The PSC provides estimates of Fraser and non-Fraser pink catches, but the stock contributions of non-Fraser catches are not estimated. Stock-assessments are further complicated by the unknown accuracy of the visual surveys and survey inconsistencies from year to year.

In general, pink salmon occupy mainly the northern half of this region (Kingcome Inlet to the Quinsam R., adjacent to Statistical Areas 12–13), and the production from the even year-line dominates. Even and odd-year pink salmon occupy streams down to the Englishman River on the east coast of Vancouver Island, but their presence is very limited south of that point. Along the mainland shore, odd-year pink salmon are obviously abundant in the Fraser River, but even-year pink salmon are limited south of the Phillips River (Phillips Arm, mid-Johnston Strait). Spawning channels in the Glendale and Kakweiken rivers and hatcheries in the Quatse, Quinsam, Oyster, Puntledge, Sechelt and Seymour rivers have also contributed to total pink salmon production since the early 1980's.

Information on population status is largely based on a cursory review of the 1953–2007 spawning escapement trends. Data on actual production (catch + escapement) and stock-specific productivities are not readily available, and there is little survival rate data for hatchery production releases. Based on the scarce data

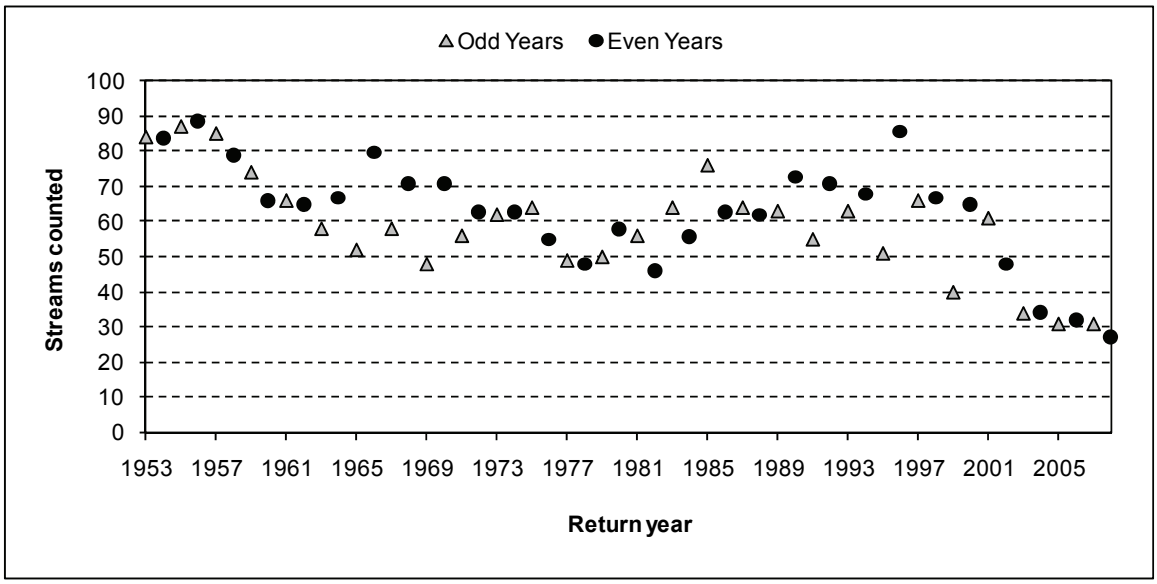
available, it has been suggested that substantial reductions in harvest rates occurred during the 1990s due to reduced fishing levels in southern BC. Larger harvest rates occur in odd-years because Georgia Strait stocks mix with Fraser River stocks when they are targeted by some fisheries. Given relatively constant survival rates, changes in harvest rates should be reflected by trends in escapement levels (Fig. 4.4). And in support of the above hypothesis, there was a marked increase in escapement levels during the 1990s, and particularly during even years. However, during the past 5–6 years, both the odd and even year-lines declined to pre-1970 levels. In the absence of stock-specific records on catches and productivity, the nature of the factor responsible for this decline has not been identified with certainty, even when using the limited survival data from hatchery production releases. It has been hypothesized that a substantial portion of the variation in the escapement trends observed could be due to (i) inconsistencies in the total number, or (ii) the set of streams surveyed each year.

FIGURE 4.4. Numbers of pink salmon spawning in the Strait of Georgia region, excluding the Fraser River. *Spawning figures grouped by year type. Figures for 2008 are preliminary.*



If only half of the streams are examined in odd years, then total escapement based on all survey reports would likely be less for the odd year-line (first hypothesis). Differences in the number of streams surveyed do not appear to be consistent or large enough to account for all differences in spawning levels reported since the 1950s (Fig. 4.5). Fewer streams were surveyed since 2002 than in previous periods, which could account for a large portion of the apparent decline in total escapement since then.

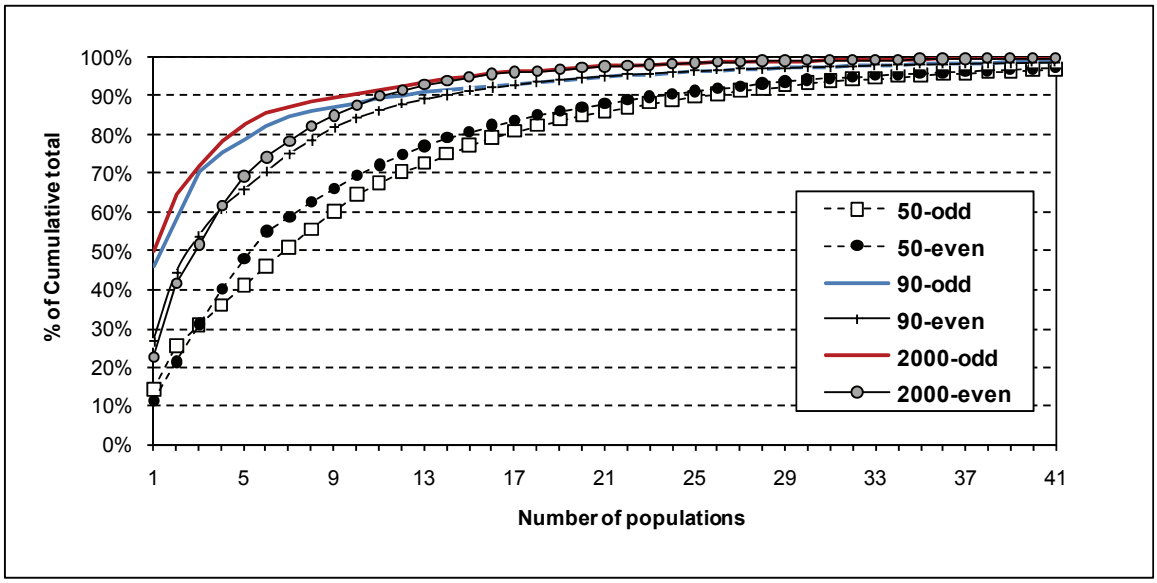
FIGURE 4.5. Numbers of streams surveyed to determine total pink salmon escapements by year type. *Figures for 2008 are preliminary.*



Both observations suggest that some of the annual variation in escapement is likely caused by inconsistent survey procedures. However, support for the alternative hypothesis could be evaluated by comparing stream specific escapement by year-line. Spawners from both year-lines tended to use the same streams, with greater numbers during the even years, mainly in northern sections. Perhaps more important is the observation that the contribution of various streams to each year-line production seems to have changed over time. To investigate this further, average stream production was determined for an early period (1953–1960) and two more recent ones (1990–1999, 2000–2008). Each stream was then ranked from largest to smallest (in escapement) by period and year-lines, and the cumulative production was determined over 100 streams.

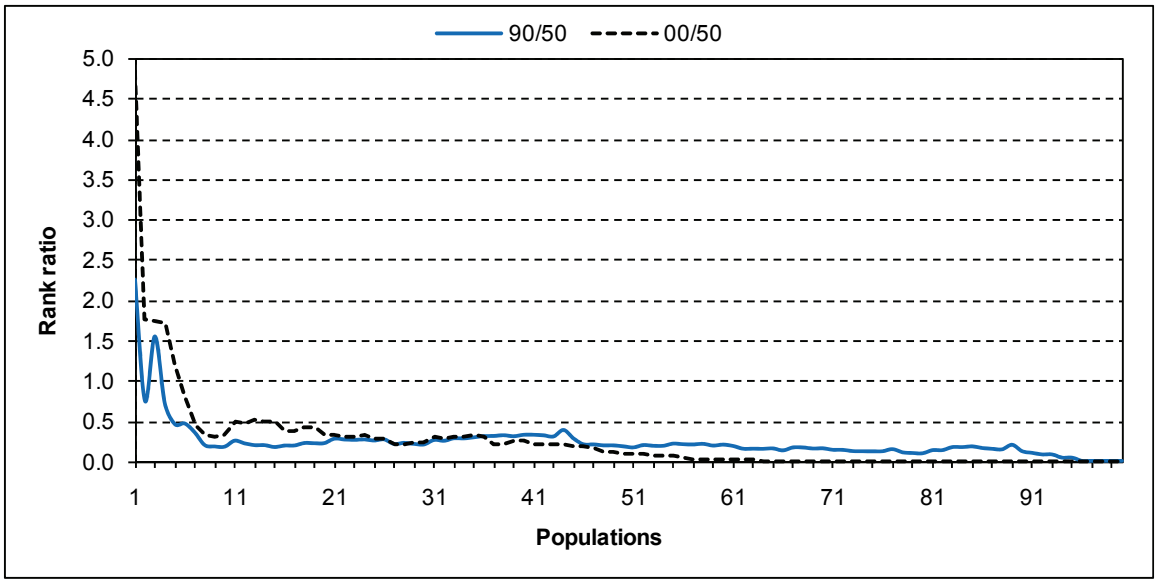
A reduction in the number of streams accounting for a certain percentage of the cumulative total production can indicate a potential loss in diversity. Fewer streams contributed to total production lately than in the 1950s, and more so for the odd year-line (Fig. 4.6). And production has been concentrated in fewer larger streams during recent periods for both even and odd year-lines. During the 1950s, about twenty-five streams accounted for over 90% of the total production in both year-lines, but by 2000, only 10 streams accounted for the same production.

FIGURE 4.6. Cumulative percentage of total escapement against number of streams surveyed during 3 periods for even and odd year-lines.



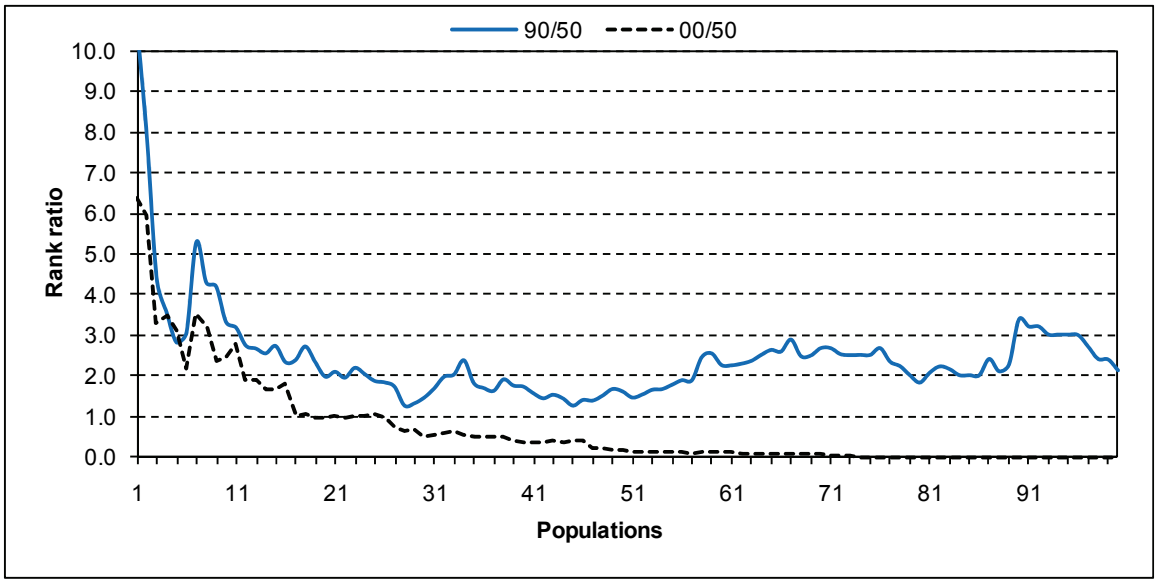
To determine if the changes were attributed to specific streams, the rank ratios (recent/old) for each stream were determined across periods. A lower ratio implies that the recent contributions to total escapement is greater for one period relative to a previous one, with values >1.0 indicating the opposite for the same stream rank. The results show lower odd year escapements across all ranked streams, except for two of the largest ones in the 1990s, and five of the largest ones monitored since 2000 (Fig. 4.7).

FIGURE 4.7. Ratio of changes in spawning escapement levels in the odd year-line since the 1950s, by stream rank order for the two most recent periods (pre-post 2000).



By contrast, the contributions of all even-year ranked streams in the 1990s exceeded those in the 1950s, but only 22 exceeded the 1950s levels since 2000 (Fig. 4.8)

FIGURE 4.8. Ratio of changes in spawning escapements in the even year-line since the 1950s, by stream rank order for the two most recent periods (pre-post 2000).



Since 2000, the ten largest spawning escapements accounted for >90% of the total escapement in both the even and odd year-lines (Table 4.1), but in terms of spawners, the odd year-line has been about 60% of the even year-line, or much greater than the 20% during the 1990s. The reduced difference between the two year-lines appears to be largely due to declines in pink salmon abundance in key production areas in some mainland inlets of Area 12.

TABLE 4.1. Largest pink salmon escapements for the even and odd year-lines in the Strait of Georgia since 2000.

Top 10 even-year populations	Area	Top 10 odd-year populations	Area
1. Kakweiken river (enhanced)	12	1. Glendale creek (enhanced)	12
2. Glendale creek (enhanced)	12	2. Quinsam river (enhanced)	13
3. Adam river	12	3. Puntledge river (enhanced)	14
4. Phillips river	13	4. Adam river	12
5. Ahnuhati river	12	5. Kakweiken river	12
6. Quinsam river (enhanced)	13	6. Oyster river (enhanced)	14
7. Salmon river	12	7. Salmon river	13
8. Wakeman river	12	8. Tsolum river	14
9. Keogh river	12	9. Quaste river (enhanced)	12
10. Amor de Cosmos	12	10. Ahnuhati river	12
Percentage of total production		Percentage of total production	
Accounted for …	87.5%	Accounted for …	90.6%

These observations indicate that non-Fraser pink salmon spawning populations using streams in the Strait of Georgia have:

- Increased slightly up to the 1970s, but most odd-year populations have been reduced to levels close to the 1950s, and currently >50% of the streams used have escapements of less than 200 pink salmon;
- For even-year populations, generally increased up to year 2000, but have been drastically reduced to 1950s levels recently, with about 60% of these having escapements of less than 200 pink salmon; and,
- In terms of the number of streams used by spawners, not declined significantly, but there has been an increased concentration of spawners in a few large systems.

It has been hypothesized that the declining escapements observed since 2000 are due to the infestation that juvenile pink salmon experienced during their outmigration from tributaries to the Broughton Archipelago (northern side of Area 12). Relatively large densities of the two prevalent species (*Caligulus celmensi* and *Lepeophtheirus salmonis*) have been detected in the vicinity of numerous fish farms located in this area. Infestation rates of juvenile pink and chum appear to vary in part due to salinity levels, location, salmon size, and were greater in 2004 than in 2003 and 2005. New regulations suggested by the PFRCC and applied to fish farms were intended to reduce the risks of sea lice population build-ups. This topic remains a source of contention, and merits further consideration given the importance of protecting wild stocks.

The information available on the state of pink salmon populations using various Strait of Georgia tributaries is not sufficient to conduct a sound assessment of the state of the population. This salmon species may be less prized by anglers and commercially less valuable than other salmon species, but it nevertheless remains an important natural resource that deserves the same basic attention and level of monitoring as other salmon species. Stock contributions to various interception fisheries should be estimated, perhaps via DNA analyses of bio-samples. Assessment problems caused by insufficient and inconsistent escapement monitoring in other coastal regions have been recognized (see Price *et al.* 2008), and for similar reasons, the survey procedures used to monitor pink populations around the Strait of Georgia should be improved so standard methodologies can be relied on to provide scientifically credible escapement indices in a consistent fashion. These two operations would greatly improve the amount and quality of data used to assess stock trends. The recent and dramatic decline in escapements is of concern, and efforts should be made to determine the major cause, and if possible, take action to restore the populations to levels commensurate with the productive capacity of the habitat. And to help clarify the issue about the impacts of fish farms on some natural runs, it might prove worthwhile to compare trends for odd/even year pink returns in streams near regions with high farm densities to those in regions further to the north and south of it. That would require implementing more rigorous escapement monitoring programs.

4.3. STRAIT OF GEORGIA COHO

Coho salmon are widely distributed throughout this region, and natural production is extensively mixed with that of several major enhancement facilities and numerous community programs. The combined production from natural and enhanced populations catalyzed the expansion of the recreational fishery during the 1980s. By the late 1980s, it became apparent that high exploitation rates on coho (Fig. 4.9) exceeded the maximum sustainable levels for natural populations of ≈65% (Anon. 1990). Ocean productivity and marine survival declined in the 1990s (Fig. 4.10), further reducing the sustainable exploitation rates.

Unfortunately, it took much time to detect and respond to the decreased productivity, during which many stocks were subject to over-fishing. The combined effects of habitat changes, over-harvests in mixed-stock fisheries,

reduced marine survival, and inter-annual variations in the distribution of Strait of Georgia coho (Beamish *et al.*, 1999) caused a production loss during the 1990s and led to the implementation of a major conservation initiative, including some fishery closures starting in 1998. There are no longer fisheries in the Strait of Georgia directed at coho salmon, except for some terminal fisheries focusing on hatchery returns.

FIGURE 4.9. Percent of total adult coho returns caught in the Strait of Georgia ocean fisheries.
The indicator stocks are releases from the Big Qualicum and Quinsam river hatcheries (BQR, Quinsam), and a naturally spawning population from Black Creek (Black Cr.).

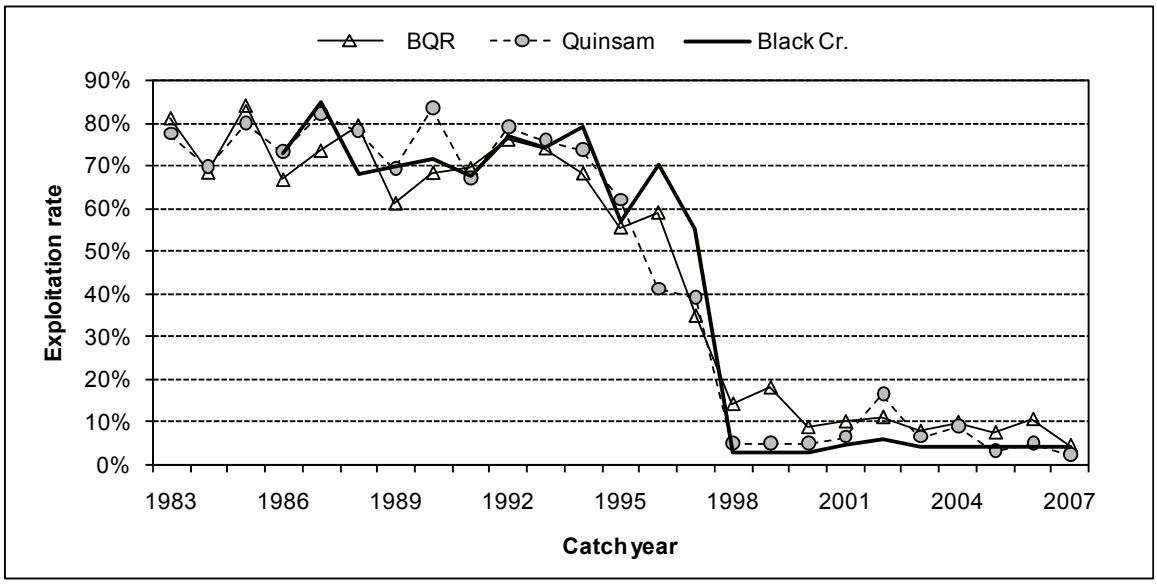
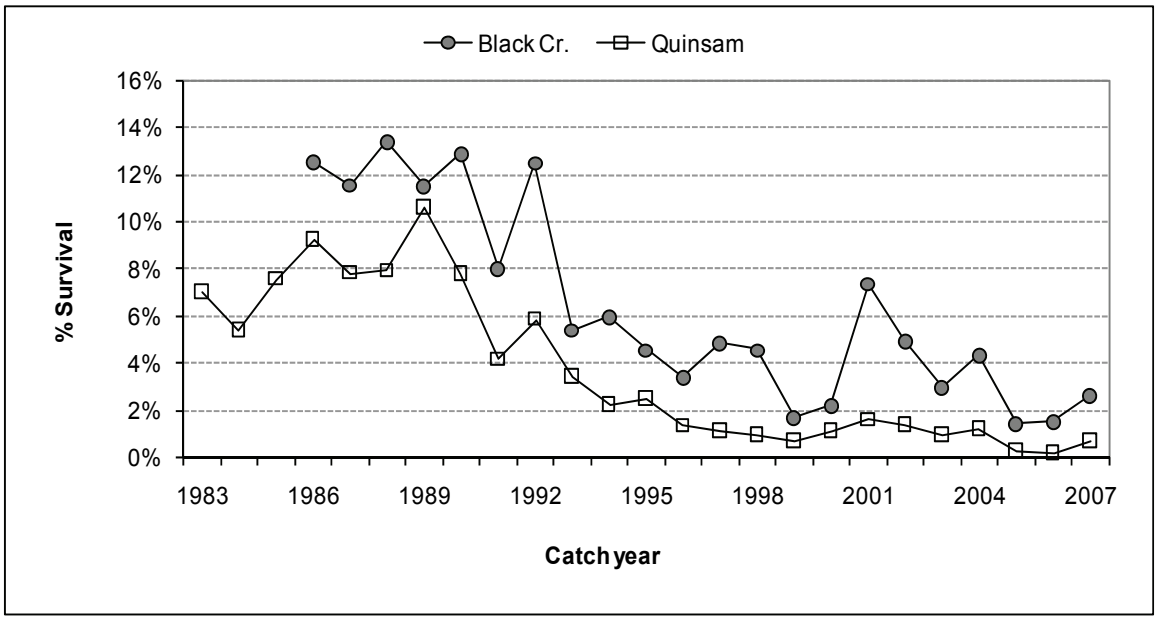


FIGURE 4.10. Marine survival from smolt to adult return year.
The indicator stocks releases from the Quinsam River hatchery, and a naturally spawning population from Black Creek (as in Fig. 4.9).



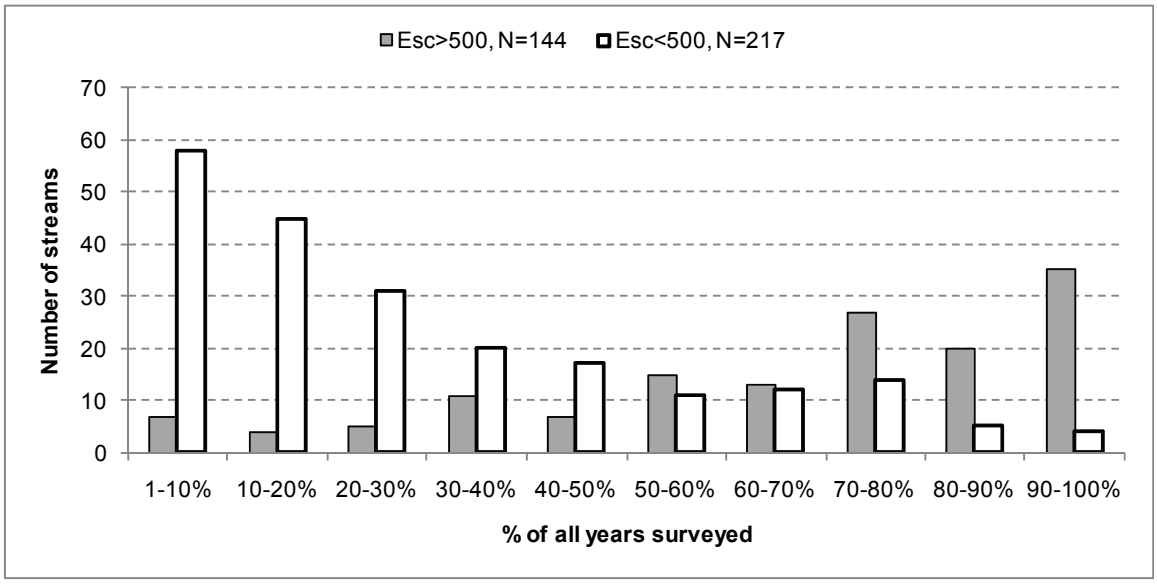
Monitoring the recovery of coho populations is not easy. They utilize a wide variety of habitats (streams, pond, lakes, and large rivers) in this region, and visual surveys are not easily conducted during fall conditions (floods, turbid waters, etc.). So, monitoring activities tend to focus on some populations or "indicator stocks" (see Simpson *et al.*, 2001). The Quinsam and Big Qualicum river populations have been subject to hatchery-rearing, coded wire tagging, and escapement monitoring for many years, and provide consistent indices of survival and exploitation. The population from Black Creek is the only natural indicator stock in the region that has been tagged and monitored for many years. Survey records exist for many other stocks, but they differ in consistency and accuracy. Still, they provide insight on production trends, and complement data from indicator stocks. Annual surveys were summarised for small and large non-hatchery populations (arbitrarily set at 500 salmon for ≥1 decade during 1953–2006). Omitting streams with no records of coho spawning leaves about 410 streams, with 144 of these in the large stream category. For the latter group, mean escapements declined in the 1980s, but increased since, along with the survey frequency rates (Table 4.2).

TABLE 4.2. Summary of coho spawning escapement for tributaries to the Strait of Georgia and Johnstone Strait (Areas 12–20, 28 and 29B).
Average spawning levels and survey frequencies are given by stream type and period. N = the number of different streams with escapement records during the period. Returns to large hatchery facilities not included.

Variable/Period	1953-60	1961-70	1971-80	1981-90	1991-00	2001-06
Mean number of spawners in large streams	2942	2712	1946	1261	1365	2378
Number of large streams (N)	102	138	133	125	123	122
Survey frequency (aver. per stream/period)	59%	63%	63%	83%	92%	96%
Mean number of spawners in small streams	132	132	96	70	61	111
Number of small streams (N)	93	92	119	151	170	85
Survey frequency (aver. per stream/period)	71%	66%	55%	51%	39%	44%

Small streams showed similar trends in mean escapement, but more of them had low escapements in the 1980s, and survey frequency has declined since 1953. The number of streams with large populations has remained fairly stable since 1953, but survey records differ in terms of reliability and coverage, and different streams may contribute to the total escapements during some periods. About 55% of the large streams were surveyed ≥70% of the time, but by contrast, over 50% of the small streams were surveyed ≤30% of the time (Fig. 4.11). As a result there are major differences in survey coverage, which makes it difficult to assess the relative contributions of both types of populations to total escapements over time.

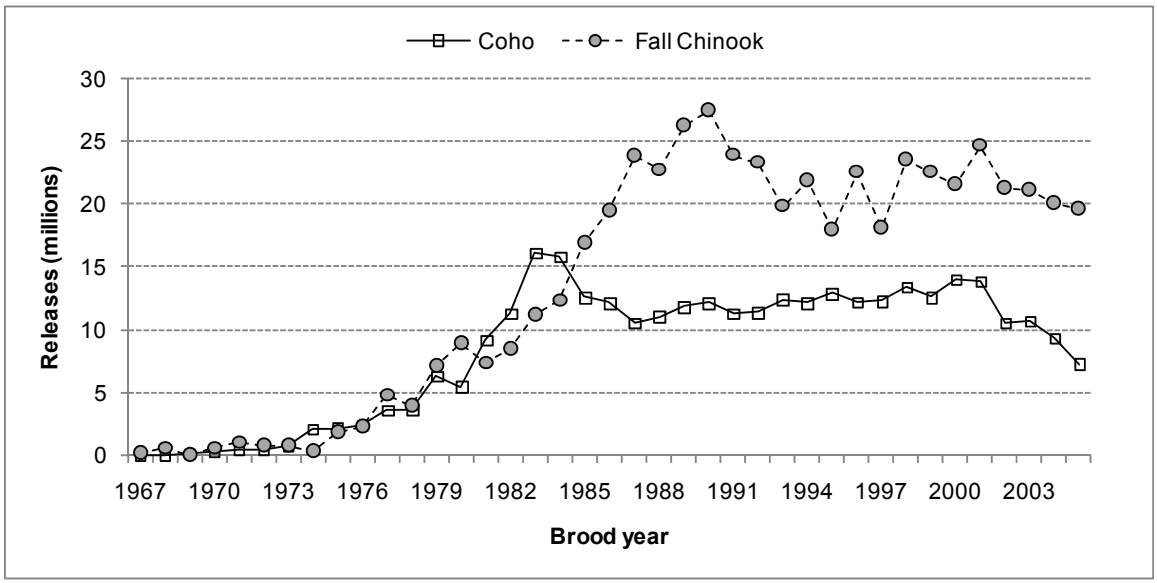
FIGURE 4.11. Percent of streams in the Strait of Georgia region with coho spawners that were surveyed during 1953–2006.
Groups based on mean escapement levels (peak >500 or <500 during any period).



Another factor confounding the assessment of natural production trends is the uncertain effect of regional enhancement activities. Major enhancement work had been conducted around the Strait of Georgia during the past 40 years. Since the early 1980s, nearly 200 enhancement initiatives have aimed to increase coho production. These involved large hatcheries, smaller community hatcheries, side channel restoration, and sea-pen rearing. Returns to natural systems (excluding large hatcheries) are included in Table 4.2, with at least one third of the large systems associated with enhancement activities. Consequently, the trends may not be representative of those of coho streams lacking enhancement benefits.

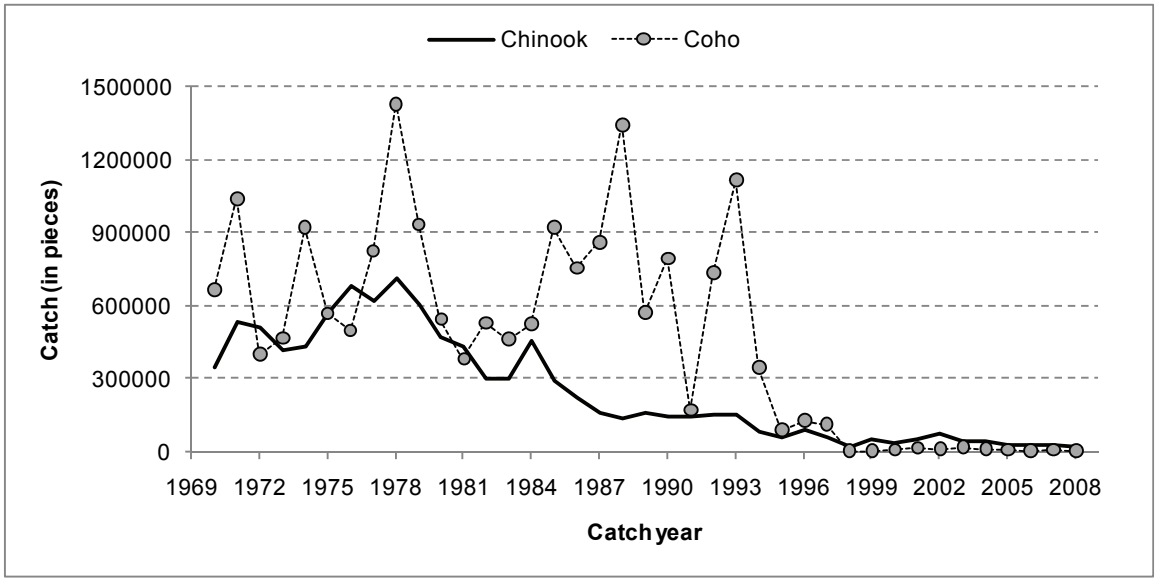
During the past 40 years, broodstock from natural and enhanced runs has been used to supply hatcheries with fertilized eggs that are reared to different stages before release. These include eyed eggs, fed fry in rivers, fed fry in lakes, smolts in streams, smolts in estuary seapens, and unfed fry in streams or channels. Fall chinook releases can be grouped into similar categories plus 'yearlings' (smolts >12 mo old, instead of <6 mo). Quantifying total output requires transforming the numbers by category into a single production index, or typically, 'smolt equivalencies' using conventional bio-standard functions. Using the categories defined in the Oceans, Habitat and Enhancement Branch (OHEB) database, coho releases in the Fed Spring, Fed Fall and Seapen categories were used to generate annual smolt production figures. For fall chinook releases in the categories Smolt 0+, Chan Fry, Seapen 0+, Fed Spring, Smolt 1+ and Fed Fall were used. Figures for some OHEB categories were not used to compute total production because they were minor or could not be converted with certainty. For coho, these included Unfed, Egg Plnt, Nat Fry, Nat Smlt, Nat Unfd, Chan Sm and Chan Fry. For chinook, they included Unfed, Nat Unfd, Nat Smlt, or Egg Plnt. Because of the omissions, the actual coho and chinook production may exceed the annual figures obtained, which nevertheless amounted to >10 million chinook and >20 million coho for most years since 1980 (Fig 4.12). In spite of large and sustained levels of enhancement activities, coho and chinook escapement levels continued to decline, so the Strait of Georgia troll fishery was severely curtailed in 1994, and limits were imposed on recreational catches. This lead to a 100 fold reduction in coho catches and a 30 fold reduction in chinook catches by the late 1990s (Fig. 4.13).

FIGURE 4.12. Hatchery production of chinook and coho around the Strait of Georgia, 1967–2005.
Release figures are in smolt equivalencies. Ocean entry year is brood year +1 for chinook, and brood year + 2 for coho.



To supplement data on natural populations, a juvenile coho survey program was initiated in 1991 to monitor the density and size of coho in streams within this region during the early fall. A positive relation was detected between spawning levels and juvenile density (r^2=0.57, n = 10 years, Simpson *et al.* 2001). Existing figures on those two variables are not considered to be accurate, and the relationship is not strong, but as the data series expands, this monitoring method may prove to be a useful and cost effective way of tracking production levels.

FIGURE 4.13. Chinook and coho catches in the Strait of Georgia troll and recreational fisheries, 1970–2008.



Despite having longer and more complete data time series on some stocks, the state of many natural coho populations and the impacts of enhancement activities remain uncertain. Indicator stocks can provide valuable information on trends in freshwater productivity (smolts produced per spawner), survival rates, marine distribution and exploitation patterns, all of which are used to set conservation and fishery management targets. However, there are too few or no indicator stocks in some regions, and even in small regions, an indicator stock does not always accurately reflect the condition of adjacent populations (Labelle *et al.* 1997). And while the catch contribution of coho produced by Canadian hatcheries around the Strait of Georgia exceeded 70% in recent years (Sweeting *et al.* 2003), the combined catches and escapements have decreased. It was hypothesized years ago that hatchery production could potentially replace natural production, in part because enhanced stocks might be able to tolerate greater exploitation rates (Argue *et al.* 1983). Alternative hypotheses are that hatchery coho can outcompete wild coho for forage, and severely reduce the forage base accessible to wild coho, because very large numbers of hatchery coho are released during short periods. This has led some to speculate that the negative impacts of hatchery coho on wild coho are more severe during periods of low marine survival. The contribution of hatchery and non-hatchery coho in the Strait of Georgia is being monitored, and there are ongoing investigations to identify the cause-effect mechanisms accounting for negative interactions, include the timing and size-at-release strategies used by large enhancement facilities. The broader issue of finding ways of maintaining some fishing which while meeting the conservation and biodiversity requirements of the WSP is also being addressed.

The Council has consistently supported a precautionary approach to management of Strait of Georgia coho to ensure that natural populations can fully utilise natural habitats. It suggests a focus of attention to future requirements for coho in the region by:

- Establishing a scientifically credible assessment framework for naturally-spawning coho populations, including monitoring of hatchery reared coho contributions to these systems (supplementation + straying);
- Maintaining or conducting new research activities on the plausible impacts of enhancement operations on natural coho populations;
- Making further efforts to stop and reverse well documented salmon habitat degradation caused by past ongoing development activities in the Strait of Georgia region; and
- Reviewing the Strait of Georgia Creel Survey Program methods to ensure that it can still provide reliable estimates of exploitation (and thus survival) under conditions of low returns, negligible catches per boat trip, reduced tagging efforts and tag reporting rates (consequences of the recently implemented mass marking program).

4.4. STRAIT OF GEORGIA CHINOOK

Chinook utilize many of the medium to large rivers in the Strait of Georgia region and are produced extensively in hatcheries and spawning channels. Chinook populations in this region have one of four life histories, two of which still exist in only one population.

- Spring-run adults enter their natal streams in spring-summer, spawn in the fall, eggs hatch in the spring and leave as smolts one year or so later (Nanaimo River);
- Summer-run adults enter their natal streams mid-summer, and smolts migrate to sea 12 months later (Puntledge River);
- Mainland Inlet summer-run adults enter their natal streams June–August, and smolts leave after 3 or 5 months of stream life (mainland inlet rivers and the Squamish River);
- Fall-run adults enter their natal streams during August to September, and juveniles migrate to sea shortly after a short stream rearing period (3–5 months).

The only remaining spring-run in the Strait of Georgia spawns mainly in the upper section of the Nanaimo River, but it is not known if others still use tributaries to large mainland inlets. The Nanaimo River population has not been subject to a rigorous assessment, so its state is mainly determined on the basis of annual escapement surveys. The population has been rebuilding slowly since the 1990s (Fig. 4.14).

With regards to summer-runs, one major population still uses the Puntledge River. Its production was likely affected by the Comox Dam completed during the 1950s, but likely increased after the construction of a spawning channel in 1965. Escapements have been increasing since the mid-1990s, and lately exceeded those observed historically (Fig. 4.15).

FIGURE 4.14. Total escapements (adults + jacks) of spring chinook to the Nanaimo River, 1979–2007.
Numbers consist of river spawners + brood removals, from both natural and hatchery production.

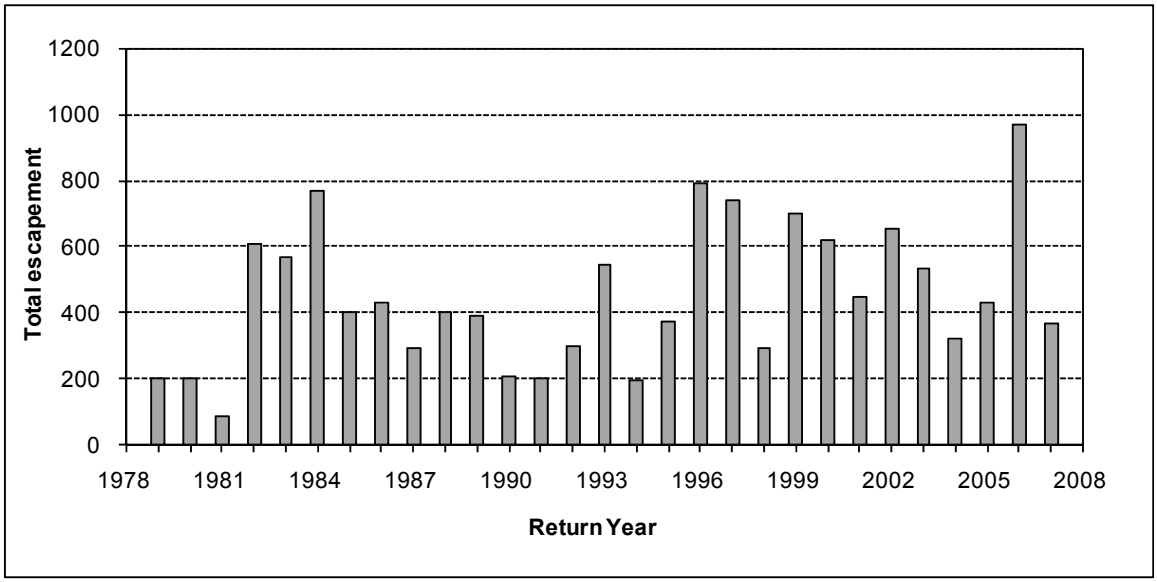
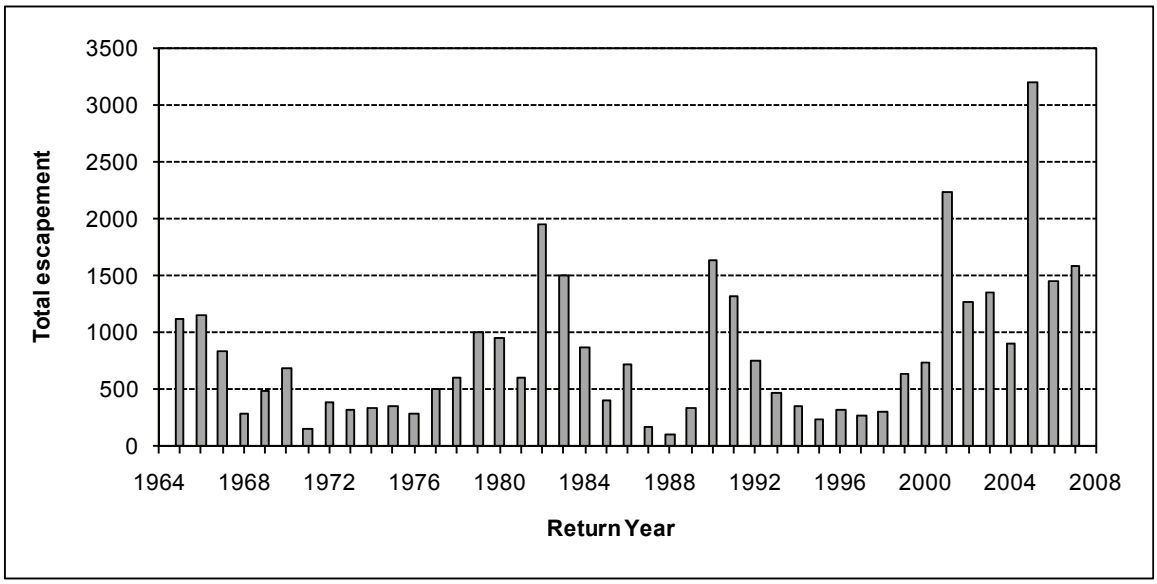


FIGURE 4.15. Total escapements (adults + jacks) of summer chinook returning to the Puntledge River, 1965–2007.
Numbers consist of spawners in the river and spawning channel, plus brood removals.

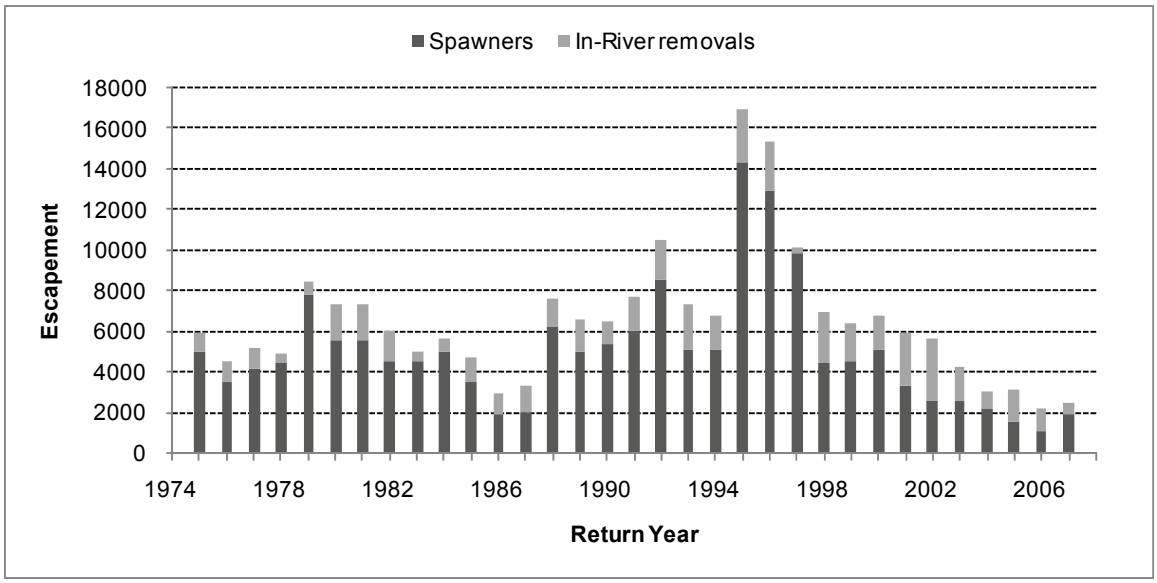


It has been hypothesized (as usual) that improvements are due to changes in ocean conditions. However, it has also been noted that a Harbour seal population foraging in waters surrounding the Puntledge River hatchery has been rebuilding since being given 'protected' status in the 1970s under the Fisheries Act. It is known to prey on both juveniles and adult salmon in/around the Puntledge River estuary, and prefers [supposedly] large chinook. There have been debates about the need to control seal predation losses, but this implies that seals cause more losses to salmon than to their predators (including other fish species). Accounting for predation losses (seals or other predators) would reduce the uncertainty, and may help identify the major determinants of return rates.

A natural, fall-run used to exist in the Puntledge River, but disappeared in the mid-1980s, perhaps due to over-exploitation and habitat loss in the lower sections of this system. Another fall-run was re-introduced since then, using brood stock from fall-runs in the Big Qualicum and Quinsam rivers. Fall-runs provide most of the production from the Strait of Georgia tributaries, which include many systems subject to hatchery supplementation. One major population uses the Cowichan River (Fig. 4.16), which has been subject to numerous hatchery rearing projects and enhancement activities since the early 1980s.

The most northerly fall-run uses the Nimpkish River. Historically, it comprised three spawning aggregations; at the outlet of the lake; at the outlet of the Anutz/Atluck sub-basin (flows into Nimpkish Lake); and in the Woss and upper Nimpkish rivers (Weinstein 1991). Only the latter group still exists. Recent records indicate that a few hundred spawners use this area, which is much less than the historical escapements to this river.

FIGURE 4.16. Total escapement of fall chinook to the Cowichan River, 1975–2007.
In-river removals include First Nation food fishery catches and hatchery brood stock collected since 1979. Dark bars represent natural spawners only.



Based on the distribution of coded-wire tagged chinook salmon caught, it has been hypothesized that this 'unique' population only occurs in central BC. Efforts have been made to restore production through a hatchery program, but recent survey records do not indicate significant improvements in escapement levels.

Information on mainland inlet summer runs is not abundant, even for the Squamish River. Many inlet tributaries are glacially-fed rivers with peak flows occurring during the chinook escapement periods. Such conditions do not facilitate escapement monitoring. Recently implemented survey operations in the Klinaklini River (and Devereux tributary) indicated spawning levels of about 10,000 adults/year since 1998, or much lower than the historical records of total escapement to the Squamish River.

Managing chinook salmon fisheries is a complex process given the variety of life history types, ocean distribution patterns and maturation schedules that affect the sizes and compositions of spawning populations. Chinook feed in the ocean for between two and five years and can migrate up to Alaskan waters. Their extensive migrations coupled with years of ocean rearing make them susceptible to interception by numerous fisheries, and their cumulative fishing mortality impact. The Quinsam fall-run and mainland summer-run populations spend little time in the Strait of Georgia after entering the ocean, and migrate further north than other runs. They are extensively exploited in Alaskan and northern BC fisheries, and along the coast as they return to spawn. By contrast, fall-runs from the south-east coast of Vancouver Island and the Puntledge summer-run tend to rear mostly in the Strait of Georgia. Based on tag returns from winter sport fisheries, it has been hypothesized that a portion of these never leave the Strait of Georgia, while others move north and are harvested in central and northern BC fisheries.

Many coastal fisheries traditionally harvested a mixture of stocks and year classes. Fishery-specific impacts are not easily dissociated, but the overall impact increased to relatively high levels until management regulations were introduced during 1980s (Walters and Riddell 1985). Based on coded-wire tag records, total exploitation rates on fall-run hatchery stocks were estimated to be 70–80% through the 1980s (Fig. 4.17a,b). In those figures, year is expressed as the spawning or 'brood' year, since chinook can be caught over several successive years. Fall-run chinook spawning in 1990 would produce juveniles that go to sea in 1991, and return as adults to

spawn during 1992–1996. Although the above stocks differ in their ocean distribution, they have been subject to similar changes in exploitation due to broad scale fishery management actions.

FIGURE 4.17a. Total exploitation on coded-wire tagged stocks from tributaries to the Strait of Georgia. *The labels are BQR = Big Qualicum hatchery, QUI = Quinsam hatchery in the Campbell River, and PPS = summer run Puntledge River.*

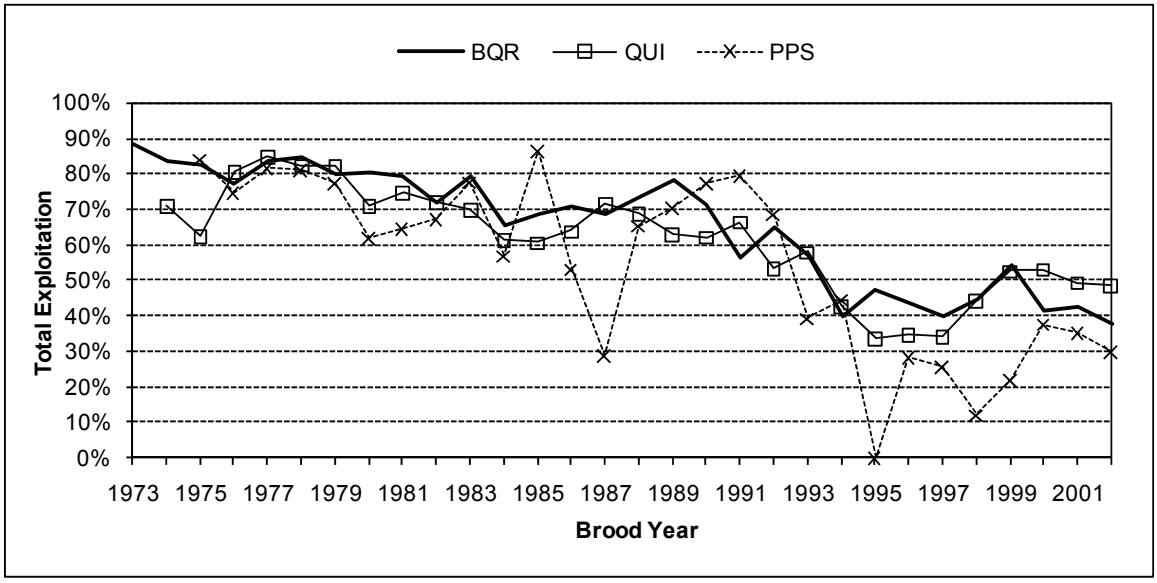
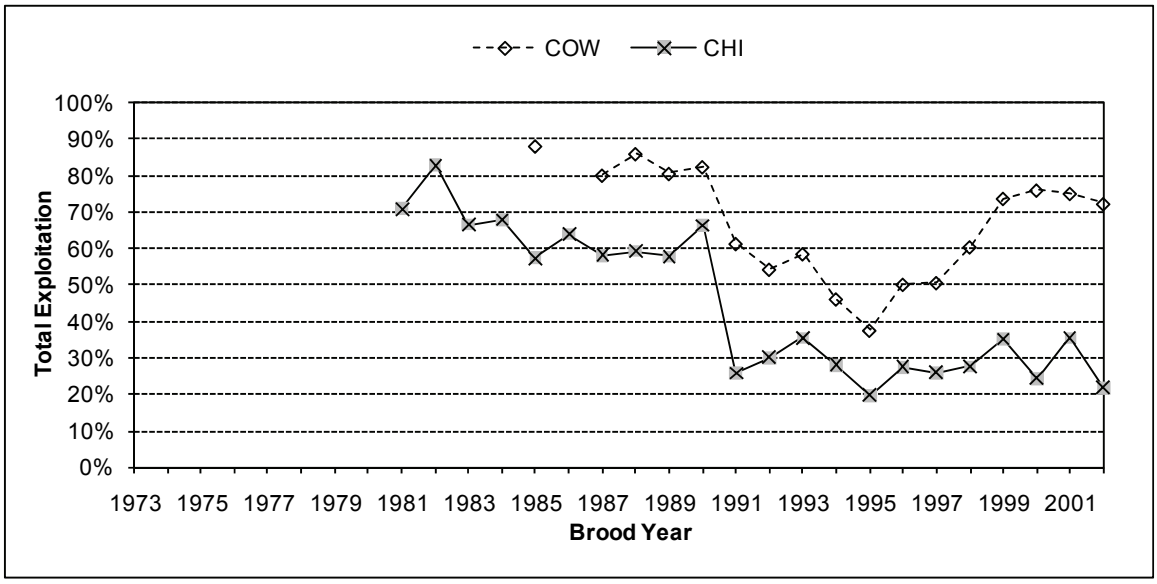


FIGURE 4.17b. Total exploitation on coded-wire tagged stocks from tributaries to the Strait of Georgia. *The labels are COW = Cowichan fall run, CHI = Chilliwack hatchery fall run white-fleshed chinook Harrison River brood stock.*



Major changes in allowable exploitation rates followed the implementation of the 1985 Pacific Salmon Treaty, and the associated 1999 amendments. Large reductions in exploitation rates during the late 1990s resulted from lower abundances in the Strait of Georgia, the closures of ocean troll fisheries, and the mandatory release of chinook caught in Canadian net fisheries. However, the justification for increased harvest rates on Cowichan River chinook since the late 1990s is unclear, but might be associated with the need to maintain recreational fishing opportunities in the Strait of Georgia and the approach waters.

Management of chinook fisheries must account for changes in marine survival. During the past thirty years, survival rates (adult production divided by the number of juveniles released) varied considerably, ranging from 0.08% for the Puntledge River 1992 brood, to 30% for the Harrison River 1981 brood (Fig. 4.18a,b).

FIGURE 4.18a. Marine survival of the chinook indicator stocks.
Gaps indicate figure not available.

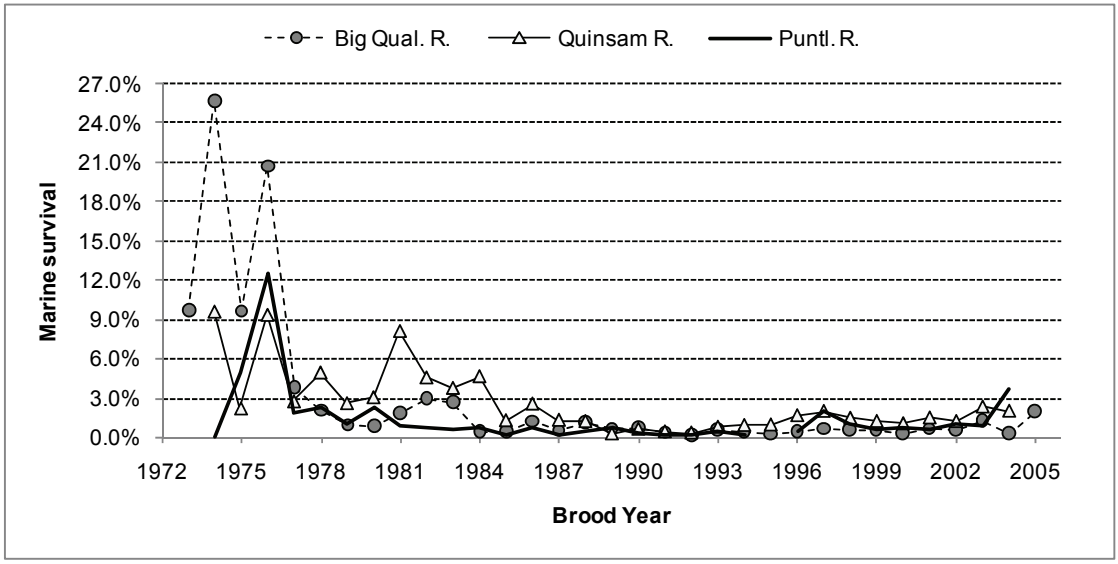
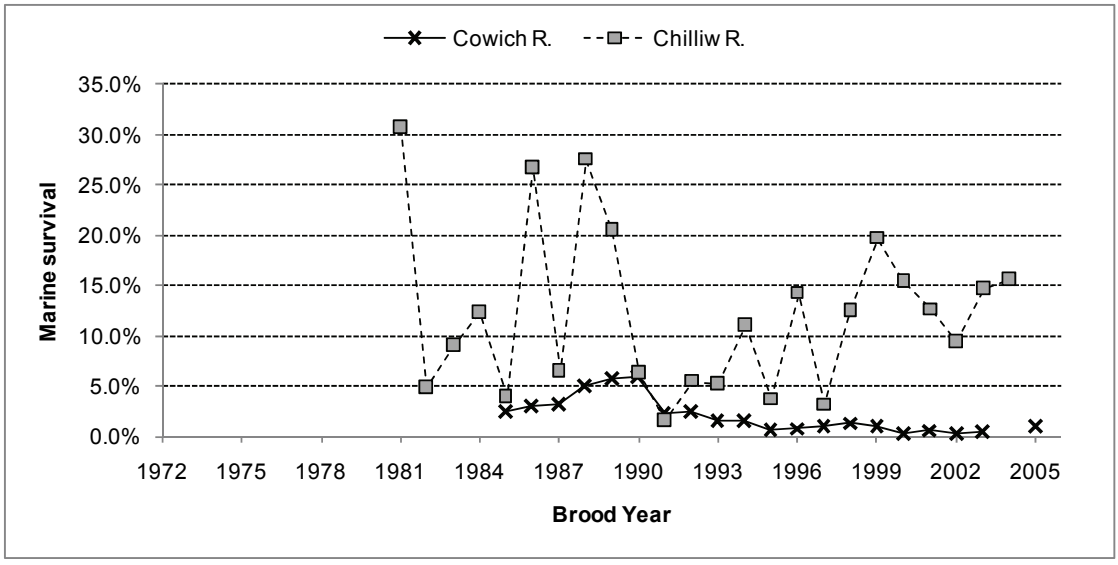


FIGURE 4.18b. Marine survival of the chinook indicator stocks.
Gaps indicate figure not available.



Stocks from the east coast of Vancouver Island show similar trends, and are intercepted in the same fisheries north of their stream of origin. Survival rates were very low during a 15 year period, but appear to be improving slowly. Chilliwack River chinook have different survival patterns, but use the lower Fraser River, rear for some time in a large estuary, and have a more southerly marine distribution than the above stocks (caught mainly in Washington State, west coast Vancouver Island, and southern Georgia Strait).

Reductions in ocean exploitation (due to fishery management changes) have allowed for some escapement each year despite the very low marine survival rates. DFO will likely consider imposing further harvest constraints if marine survival rates do not improve. There are obviously substantial uncertainties that remain about the condition of stocks using mainland inlets. Most of the tributaries are glacial rivers with very high sediment loads and braided channels that can potentially support large populations. The Devereux River in the Klinaklini drainage has relatively clear water which facilitates monitoring, but it may not be a good indicator of stocks using the main river channels. Setting up a systematic monitoring program for many large river channels would be costly, but would help determine and adjust the exploitation rates on neighbouring summer-run stocks.

There are also substantial uncertainties about the state of the Squamish summer-run. Mature adults return to the Strait of Georgia in mid-summer, and are susceptible to harvest in local fisheries until they enter Howe Sound. The Squamish basin is potentially the largest production area in this region. DFO has funded tagging operations on juvenile chinook released from the Tenderfoot Hatchery. But current assessments of the Squamish River stock assemblages are inadequate to effectively manage this potentially important population and significant resources would be required to improve the current situation.

The Council notes that some 'unique' chinook stocks still exist in this region, namely the Nanaimo River spring-run, the Puntledge River summer-run, and depressed Nimpkish River fall-run. The state of stocks using large mainland inlet tributaries is uncertain due to limited assessments. Wild and hatchery reared fall-run stocks continue to provide most of the production in the Strait of Georgia, but hatchery production may exceed natural production and increase the difficulty of managing mixed-stock fisheries impacting wild runs. Sustained chinook production requires continued [or increased] protection of freshwater and near-shore marine habitats, as well as rigorous controls of fishing impacts. There is currently only one indicator stock for natural runs from the Strait of Georgia, with most monitoring programs largely dependent on hatchery releases subject to coded-wire tagging. But given substantial variation in marine survival, plausible climate change impacts on fresh water rearing conditions, and hypothesized differences between wild and hatchery stocks, the Council recommends that a scientifically defensible monitoring program be implemented for wild stocks, and in accordance to the recommendations of the Wild Salmon Policy.

4.5. STRAIT OF GEORGIA CHUM

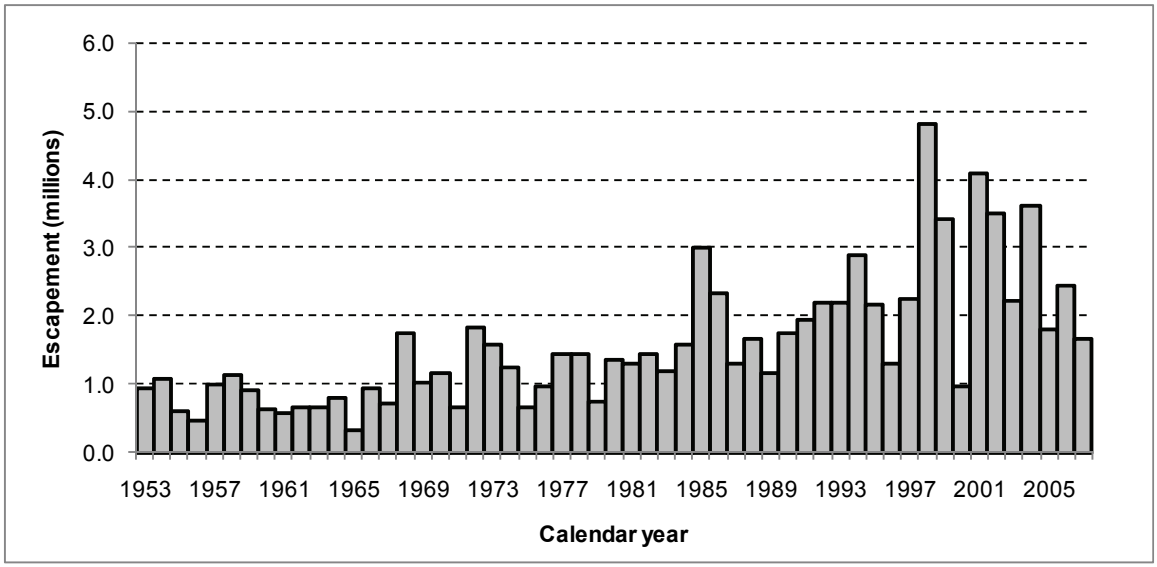
As noted in the Fraser River section, chum salmon in southern BC are managed as a large spatial aggregate of populations, and the absence of stock-specific catch estimates limits the assessment of population status. Populations from northern Vancouver Island, mainland inlets, the Strait of Georgia, the Fraser River, and the Juan de Fuca Strait make up the Inner South Coast (ISC) grouping. This area includes >400 populations, of which 10% of these account for most of the production, with the Fraser River having the largest populations (Ryall *et al.* 1999, Anderson and Beacham 1983).

The ISC group covers 15 regions that are monitored each year. The most northern region (Seymour/Belize Inlet) and the most southern regions (South Vancouver Island) regions are not part of the "Inner Study Area" (ISA) sub-group. Populations from the first two regions are not harvested in the Johnstone Strait, Strait of Georgia or Fraser River fisheries, that are managed under the "Clockwork" plan since 1983 (Hilborn and Luedke 1987), and

the Fraser River plan since 1987 (Gould *et al.* 1991). These plans set allowable harvests based on in-season run size estimates and escapement objectives. Allowable harvests were lowered when run sizes were small, and increased when they were large, so the populations could rebuild while maintaining at least minimum fishing opportunities. Ryall *et al.* (1999) provides details on these populations, the supported fisheries, and the enhancement programs conducted up to 1997.

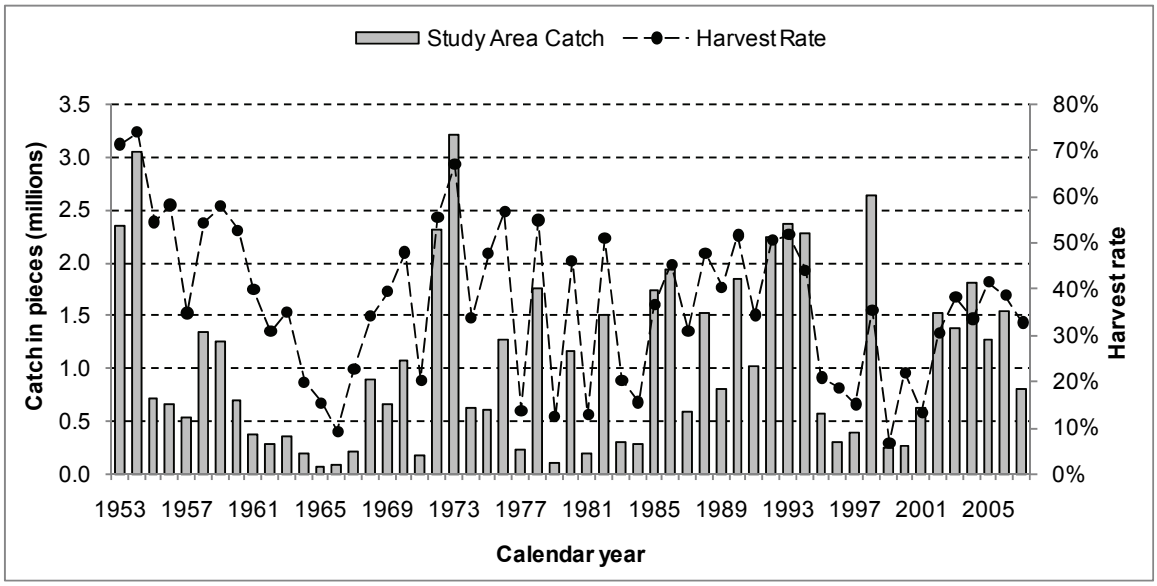
The implementation of the Clockwork plan lead to increased escapements (Fig. 4.19) until about 1998, but these decreased since then to pre-Clockwork levels.

FIGURE 4.19. Trends in total chum escapements for the ISA grouping (defined in text).



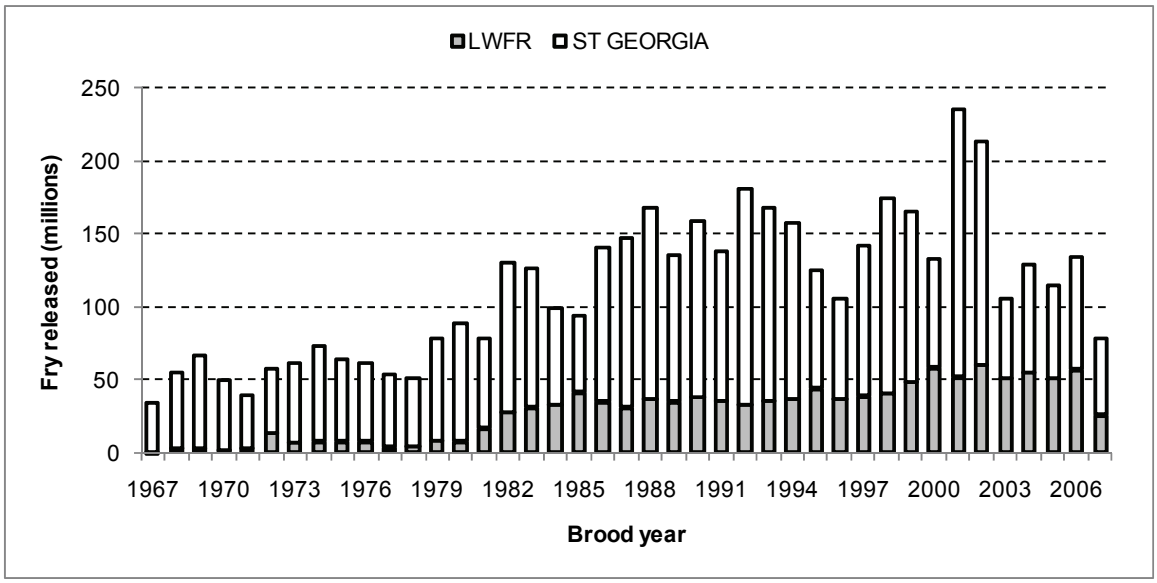
Annual harvest rates on ISA populations varied considerably since the 1980s (Fig. 4.20). The period of peak escapements corresponds to that of low exploitation rates during the late 1990s, and the recent period of reduced escapements corresponds to that of increased exploitation. Recently, the Clockwork plan was replaced by an alternative fixed harvest rate strategy (~20%, PSC 2008) supposedly because the data requirements of the Clockwork plan could not be met given the recent funding cutbacks. However, the relative merits of this new plan have yet to be determined. It should also be noted that the apparent link between exploitation rates and escapement levels is not clear as it does not account for the effects of concurrent changes in hatchery production.

FIGURE 4.20. Trends in total chum catches and harvest rates of the ISA grouping in US and southern BC fisheries.
Annual harvest rates expressed as the percent of total return (catch + escapement).



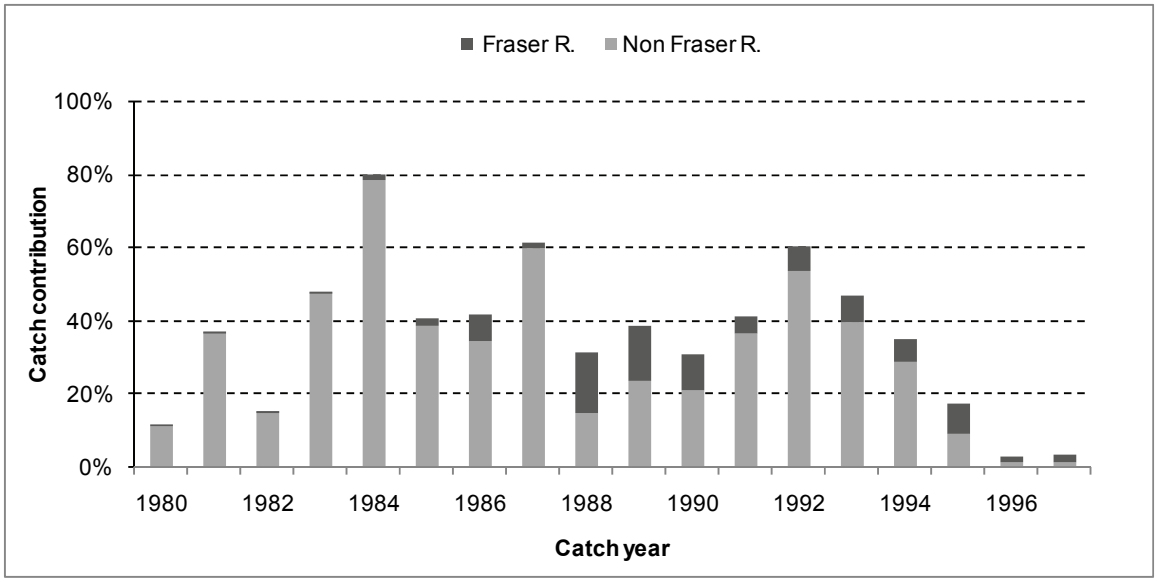
The first major chum enhancement project was one the Big Qualicum River and was aimed to increase egg-fry survival by means of an artificial spawning channel and controlled flows. This involved limiting the access of mature adults to the spawning channels to maximize production. Most of the progeny (unfed fry) left the channels as fry soon after hatching, but some were held and fed for a few weeks before allowed to leave (fed fry). As noted earlier, the survival of fed fry was about twice that of unfed fry, but despite this, most of the production still consists of unfed fry. Releases from all ISA facilities combined exceeded those from the Lower Fraser river facilities (Fig. 4.21), but one must account for differences in survival rates to determine their respective contributions to commercial catches.

FIGURE 4.21. Total release of chum fry (fed + unfed) into the Strait of Georgia.
Releases grouped by production region, namely the lower Fraser River (LWFR), and other areas around the Strait of Georgia.



Ryall *et al.* (1999) estimated that the ISA enhanced chum production contributed substantially to the net fishery catches during 1980–1997, the last reported year for which estimates were generated (Fig. 4.22).

FIGURE 4.22. Contribution of enhanced chum production to Clockwork managed fisheries harvesting ISA populations, 1980–1997.
From Ryall et al. 1999.



Contributions to spawning escapements are uncertain, because the vast majority of non-enhanced stocks are not routinely surveyed, and the proportion of hatchery strays is unknown, and are likely influenced by fishery removals. Terminal fisheries on enhanced stocks have been justified as a way of reducing impacts on natural populations. These include those targeting chum returning to the Big Qualicum and Puntledge River facilities, and Fraser River populations with middle run-times. Given the magnitude of chum releases and the potential for mixed-stock harvest impacts on naturally produced chum in the ISA grouping, the current status of the natural populations cannot be assessed with certainty.

Ryall *et al.* (1999) highlighted deficiencies in the escapement monitoring procedures that limit the scope and depth of stock status assessments. The authors expressed concerns about the reduced geographic coverage of the surveys, and inconsistencies in the survey procedures. Some of these were noted in the 2002 PFRCC report, and will not be re-iterated here. Suffice to say that by 1997, <10% of the streams were monitored each year than during 1953, recent monitoring efforts declined to <40% of the 1985 levels, with fewer and different populations contributing to total escapement in recent years.

Using the data presented in Ryall *et al.* (1999), and recent survey records, the current status of the spawning escapements for chum salmon in the fifteen geographic areas that comprise the ISC chum stock aggregate was summarized (Appendix D, Table D.1). While it is not possible to assess the status of these populations based only on escapement records, the summaries are a source of concern. Spawning escapements of ISC chum stocks are not all increasing nor stable, but this could be expected given the large geographic area occupied by the population aggregate. Nine regions show signs of improvement, particularly since the 1990s. One region shows signs of reduced abundance, and five regions show no clear trends, largely due to insufficient or inconsistent survey coverable. There are no clear trends for many small to mid-size populations in most regions for recent periods due to reductions in survey coverage.

The summary does not include “summer” stocks. One of these returns in July to the Ahnuhati River (Knight Inlet), while the other returns in August to the Orford River (Bute Inlet). Returns of Ahnuhati River decreased until the 1990s, but those to the Orford River increased until over the same period. Survey records indicate some relatively high escapements in the 1980s, but no clear trend can be established over 1953–2007 for lack of data. They are the most southerly summer run chum populations known in BC, but despite this uniqueness, they are not surveyed regularly, and not subject to special conservation initiatives.

The PFRCC notes that the detailed assessment reported by Ryall *et al.* (1999) is most informative, should be updated periodically. The ISA populations seemed to be rebuilding until 2001, under stable hatchery production and declining exploitation rates. Since then, hatchery production has declined, exploitation rates increased, and escapements are declining again. One might conclude that the natural populations were not allowed sufficient time to rebuild before harvest rates were allowed to increase again. Even recent rates might not be sustainable under current environmental conditions without stable or increased enhancement efforts.

The Council highlights the lack of even crude trends in escapement for many populations in the ISA grouping that are largely due to reductions in survey coverage and periodicity. As noted earlier, assessment problems caused by insufficient and inconsistent escapement surveys in other coastal regions have been recognized (see Price *et al.* 2008), and for similar reasons, those used in this region should be improved so standard methodologies can be relied on to provide scientifically credible escapement indices in a consistent fashion. Ideally, new and improved monitoring procedures should be established shortly so as to provide adequate data for each CU, as required by the new WSP.

5. WEST COAST OF VANCOUVER ISLAND

The West Coast of Vancouver Island (WCVI) is a rugged barrier that shelters the inner Strait of Georgia region from Pacific storms (Fig. 1.2). This region includes hundreds of relatively short and steep rivers from Port Renfrew to the northern tip of Vancouver Island. It has a relatively low human population density, but has experienced substantial habitat impacts caused by human and industrial developments. There are substantial environmental differences between the WCVI and the ECVI. The marine environment off the WCVI is a dynamic and productive ecosystem that is a major determinant of salmon production in this region. There are also pronounced climatic differences between the two regions. Annual rainfall on the WCVI is 3–4 times greater than at comparable locations on the ECVI (Fig. 5.1a,b).Relatively large precipitations over steep basins can have major impacts on salmon movement and survival patterns. Extreme events tend to be more pronounced and more frequent on the WCVI and are major determinants of stock productivity. Add to this the greater productivity of marine environments off the WCVI, relative to those inside the Strait of Georgia, and a distinction between the WCVI and the Strait of Georgia populations is obviously necessary.

FIGURE 5.1a. Average monthly precipitation on the east coast (Nanaimo) and west coast (Tofino) of Vancouver Island.
Figures based on the 1971–2000 Environment Canada records obtained at similar latitudes and elevations.

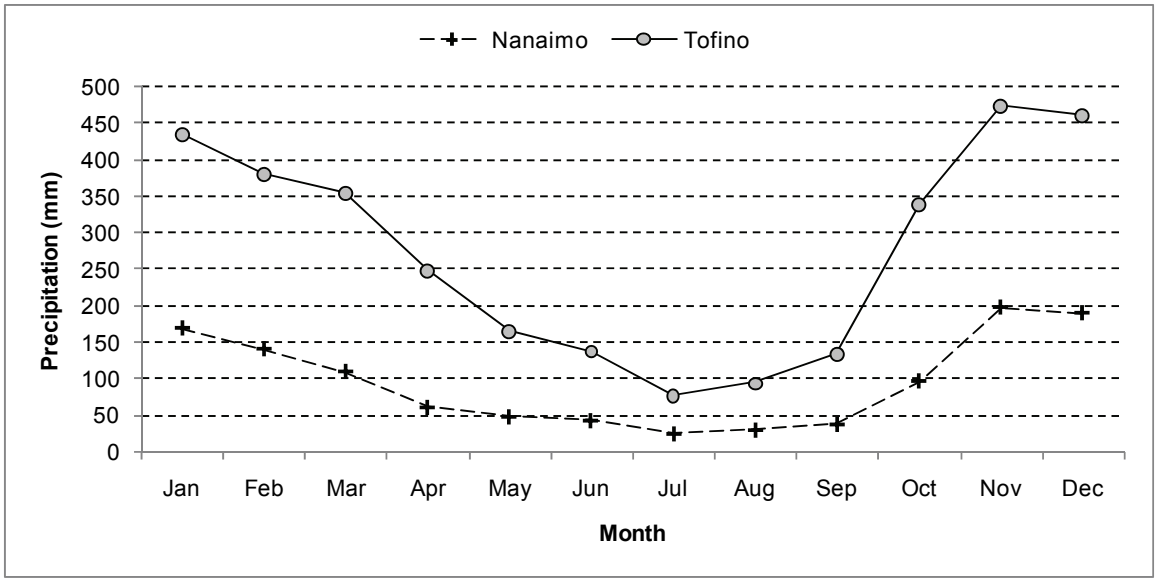
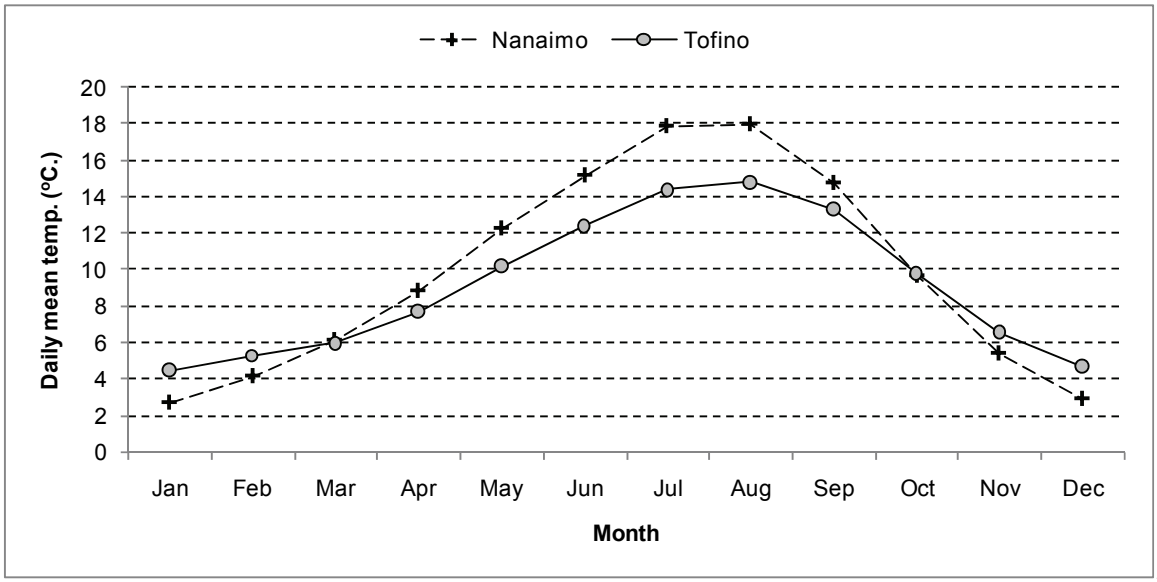


FIGURE 5.1b. Average daytime temperatures, by month, on the east coast (Nanaimo) and west coast (Tofino) of Vancouver Island.
Figures based on 1971–2000 Environment Canada records obtained at similar latitudes and elevations.



5.1. WCVI SOCKEYE

Sockeye production on the West Coast of Vancouver Island is influenced by factors that do not have similar effects on those of other systems in the Fraser River and the Strait of Georgia. WCVI sockeye are produced in many lake systems, but are also common in rivers without lakes. Available escapement records indicate that sockeye occupy 75 streams and lakes, but only half of these are "typical" systems that include a rearing lake. Most of the latter are in the central portion of the WCVI region, north of Clayoquot Sound. The major stocks along the WCVI are from the Barkley Sound basin, with juveniles rearing in Henderson, Sproat, and Great Central lakes. A very productive population used to utilise Kennedy Lake before the 1950s, but has declined to very low levels since then.

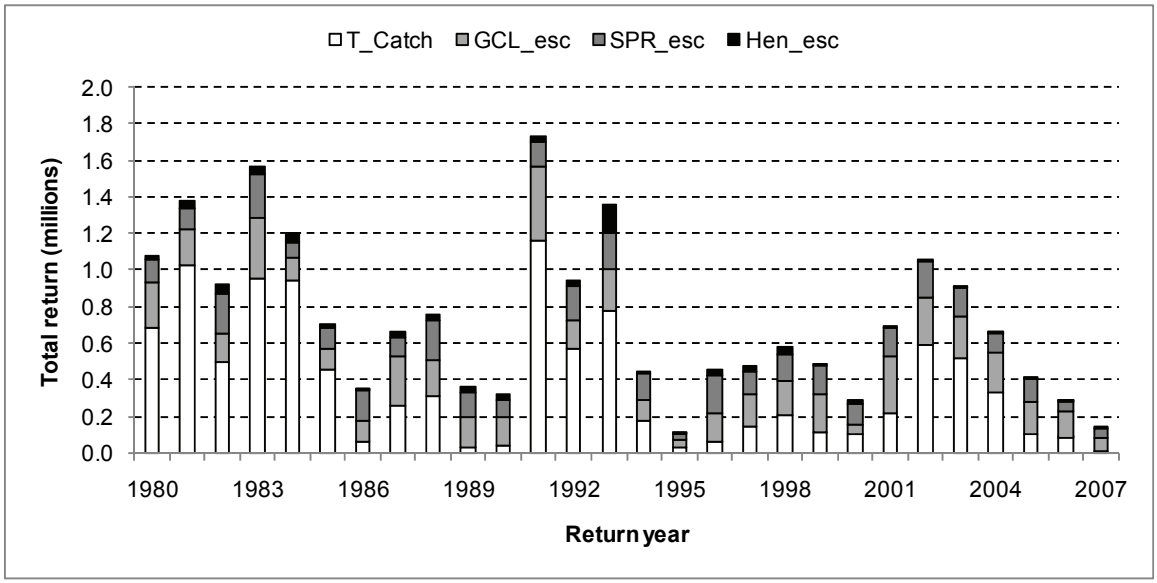
Hyatt and Steer (1987) documented the history and features of the Barkley Sound sockeye production system over the past century. The Henderson Lake hatchery (once known as the Anderson Lake hatchery) was one of Canada's first hatcheries, and operated during 1910–35. It mainly produced sockeye to supplement natural production from Henderson Lake, but during 1922–33, it also served to facilitate sockeye egg collection and transfers from Sproat and Great Central lakes to other systems. Efforts were made to increase sockeye production via other means like building water control dams and fishways, and more recently via a large lake enrichment experiment. The latter was largely supported by an apparent relation between adult salmon returns and subsequent productivity in freshwater lakes (Stockner 1987). In years of low adult returns, it is hypothesized that fewer nutrients remain in the lake from decomposing carcasses, which reduces forage production for the juvenile produced. This implies that large fishery impacts on returning adults can also cause reduced growth and survival of juveniles, and in turn, influence future production. Nutrient loading was proposed as a way to compensate for the loss of carcasses partly caused by fishing impacts.

Enrichment experiments started in Sproat and Great Central lakes, and were conducted during 1969–73 mainly in the latter system. LeBrasseur *et al.* (1978) noted that summer primary production increased five-fold, zooplankton production increased nine-fold, egg to juvenile survival increased 2.6 times, and adult production

increased from less than 50,000 spawners in the spawning years, to over 360,000 in the return years. Based on these results, lake enrichment operations were initiated in other BC lakes as part of the DFO Salmonid Enhancement Program (SEP). The experiments showed that nutrient loading could increase juvenile survival and growth, and that recent production levels from Sproat and Great Central lakes might increase if more adults reached the spawning grounds. Escapement goals were subsequently raised to >100,000 sockeye per lake. Production levels in many years since then exceeded those of the 1970s, but varied considerably perhaps due to changes in ocean conditions (Fig. 5.2).

Recent escapements to Henderson Lake have declined to relatively low levels for reasons that are not known with certainty. Following a meeting of the PSARC committee in 2002, the DFO initiated a review of the status of the Henderson Lake stock to set new escapement goals and determine conservation measures to reduce fishing impacts on this stock. Escapement levels continued to decline to an average of about 3,000 spawners per year since 2003. An recent assessment of exploitation rates on three major Barkley Sound populations over 1997–2007 (Labelle 2009) indicate that Henderson sockeye were subject to exploitation rates averaging about 12% since 1997, with a peak of 23% in 1998.

FIGURE 5.2. Total sockeye returns of Barkley Sound sockeye.
Figures include escapements to each lake, plus combined catches of each stock in the Barkley Sound inlet.



Only in 1997 and 1998 were Henderson sockeye subject to exploitation rates similar to those of Great Central and Sproat sockeye. Exploitation rates on the latter two stocks tended to be 2–3 times greater (17–60% over all years). These preliminary results suggest it is unlikely that the depressed state of Henderson sockeye is mainly caused by over-exploitation in recent years.

While the Barkley Sound populations remain the largest component of the WCVI sockeye production, there are other smaller stocks with similar life history patterns (i.e., rear in lakes for one year before going to sea). Few of these are monitored as well as the Barkley Sound stocks, and the abundance of many has declined to levels lower than in the 1950s and 1960s. The state of WCVI sockeye populations with access to rearing lakes has been summarized using mainly information from escapement survey records (Table E.1, Appendix E). Not all lake populations have been bio-sampled, so the level of genetic distinctiveness among these is not known with certainty. Evidence from various investigations in North America suggests that each of these is distinct to some

extent, with little exchange between adjacent systems. Should this be the case, maintaining viable populations in each system will be required to protect the genetic diversity of this population assemblage.

A few of these systems are subject to annual monitoring and assessment, such as Hobiton and Kennedy Lake, but historically, these were somewhat superficial and infrequent, which precludes an in-depth evaluation of their recent state relative to past states. In recent years, the DFO has been relying on the additional assistance of First Nation technicians to provide more survey data on the abundance of many WCVI populations, but it remains to be shown that the survey data provide anything more than a basic index of bio-diversity.

The above comments apply mainly to a 'typical' population using a river connected to a large lake, i.e., a lake-rearing population. However, there are many others with different life histories. Some rear in larger rivers, but the frequency of rearing in small-to-moderate size streams along the WCVI is unknown and somewhat uncommon in other southern BC regions. It has been hypothesized that the spawners are strays from other populations. In areas such as Barkley Sound, where very large populations have developed, strays might account for the small numbers of sockeye observed in the Sarita, Nahmint, Franklin, and Effingham rivers. But this does not explain why sockeye are found in tributaries to other inlets lacking large runs. For example, in Nootka Sound sockeye are observed in all salmon bearing tributaries, although the only sizeable lake-rearing population is found in Muchalat Lake near Gold River.

In 1997, large numbers of mature sockeye were observed in many tributaries to the Strait of Georgia. Some DFO scientists hypothesized this was caused by an unusual large straying of Fraser River sockeye. Bio-samples were collected in tributaries to the Strait of Georgia and the WCVI. The results supported the hypothesis that some sockeye in the Strait of Georgia tributaries were Fraser River strays, but not those using the WCVI tributaries. Dr. Chris Wood (DFO,PBS) hypothesized the latter might consist of sockeye with "creek-type" life histories, akin to those using rivers with no lake-rearing environments. Further evidence is needed to support this hypothesis, but it would explain why sockeye are found in many habitat types and why productivity varies between years within a system.

The WCVI sockeye populations have a more complex history and diversity than those of other regions. Monitoring efforts limit the depth of assessments on stock status and the available knowledge on the dynamics of this stock aggregate. Many small lake systems seem to have experienced substantial production losses in recent years, and even larger ones subject to regular monitoring (Sproat, Great Central, Hobiton, Kennedy). This may be related to the recent warm phase of the Pacific Decadal Oscillation (PDO) phenomenon. Sockeye stocks are not subject to extensive tagging programs (like coho and chinook) in part because there are no longer any fisheries operating outside the surf line, so uncertainties concerning recent survival and production are now largely due to escapement monitoring limitations and uncertainties about terminal fishery catches.

There are several habitat issues that should be highlighted. Great Central and Sproat Lake sockeye are occasionally subject to high river temperatures causing pre-spawning mortality (as in the Fraser River), and substantial mortality while holding near the river mouth due to low oxygen in Port Alberni harbour from fibre mat sediments from the old pulp mill. A wooden dam near Boot Lagoon on Great Central Lake is in very bad condition, and severe draw-downs are now required to prevent breaching. A recent one in October 2008 is reported to have caused major losses of coho fry rearing in various pools, and sockeye embryos in lake shores.

It should be emphasized there are important opportunities for increasing the production of the WCVI sockeye population. The Nahmint Lake and river system located between Henderson and Sproat lakes constitutes a very large habitat suitable for sockeye reproduction and rearing. If fully utilised, it could yield tens of thousands of sockeye returns per year. Sockeye do not use this system [supposedly] because of steep gradients and falls in the river that block their upstream migration (although not that of steelhead trout). Removing these barriers via

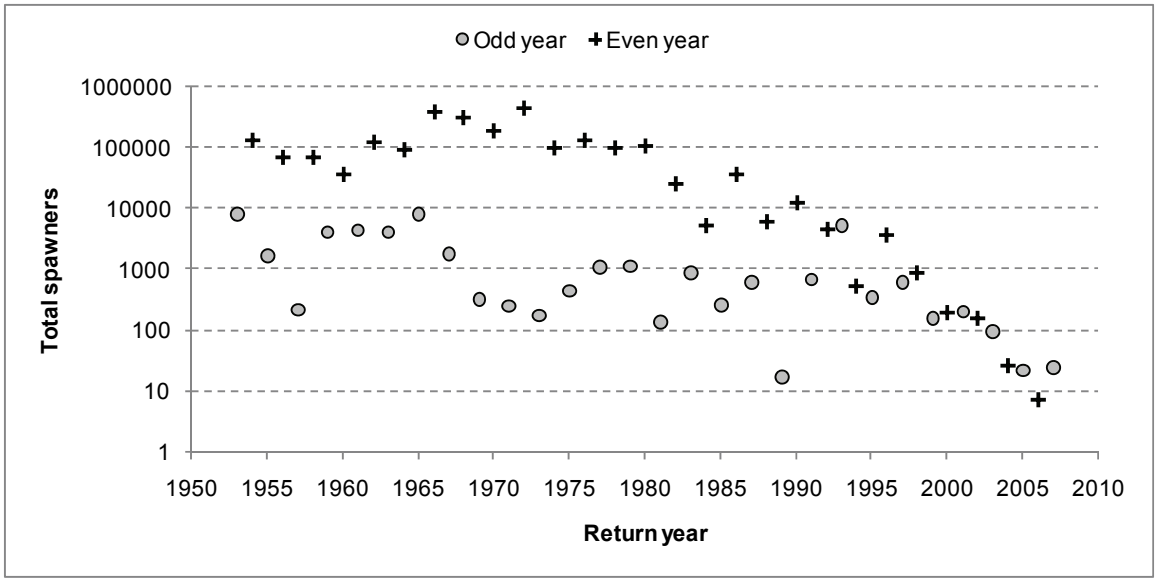
minor canyon modifications and some re-seeding might allow sockeye to progressively utilise this habitat, and increase returns to the Barkley Sound area. Another important habitat issue that needs attention concerns Kennedy Lake, located north of Ucluelet. Historically, this system was the largest WCVI sockeye producer. The factors responsible for the production loss are not known with certainty, but it has been hypothesized that the stickleback population increased to the point where it decreased the forage base available to sockeye fry leading to lower survival. This hypothesis should be re-evaluated, and if correct, DFO should consider using a combination of stickleback controls, sockeye enhancement operations and lake enrichment activities to ensure that sockeye can progressively use the proven production capacity of this very important habitat. And finally, efforts could also be made to reverse the major production losses from Henderson Lake, assuming these are not entirely caused by detrimental climatic conditions. It has been hypothesized that better flow controls could allow returning adults to detect the entrance and migrate upstream to the lake where they hold before spawning, especially during years with low river discharges due to prolonged droughts.

In light of the above facts, DFO should allocate additional resources to improve the level of knowledge of these populations and their environments so as to determine how best to proceed to rebuild a population assemblage that includes a variety of life history types. Resources should also be provided to prevent further habitat losses, and improve habitat conditions where possible to regain productive capacity.

5.2 WCVI PINK

The West Coast of Vancouver Island is not a major centre of pink salmon production, and historically, spawning populations tended to be smaller than in other regions. Of the 272 streams with salmon escapements recorded since 1953 along the WCVI, odd year-line runs have been reported in 85 streams and the even year-lines were in 119 streams. Until the 1990s, spawning escapements tended to be larger in even years, but since then, there has been a major decline in abundance for both year-lines, and the dominance of the even year-line is no longer obvious (Fig. 5.3).

FIGURE 5.3. Total spawning escapements of pink salmon, by run type, for WCVI streams, 1953–2007.
Escapements levels denoted using a logarithmic scale.



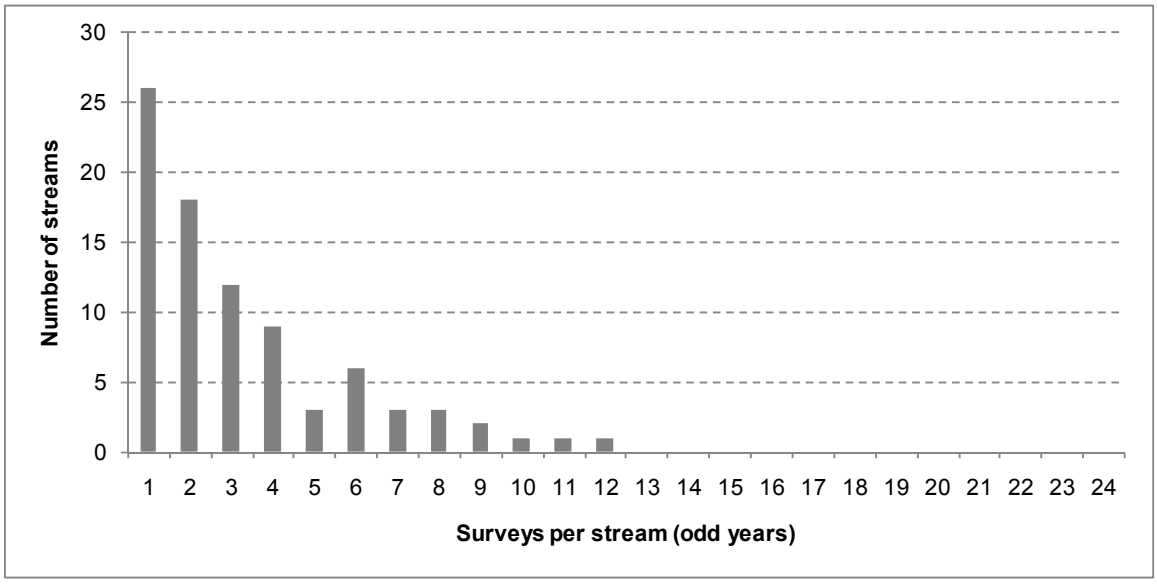
In the previous report (PFRCC 2002), it was noted that during 1953–2000, only 14 streams with odd year-line spawning had at least one 10-year average exceeding 100 spawners, with many odd year-line populations considered as being somewhat marginal. Fewer stream surveys were conducted in odd years, and escapement records were characterized by greater uncertainty than those of even year-line populations. During the 1980s, some even year-line populations declined to very low levels, inducing a shift in the stream survey effort (Table 5.1).

TABLE 5.1. Summary of the reported pink salmon spawning escapements on the WCVI (summation of decade averages by stream).
For the earliest and latest periods, the figures presented cover 7 year periods, and not the entire decades.

Variables/Periods	1953-60	1961-70	1971-80	1981-90	1991-00	2001-07
Total number of odd-year spawners	9,100	9,250	2,100	1,350	2,100	347
Streams with spawners detected	16	48	35	33	63	15
Total number of even-year spawners	102,000	239,000	212,000	19,800	4,700	193
Streams with spawners detected	80	90	84	24	36	8

However, stream occupation trends are not totally representative of general abundance trends, because systematic monitoring operations have not been conducted since 1953. The previous PFRCC 2002 report, noted that there were about 24 survey years (per line) during 1953–2000, during which odd year spawning was detected in 85 streams. Over 75% of these had one or less escapement record for every five return years (Fig. 5.4). Of the 14 odd year-line populations mentioned previously, spawning levels declined significantly between decades in nine populations, showed no trend in four, and increased significantly in one.

FIGURE 5.4. Escapement records by streams known to support pink salmon on the WCVI during odd numbered years, 1953–2000.
Total streams = 85. After PFRCC 2002.



But given inconsistent survey efforts coupled with small abundance levels, the statistical significance of these trends is uncertain. Stream survey efforts were more consistent for even year-line populations. Until the 1980s, the number of streams surveyed and the total escapements were relatively stable (≈2.7–3.2 surveys per stream/decade, averages ≈2,500 spawners per stream). The number of streams surveyed declined in the 1980s,

but those surveyed were visited as frequently (≈2.8 per stream). Stream surveys increased in the 1990s, but survey frequency decreased to ≈1.8 per stream. During 1953–2000, about 27% of the even-year stream populations were surveyed once for each 2 return years, and 50% were surveyed once for every 3 return years (Fig. 5.5). As for the odd year-line, survey accuracy has been highly variable and difficult to quantify. Furthermore, during 1953–2000, total production figures were progressively based on fewer stream surveys, so fewer streams accounted for the total production (Fig. 5.6).

FIGURE 5.5. Escapement records by streams known to support pink salmon spawners on the WCVI in even numbered years, 1953–2000.
Total number of streams is 85 (after PFRCC 2002).

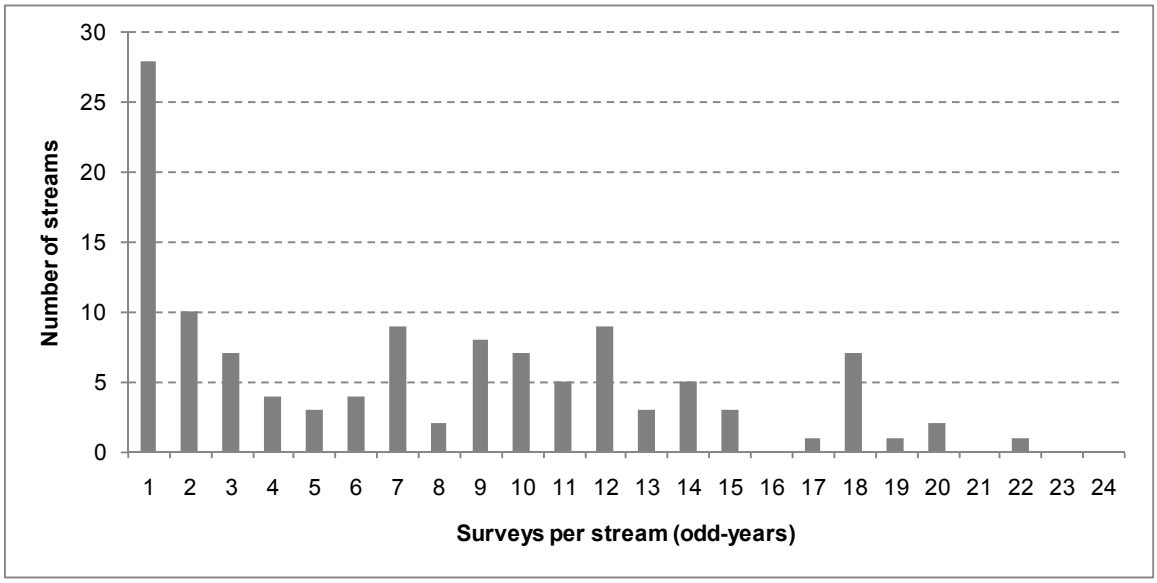
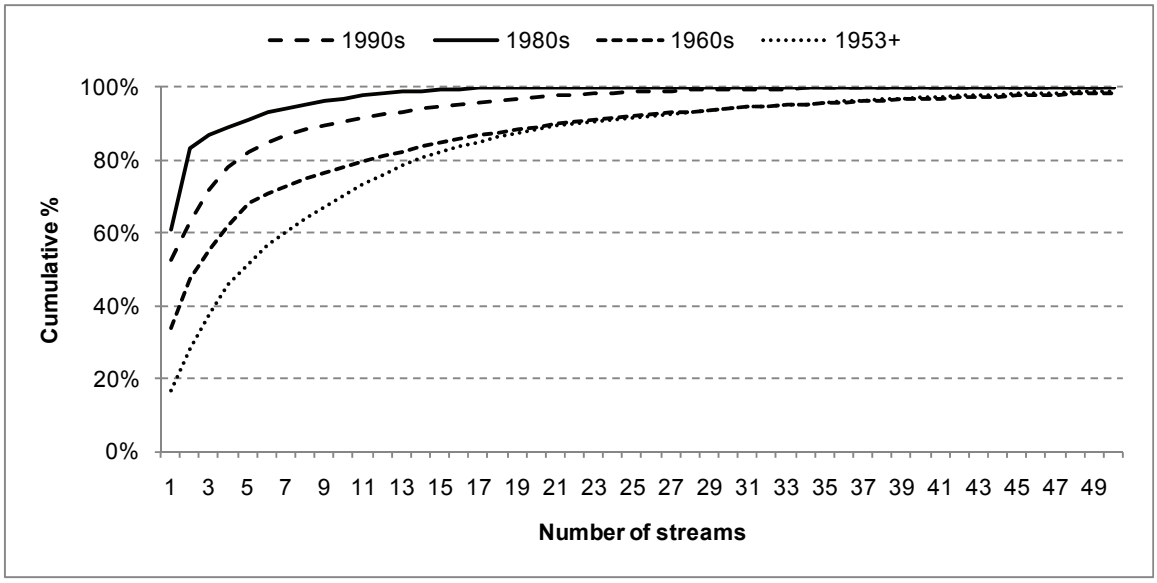


FIGURE 5.6. Percent of cumulative WCVI pink escapements across streams.
Stream numbers ranked by escapement levels (greatest to lowest). Overlapping curves for some decades omitted for purposes of clarity (after PFRCC 2002).



During the 1950s, fifteen streams provided about 80% of the total production, but only two streams accounted for 80% of it by the 1990s. With some additional losses in production since 2000, this situation has not improved. Changes in stream survey patterns were also accompanied by a change in the major contributors of total production, as evidenced by the rank of various streams based on average escapements per decade (Table 5.2). Many streams that were in the 'top ten' category during several decades are no longer in this group, and have been replaced by others that were historically of lower rank. Furthermore, seven of the top ranked populations averaged fewer than 100 spawners during the 1990s, and nine of them were reduced to that level in 2001–07. Given such low abundance levels, recent changes in ranked status are not surprising. Furthermore, the historical spawner abundance records are much less reliable than the more recent ones, so one should be cautious about drawing conclusions based on a direct comparison of ranks.

With little information on historical exploitation, habitat conditions, and ocean survival rates, one cannot identify with confidence the major factors responsible for the decline in total abundance that started in the 1950s. Pink salmon populations are not subject to tagging like other species (chinook, coho), so historical trends in fishery contributions and exploitation have not been estimated. However, there have been no major fisheries targeting WCVI pink salmon populations for quite some time, so over-exploitation is not considered to be a major factor. It is hypothesized that extensive logging operations conducted on the WCVI during the past decades had a pronounced negative impact on the river habitats. It has also been hypothesized that pink populations declined mainly in systems when chum salmon are rebuilding (discussed in the next section). No analysis has been done for this report to evaluate this hypothesis, but it does not sound unrealistic since pink and chum salmon fry tend to compete and do not coexist well. So if true, these hypotheses could account for at least part of the decline in abundance observed since the 1950s.

TABLE 5.2. Ranked values of major even-year WCVI pink salmon stocks based on the average spawning escapements per decade.
Asterisks (*) note that averages by period have declined to ≤100 spawners. NR indicates no records for the stream in a decade.

Stream Name, location	1953-60	1961-70	1971-80	1981-90	1991-00	2001-07
Burman River, Nootka Sound	4	1	1	2	26*	9*
Waukwaas Creek, Quatsino Sound	3	4	3	1	1	33*
Kauwinch River, Kyuquot Sound	10	2	4	NR	24*	25*
Koprino River, Quatsino Sound	1	5	15	13*	10*	34*
Kaouk River, Kyuquot Sound	14	6	2	3	28*	13*
Kwatleo River, Quatsino Sound	2	3	20	6	6	35*
East Creek, north Brook's Peninsula, Brooks's Bay	9	19	5	4	4	36*
Leiner River, Nootka Sound	20	7	8	14*	11*	11*
Zaballos River, Espinosa Inlet	34	13	7	10	13*	5*
Little Zeballos R, Espinosa Inlet	39	8	10	NR	35*	37*
Sample size (Total # ranked)	80	90	84	24	36	37

The WCVI pink salmon population is a valuable natural resource that contributes to the biodiversity of that region, and based on historically levels, could certainly support some small scale fisheries. DFO seemingly opted to reduce survey efforts relative to abundance levels, in part because there are no major directed fisheries. The implementation of the Wild Salmon Policy requires setting conservation requirements for each pink salmon CU, but all pink salmon populations on the WCVI area will likely comprise a single CU. While some populations or year-lines have declined to negligible levels, it is unlikely that major investments can be justified to

systematically monitor their rebuilding in the absence of directed fisheries. However, DFO should provide sufficient resources to determine the major cause of decline, and if habitat degradation turns out to be the likely culprit, habitat restoration activities should be expanded to allow the population to rebuild to sustainable pre-1960s level.

5.3. WCVI CHUM

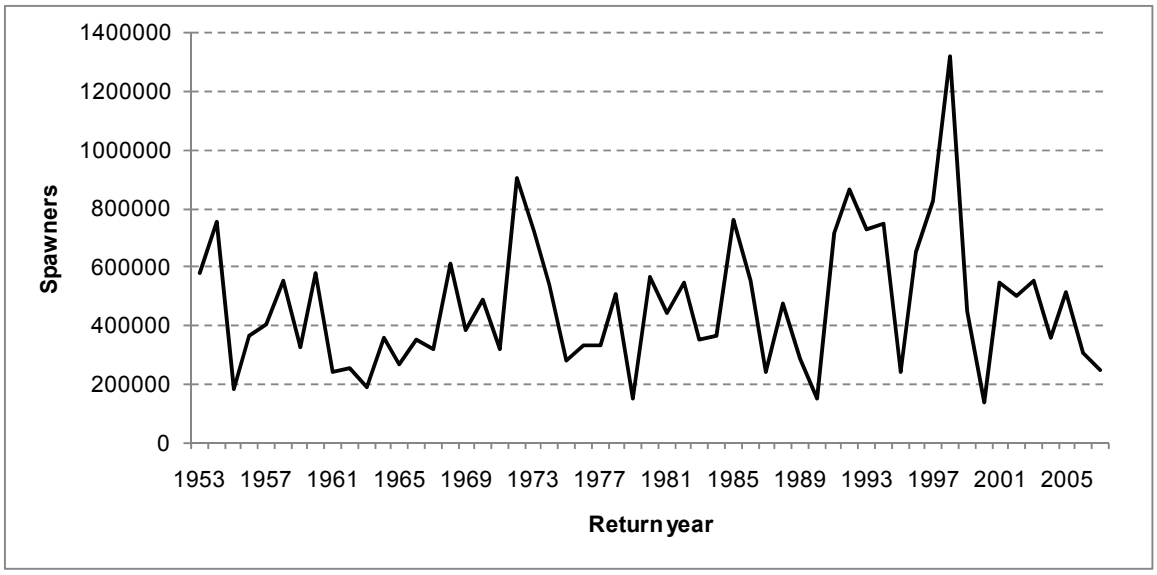
Unlike pink salmon, the WCVI chum salmon populations are widely distributed and have been reported in 241 of the 272 salmon streams and annual escapement surveys have consistently occurred. These indicate that fairly stable escapement levels since 1953, with a peak in the 1990s that corresponds to a peak in the number of streams surveyed during the same period (Table 5.3). There has been a progressive reduction in survey frequency since the 1950s, and a large reduction in the number of streams surveyed in the past decade. This should not be considered to reflect a monitoring problem per se. During the 1990s, historical escapement records were considered to be too inaccurate for various assessment purposes, and DFO opted to conduct more systematic surveys in systems identified as being important.

TABLE 5.3. Total spawning escapements, streams surveyed, and mean survey frequency by period for WCVI streams with chum salmon.
Totals escapements are sums of averages by stream over a period. Streams survey figures include only those where escapements were detected. First and last survey frequencies are adjusted for incomplete periods (<10 years).

Variables/Periods	1953-60	1961-70	1971-80	1981-90	1991-00	2001-07
Total escapement reported	485,246	357,077	484,862	482,815	748,300	563,149
Number of streams surveyed	184	189	198	194	211	130
Survey frequency (aver. per stream/period)	87.0%	86.1%	76.6%	60.9%	54.1%	52.5%

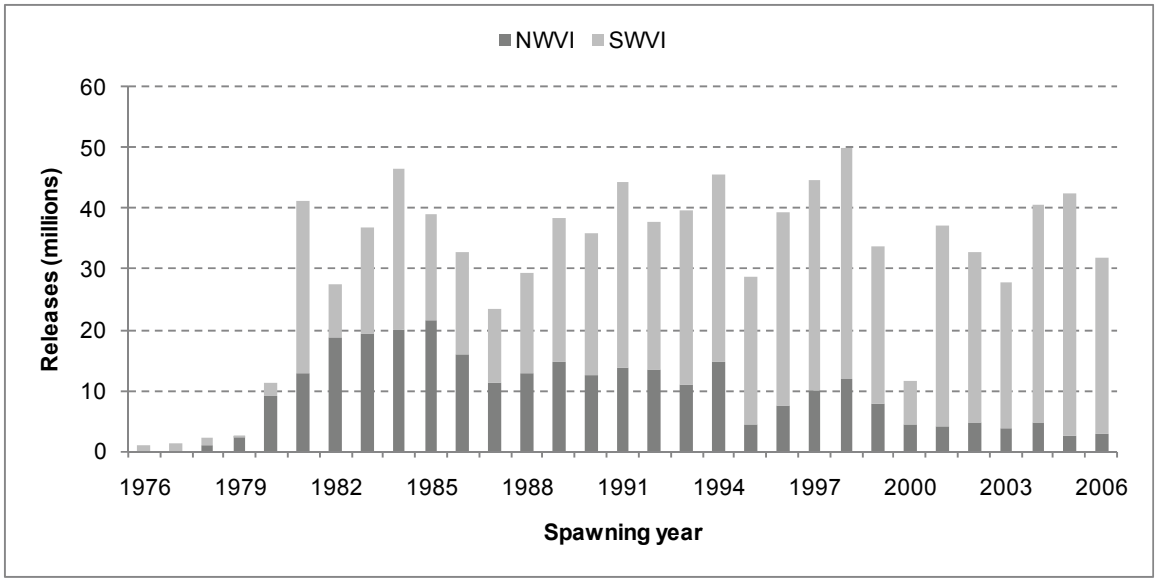
There is no current stock assessment for WCVI chum salmon. There are detailed catch records by fishery/period, but the historical stock contributions to Canadian and US fishery catches have not been routinely estimated due to the lack of funding and the limitations of older stock identification methods. In recent years, all mixed stock fisheries were eliminated, and there remains only some commercial fishing inside the surf line directed on hatchery returns, and occasionally there are small scale gillnet fishery openings in some inlets and for periods when there are indications of substantial returns. Consequently, trends in overall population status are largely based on escapement records that are to some extent influenced by some fishery removals, survey frequencies, survey coverage, and hatchery production levels associated with the Salmon Enhancement Program (SEP) since the 1980s. Based on these data, total production appears to have increased somewhat during 1953–1998 (Fig. 5.7), in part due to the effects of hatchery production.

FIGURE 5.7. Total numbers of chum spawners in WCVI streams, 1953–2006.



The hatchery production program involved the release of millions of fry from major hatcheries (Nitinat and Conuma) and from numerous smaller facilities since the early 1980s (Fig. 5.8).

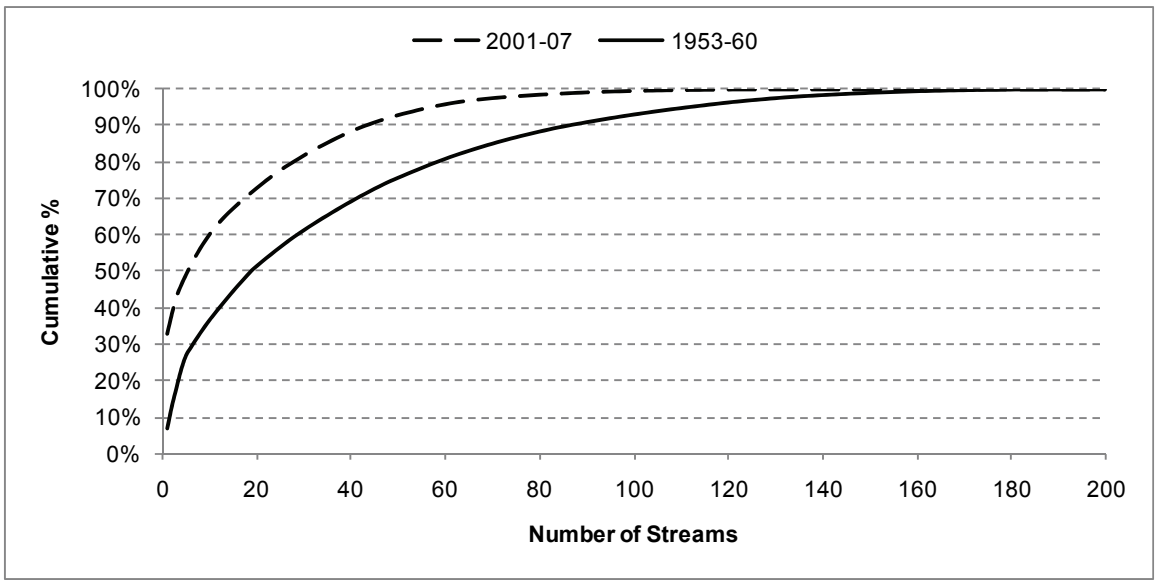
FIGURE 5.8. Chum salmon fry released from all WCVI enhancement facilities.
Total releases by spawning year are for the northwest of Vancouver Island (NWVI; Statistical areas 25–27), and the southwest of Vancouver Island (SWVI; statistical areas 20–23). Fry from a spawning year migrate to sea in the following spring.



In recent years, about 2 million fry have been released each year in various streams along the northwest region of Vancouver Island (NWVI), and another 28–38 million released along the southwest region of the Island (SWVI). The major areas of return are Nootka Sound (from Conuma hatchery releases), Nitinat Lake and several coastal streams (from Nitinat hatchery releases). Given the large hatchery fry releases in recent decades, one would expect that escapement patterns would reflect the greater contributions of a few large enhanced populations.

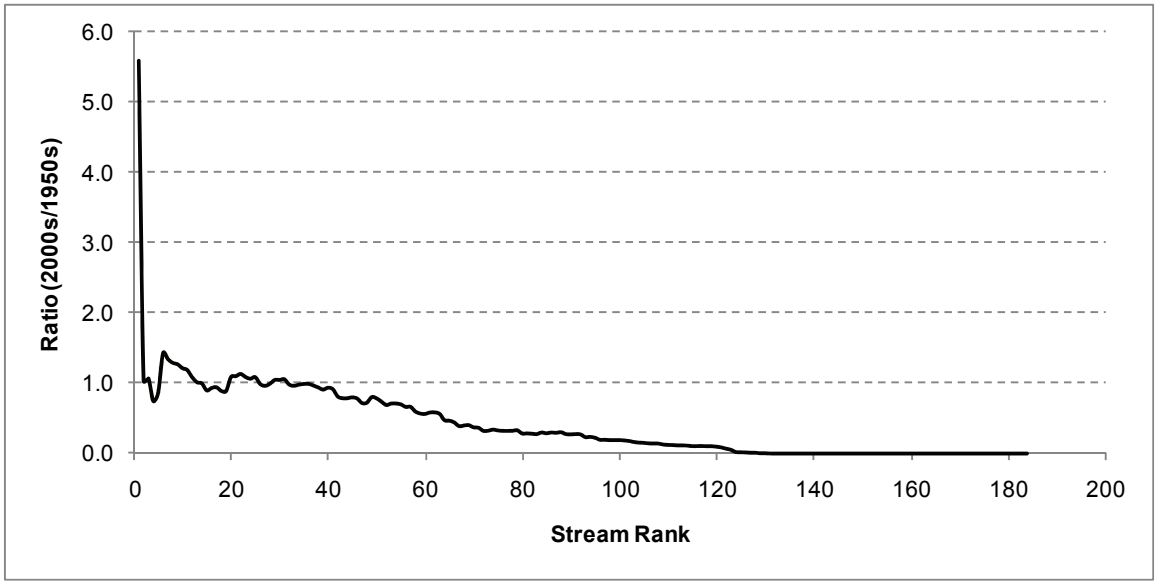
As expected, fewer populations now account for more to the total escapement than during the 1950s, as shown by a shift in the cumulative proportions to total escapement (Fig. 5.9). However, the shift may be partly caused by changes in survey procedures.

FIGURE 5.9. Percent of cumulative WCVI chum escapement across streams.
Stream numbers ranked by escapement levels (greatest to lowest). Overlapping curves for the middle decades omitted for purposes of clarity.



The enhanced population areas include the Nitinat River and several rivers in Tlupana Inlet (Nootka Sound). In principle, enhancement activities can provide opportunities to direct some of the fishing effort on enhanced populations while reducing impacts on natural ones. Despite this, only about 25 historically important populations now have escapements larger than reported during the 1950s (Fig. 5.10).

FIGURE 5.10. Ratio of changes in spawning escapement levels by stream rank for WCVI chum populations.
(e.g., size of the 10th ranked population in the 1990s divided by the 10th ranked population size in the 1950s).



These represent only 10% of the streams with chum salmon, but now account for 80% of total production. Some streams with the largest historical escapements are still among the largest, but the ranks of many other streams have changed, and sometimes considerably (Table 5.4).

TABLE 5.4. Ranked value for historically important chum stocks of the WCVI, 1953–2007.
Lowest ranks indicate greatest average escapements by period. Streams listed sequentially using initial (1953) rank orders.

Streams/Stocks	Ranks 1953-60	Ranks 1961-70	Ranks 1971-80	Ranks 1981-90	Ranks 1991-00	Ranks 2001-07
Nahmint R.	1	3	4	4	3	2
Sarita R.	2	1	2	3	5	7
Nitinat R.	3	2	1	1	1	1
Toquart R.	4	7	5	8	11	36
Tranquil Cr.	5	22	32	45	44	9
Tahsis R.	6	5	6	15	8	11
Tahsish R.	7	11	10	7	15	25
Inner Basin R.	8	4	21	30	46	85
Zeballos R.	9	20	14	19	12	13
Henderson L.	10	25	50	126	126	88
Atleo R.	11	19	3	5	31	4
Conuma R.	12	14	11	2	2	33
Burman R.	15	10	23	38	16	23
Megin R.	16	24	8	20	33	41
Malksope R.	18	6	13	17	29	26
Tsowwin R.	25	8	22	10	4	17
Deserted R.	28	16	15	6	10	19
Park R.	32	9	16	21	28	35
Canton R.	45	65	56	23	9	16
Sucwoa R.	53	23	20	12	7	37
Kaouk R.	54	79	17	9	14	14
Cayeghle S.	55	29	7	11	19	20
Leiner R.	57	13	9	18	17	22
Tlupana R.	121	54	37	14	6	10

Some top ranked streams in the 1950s (before enhancement) remained in that category during each decade. From rank 5 onwards, there is less consistency, with some remaining in the top category during some decades, while others dropped in rank (Inner Basin River, Henderson Lake). The influence of hatchery production is evident, particularly in Nootka Sound, with the Conuma hatchery releases likely increasing or maintaining high ranks for populations in the Conuma, Deserted, Canton, Sucwoa, and Tlupana rivers. Still, about 200 streams now have smaller escapements than during the 1950s. Many populations with relatively large escapements decades ago no longer have significant spawning populations. For instance, during 1988–1998, over 2000 chum were reported to spawn in the Somass River during the years when surveys were conducted, but recently, spawning levels declined to <100/year. This could potentially be caused (at least in part) by a prolonged period of reduced marine survivals as hypothesized for other species and regions. Escapements declined considerably during the last 10+ years, and particularly north of Nootka Sound. Many streams associated with the Conuma hatchery, and other small-to-moderate streams have much lower escapements since 1998, particularly in the northern region. Unfortunately, many small-to-moderate size streams are no longer inspected regularly, so there is uncertainty on their status.

Since the fisheries likely have localized impacts on specific runs, over-exploitation is likely not the cause of the general decline observed since 1998. Unfortunately, the available data sets are not complete enough to categorically determine whether the recent declines are due to lower ocean survival, recent habitat losses, or changes in the escapement monitoring and hatchery production and release procedures. While recent escapement levels are not lower than historical ones, one would expect they would be considerably higher if the benefits of a successful hatchery program were constant and not eliminated by other potential factors.

The WCVI chum population is a productive and valuable natural resource that contributes to the bio-diversity of that region. In the absence of large scale fishery impacts on the WCVI populations, it would seem that attention should focus on other factors potentially responsible for the recent decline, including recent habitat losses, interactions with pink salmon populations, and changes in enhancement procedures. It may be that the recent decline is simply a natural phenomenon that cannot be easily changed, but maintaining the hatchery production of chum salmon may be needed to help safeguard against further declines, and maintain at least the larger commercial fisheries targeting hatchery returns.

5.4. WCVI COHO

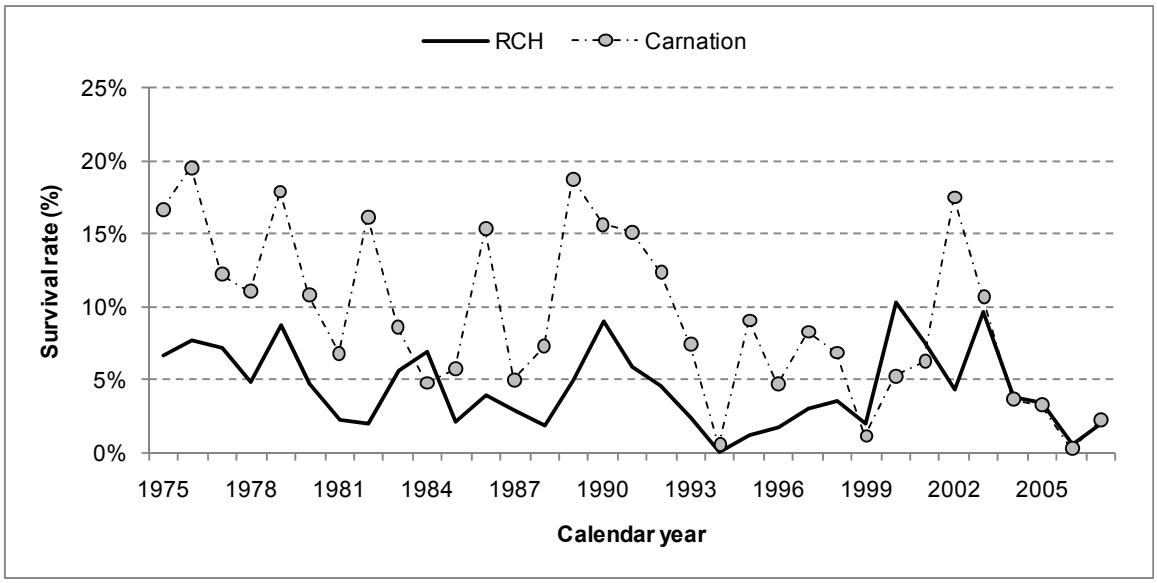
Coho are the most widely distributed salmon species along the WCVI, having been reported in 700 streams and tributaries within 243 watersheds. Coho escapements are difficult to monitor because of their elusive behaviour, and because high turbidity levels during in-river migration and the spawning period limit the availability and accuracy of visual surveys conducted since 1953. Because of such facts, the assessment and management of the WCVI coho populations is largely based on data from a few indicator stocks rather than on annual escapement surveys. There is considerable uncertainty as to whether or not the variation in escapement trends (Table 5.5) is due to changes in freshwater or ocean habitat conditions, inconsistent monitoring, variable exploitation in large ocean mixed-stock fisheries (or a combination of these).

TABLE 5.5. Total spawning escapements, streams surveyed, and mean survey frequency by period for WCVI streams with coho salmon.
Totals are sums of averages by stream over a period. Streams survey figures include only those where escapements were detected. First and last survey frequencies are adjusted for incomplete periods (<10 years).

Variables/Periods	1953-60	1961-70	1971-80	1981-90	1991-00	2001-07
Total escapement reported	135,310	173,582	127,057	80,773	74,785	108,215
Number of streams surveyed	176	186	195	197	203	135
Survey frequency (aver. per stream/period)	80.0%	74.0%	64.6%	40.1%	42.2%	47.7%

Coded-wire tagging of juvenile coho from indicator stocks is conducted to help distinguish the effects of variation in survival and exploitation. The only indicator stock along the WCVI is from the Robertson Creek Hatchery (RCH) in the Somass River near Port Alberni. Some complementary information has been provided via the long-term monitoring of a natural population from Carnation Creek on the south shore of Barkley Sound. Reports summarizing the history and importance of these datasets are available from the PSARC website (www.pac.dfo-mpo.gc.ca/sci/psarc/), and include the Stock Status Report D6-06 (2002); Status in 1999 of coho stocks on the West Coast of Vancouver Island; and, Forecast for southern BC coho in 2002. PSARC Salmon Working Paper S2002-02. The trends for indicator stocks suggest that marine survival started to decline in the mid-1990s (Fig. 5.11).

FIGURE 5.11. Marine survival variation in Robertson Creek hatchery (RCH) coho and naturally produced coho from Carnation Creek.
Survival rates presented by calendar or catch year (Age 3 coho escapement year). Subtract 3 years for brood year equivalencies.



Coho produced from the 1991 spawning entered the ocean in 1993 and were caught in the 1994 fisheries. These had some of the lowest survival rates observed, with less than 1000 adults counted through the Stamp Falls fishway (returning to RCH), or roughly 1–2% of past returns. To help rebuild the populations, exploitation rates in the WCVI fisheries were reduced during the mid-1990s. They were almost negligible during 1998, but increased subsequently, although only coho lacking an adipose fin could be retained in mixed-stock areas in 2000. Exploitation rates on the indicator stock (RCH) increased from 1999 onwards (Fig. 5.12), but these were much lower than the pre-1998 levels. They are thought to be about 20 percentage points greater than those on the natural populations since the latter are not marked, and must be released. The major reduction in exploitation coincided with a second period of low ocean survival affecting mainly the progeny of 1996 spawning. This second period of low ocean survival is not clearly evident in all escapement trends, but that is not surprising given the uncertain accuracy and completeness in annual survey records, coupled with the effects of enhancement activities along the WCVI. The total release of coho salmon from enhancement programs (large hatcheries and local initiatives) has been substantial, beginning with RCH releases in 1973 (Fig. 5.13).

FIGURE 5.12. Exploitation rates on Robertson Creek hatchery coho since the 1973 spawning year.
Exploitation rates presented by calendar or catch year (Age 3 adult coho). Subtract 3 years for brood year equivalencies.

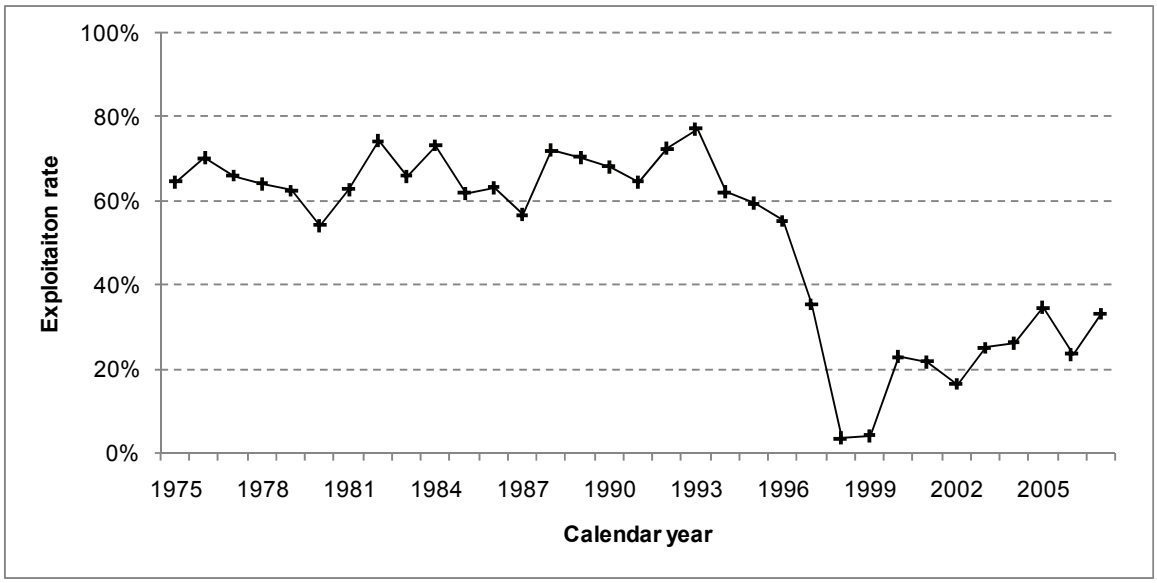
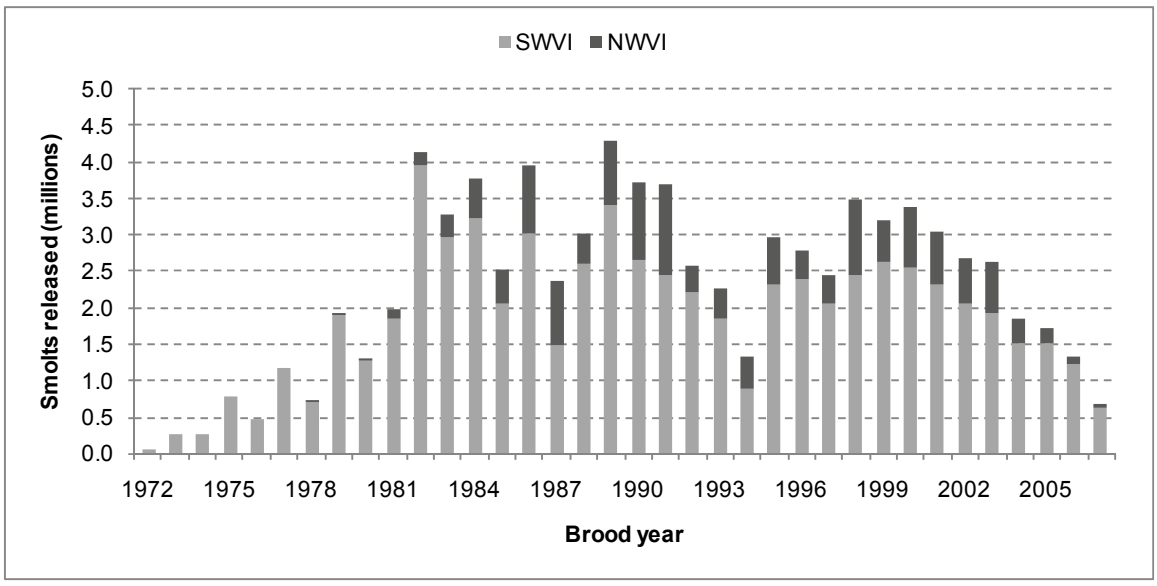


FIGURE 5.13. Total numbers of coho smolts released from the WCVI enhancement facilities since 1972.
Releases aggregated by large regions; south of Clayoguot Sound (SWVI), and north of Nootka Sound (NWVI).

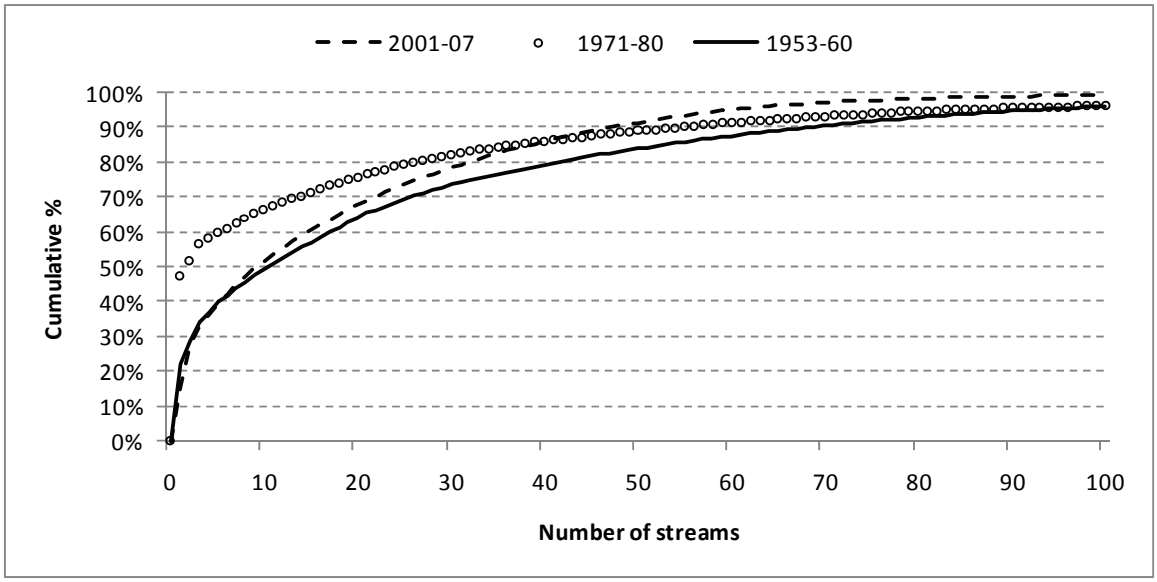


The low ocean survival during 1993 caused a shortage of available brood stock during the fall, which in turn, slowed down the hatchery production levels.

Much of the enhanced production is released in larger river systems, but dispersals and returns from releases across many small systems are not well monitored. There can also be considerable straying in some years (Labelle, 1992), and the proportion of jacks (coho with <6 mo of sea life before returning) in the spawning population monitored can vary substantially between years but is rarely recorded. Consequently, escapement

trends for all systems subject to hatchery supplementation or not, are characterized by considerable uncertainty. Trends in cumulative escapement across streams (Fig. 5.14) shows there may have been some loss in diversity during the 1970–80s, but this situation improved subsequently as evidenced by the most recent period pattern.

FIGURE 5.14. Percent of cumulative WCVI coho escapement across streams.
Stream numbers ranked by escapement levels (greatest to lowest). Overlapping curves for some decades omitted for purposes of clarity.

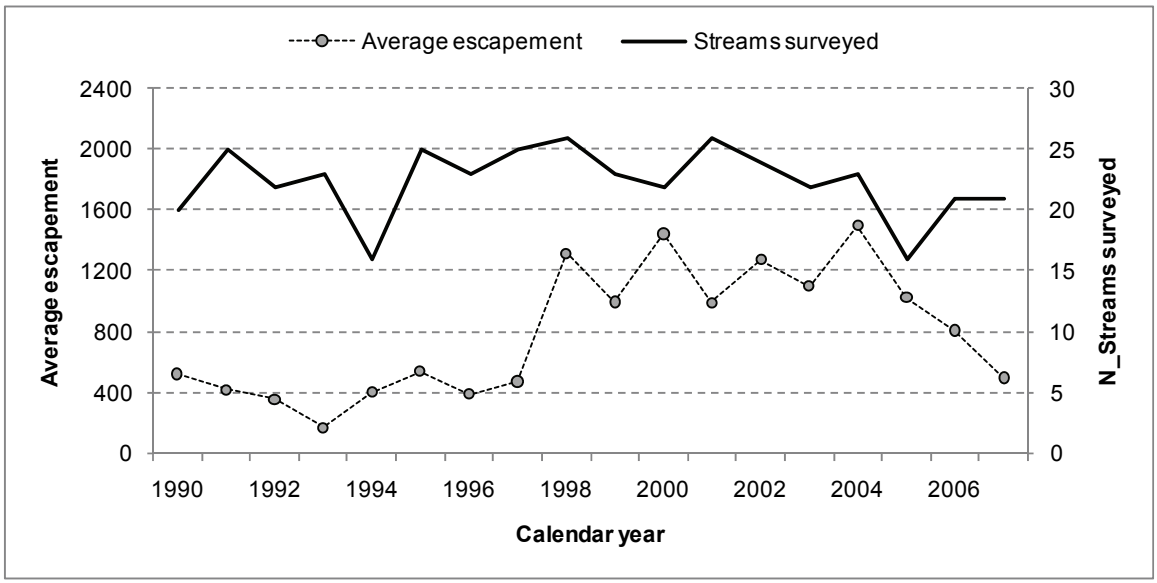


Shifts in cumulative escapement patterns can be caused by changes in exploitation, enhancement activities and escapement monitoring practices. To help dissociate these effects, following the second period of low ocean survival, DFO implemented more thorough surveys in 58 streams, and a larger set of streams was used to track natural spawning populations.

Starting in 1995, escapement to each system was obtained by first determining the numbers of salmon of a species at given times/places, and then using each data set to generate an AUC estimate of total escapement for a given stream/year. Unfortunately, escapement surveys could not be conducted consistently in all the systems selected initially (see Dobson *et al.* 2000). So a smaller set of 28 natural populations with relatively consistent records was used to show trends in natural abundance (see PFRCC 2002). The systems are distributed between the Strait of Juan de Fuca and Quatsino Sound, and are listed here by statistical area (23 to 27); Gordon R., Klanawa R., Carnation Cr., Maggie R., Nahmint R., Sarita R., Thornton Cr., Toquart R., Bedwell R., Megin R., Moyeha R., Tranquil Cr., Burman R., Canton Cr., Leiner R., Sucwoa R., Tahsis R., Tlupana R., Tsowwin R., Zeballos R., Artlish R., Easy Cr., Kaouk R., Kashutl R., Kauwinch R., Tahsish R., Cayeghle Cr., and Marble R.

Not all streams in this smaller subset were systematically monitored each year since 1990, but the trends are considered to be more representative of those obtained by using all WCVI streams. The trends indicate that spawning levels have been fairly stable since 1990 (Fig. 5.15). Escapements of natural populations do not show a major decline in returns in 1994 as observed for the WCVI indicator stocks, although they did respond positively to reductions in fishing pressures initiated in 1998.

FIGURE 5.15. Trend in the average coho escapement to some WCVI natural populations, 1990–2007.
Averages are estimated from the number of streams surveyed annually, with escapements >0.



These observations suggest that indicator stocks do not always accurately reflect the response of distant populations to large scale environmental and human impacts. By comparing escapements by geographic area and year, it was noted that escapement declines were greater in the SWVI region (where the indicator streams are located), so the greater survival rates of the NWVI populations of this "index" group may have helped reduce the average decline (PFRCC 2002). And the natural escapements did not increase substantially during 2000–01 (Fig. 5.13) despite low exploitation rates and increased survival affecting the indicator stocks. Since 2001, the marine survival rates of the indicator stocks decreased again (<5%), as did the escapements of natural populations. Exploitation rates slowly increased (on indicator stocks), while enhanced production decreased. So in spite of perceived differences in the response of WCVI coho populations to environmental conditions and human impacts, it appears that during periods of low ocean survival, increased exploitation coupled with reductions in enhancement slowed the recovery of all WCVI populations. Ideally, this hypothesis should be assessed using more data, but as noted earlier, the dispersals, releases and returns of enhanced production to many systems is not well monitored, and there are no indicator stocks for NWVI regions.

Recent indices of escapement levels for various WCVI coho populations are a source of concern, particularly in light of the positive response of natural populations to lower exploitation rates. However, a continuation of limits to recreational fishing opportunities in mixed stock areas in an appropriate precaution, at least until ocean survival rates and natural escapement levels increase to sustainable levels. While substantial efforts were made to improve the escapement monitoring system, further changes may be required to provide better insight on population status and comply with the requirements of the new Wild Salmon Policy. Small scale enhancement activities need to be monitored closely to determine if these simply compensate for lower ocean survival and increased exploitation. More indicator stocks should also be used to determine exploitation levels and survival rates on NWVI populations. Ideally, these should be subject to coded-wire tagging, as are large hatchery releases, so as to determine the extent of regional differences in exploitation and survival. There is also a continuing need to maintain a precautionary approach when establishing future fishery management plans.

5.5. WCVI CHINOOK

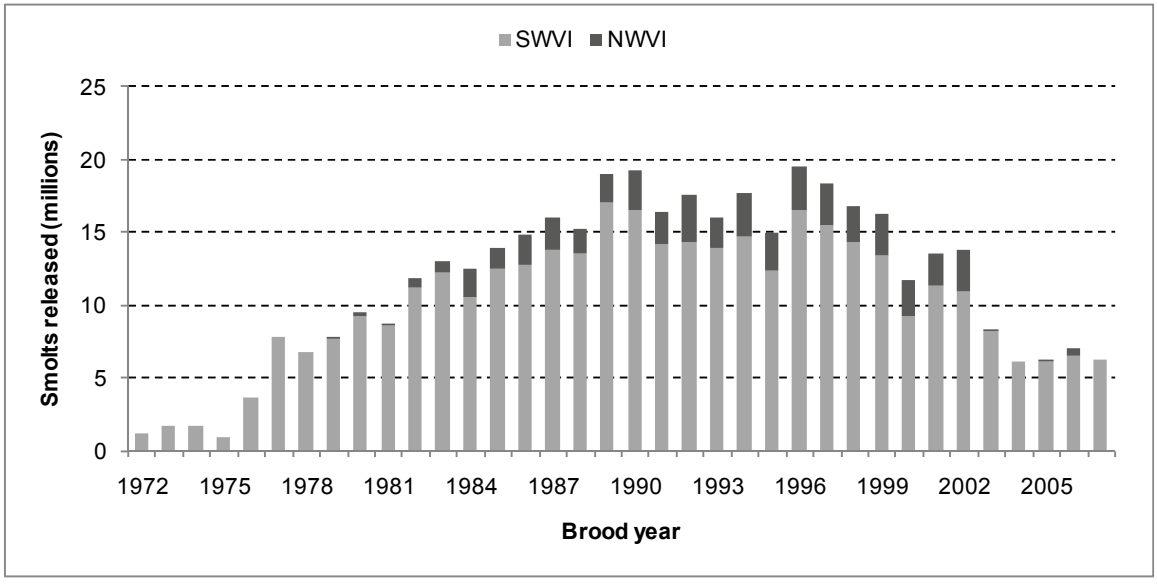
Chinook salmon have been recorded in 133 streams on the WCVI since 1953. They tend to occupy mainly moderate-to-large rivers. Mature chinook return to WCVI streams mainly from late August to early October, except those from Conuma, Burman and a few NWVI populations that return one month earlier. All are referred to as "far-north migrating" stocks. They are subject to extensive harvest as they migrate through Alaskan waters, and during their return by fisheries in northern BC and terminal areas (i.e., in inlets and approach waters). Historical escapement records are not very reliable, partly because the large systems occupied have not been surveyed extensively over time. Since 1953, 72% of the chinook streams were surveyed ≤5 times per decade, and 55% were surveyed ≤2 times per decade. The numbers of streams surveyed and the populations are smaller than for chum and coho populations (Table 5.6).

TABLE 5.6. Total spawning escapements, streams surveyed, and mean survey frequency by period for WCVI streams with chinook salmon.
Totals are sums of averages by stream over a period. Streams survey figures include only those where escapements were detected. First and last survey frequencies are adjusted for incomplete periods (<10 years).

Variables/Periods	1953-60	1961-70	1971-80	1981-90	1991-00	2001-07
Total escapement reported	33,093	32,225	24,937	71,094	122,082	115,275
Number of streams surveyed	66	83	87	68	105	68
Survey frequency (aver. per stream/period)	72.5%	64.1%	53.3%	47.2%	42.9%	55.0%

The accuracy of the old stream survey records and the reported escapements cannot be determined with certainty. However, as for coho, more systematic escapement monitoring operations were initiated in 1995, and now provide more consistent estimates of total escapement in selected streams each year. If one assumes that the old records are not systematically biased, the escapement levels have increased considerably during the past two decades. The benefits are largely attributed to a successful hatchery program that produced millions of smolts each year (Fig. 5.16).

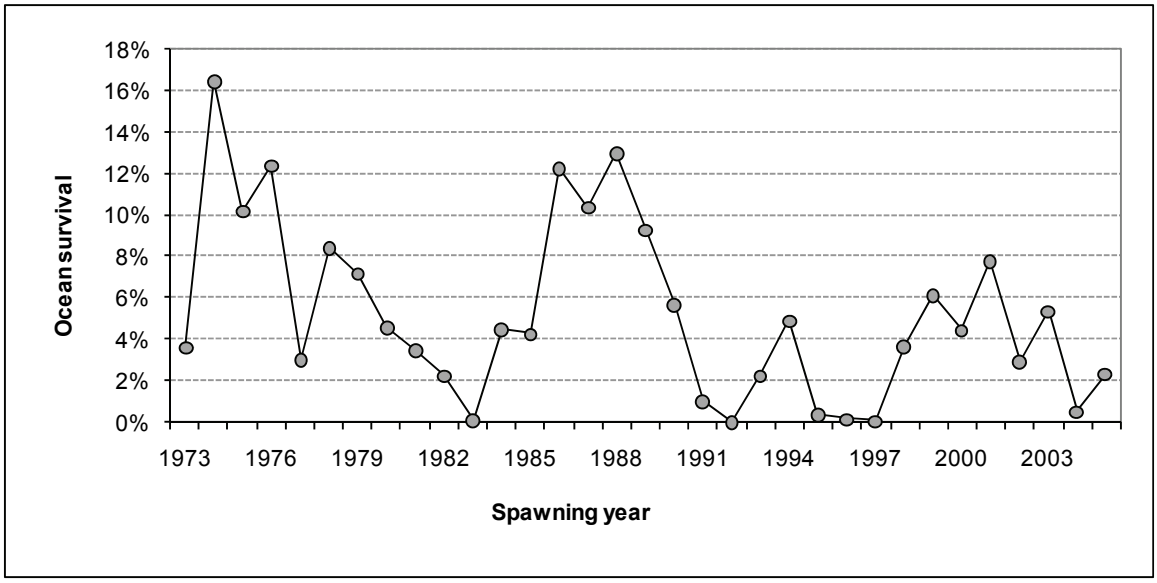
FIGURE 5.16. Total numbers of chinook smolts released from the WCVI enhancement facilities since 1972.
Releases aggregated by large regions; south of Clayoguot Sound (SWVI), and north of Nootka Sound (NWVI). The major SWVI hatcheries are on the San Juan R., Nitinat R., and Robertson Cr. The only major hatchery in the NWVI is on the Conuma R.



Major production initially started with increasing numbers released from the Robertson Creek hatchery. In the early 1980s, production continued to increase via a major facility on the Nitinat River, and several smaller facilities associated with Public Involvement Projects (PIP) and Community Development Projects (CDP). Production cutbacks were initiated in the late 1990s, and major hatchery production has progressively been reduced since 2000.

Assessing the state of the WCVI chinook population aggregate requires dissociating the effects of enhancement, survival variation, and changes in exploitation. Information from indicator stocks subject to coded-wire tagging is particularly useful for assessment purposes. The principal indictor for this region is the fall chinook stock from the Robertson Creek hatchery (RCH). Data provided by the analysis of tag returns is used for abundance forecasts and pre-season fishery planning. These exercises are conducted each year because of the large variation in the marine survival rate observed for this stock (Riddell *et al.* 2001[9]). Since the 1973 spawning year, there has been a one-thousand-fold variation in survival of fall chinook released from RCH (Fig. 5.17). Conservation of WCVI chinook became a major issue in the 1990s due to four years of very low survival, and especially the three successive ones in the mid 1990s. Chinook spawning populations each season can consist of multiple age-classes (ages 2–5). The effect of one year of low survival can be spread over a few years of adult returns, but a sequence of low survival years could result in no spawners returning at all. For this reason, some WCVI and northern BC fisheries were closed, or have been reduced several times since 1996.

FIGURE 5.17. Ocean survival of fall chinook salmon released from the Robertson Creek hatchery on the WCVI.
Survival rates based on smolt to age 2 returns. The smolt ocean entry year is 1 + spawning year.



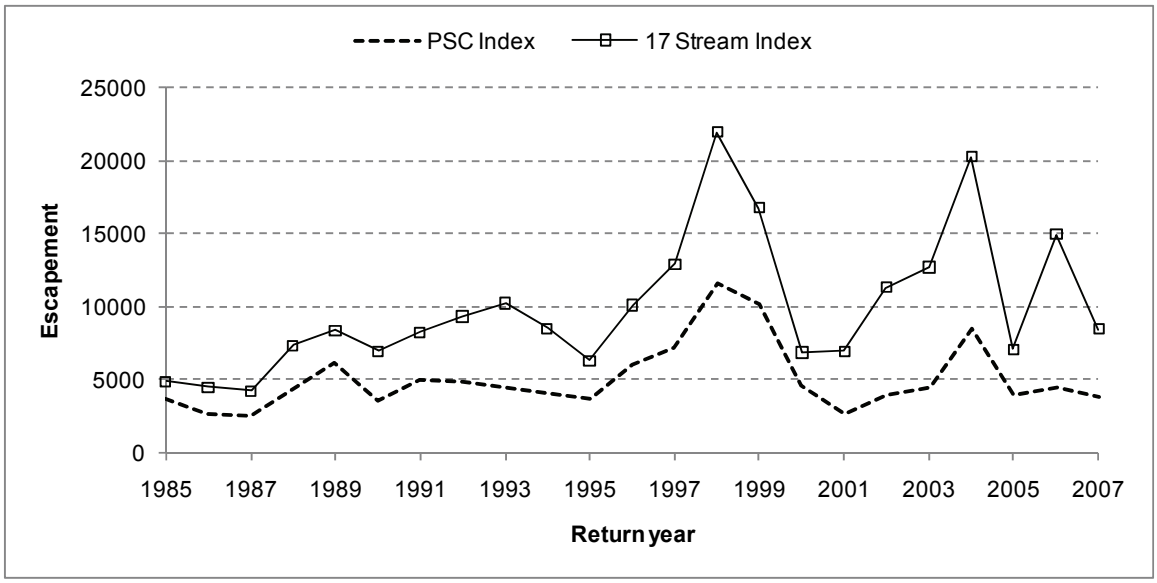
These restrictions were largely implemented on the basis of the RCH indicator stock trends. However, escapement monitoring in several key streams was expanded and improved in 1995 with estimates based on ground survey data processed using the Area-Under-the-Curve method (AUC). Since then, escapement monitoring efforts have focused mainly on two naturally-spawning population aggregates (major hatchery systems tracked separately). The first one is the Pacific Salmon Commission Index (linked to the 1985 PSC treaty obligations), that initially included the most "consistently" monitored systems, namely the Burman, Gold, Tahsis, Kaouk, Artlish, Tahsish and Marble. However, some of these were affected by enhancement activities (at times

[9] www.dfo-mpo.gc.ca/csas/Csas/English/Research_Years/2001/2001_155e.htm

large in the Marble R.), and all are in the NWVI region (Nootka Sound and north). Furthermore, chinook escapements to the Gold River were found to consist largely of strays from the RCH facility, so it was eliminated from the PSC Index. A second aggregate of 11 systems was identified (like for WCVI coho) and consists of populations subject to improved escapement monitoring. It includes the San Juan, Sarita, Nahmint, Liener, Zeballos, Gordon, Toquart, Bedwell/Urus, Moyeha, Megin, and Colonial/Cayeagle systems.

Both indices can be used separately for assessment purposes, but the PSC index is generally compared to the combined index aggregate of 17 streams, considered to be more representative of the overall WCVI escapement patterns. The two trends obtained tend to be similar, both showing peak years (1998, 2004), although the 17 stream index shows slightly more variation in naturally spawning chinook populations from stream in both the northern and southern part of the WCVI (Fig. 5.18).

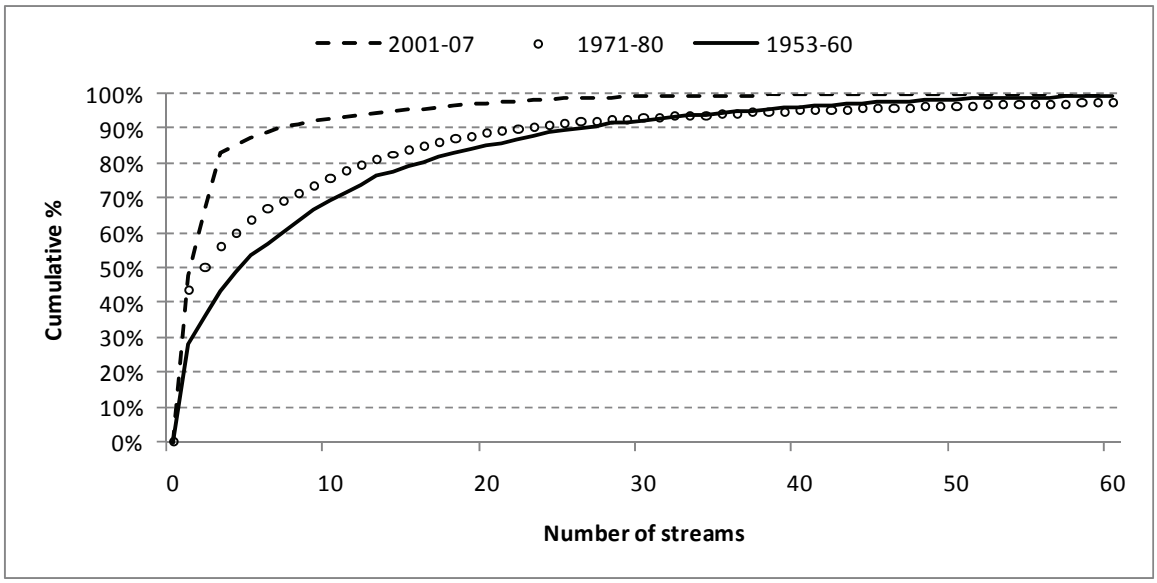
FIGURE 5.18. Escapement trends for [mostly] naturally spawning chinook stock aggregates.
The 17 Stream Index is a combination of the PSC index and 11 additional streams.



The above trends show declining escapements in 2000–2001, that were likely caused by the low ocean survival of smolts from the 1995–97 brood-years. By contrast, the low survival rates of smolts entering the ocean in 1992–93 are associated with relatively high escapement levels in 1997–1999, which could be mostly attributed to major reductions in fishing pressures during the mid-late 1990s. Unfortunately, this cause-effect hypothesis cannot be evaluated systematically because the RCH trends are likely more representative of neighbouring populations, and none of NWVI stocks are coded-wire tagged for assessment purposes.

With increased hatchery production and fishing pressures, one might expect the distribution of production between streams would have changed substantially since 1953. Prior to major increases in hatchery production, the trends are similar until 1980. Since then, there has been a steep shift to the left, as exemplified by the 2001–2007 trend, with >85% of the total escapement associated with only four systems, that generally include the Somass, Nitinat and Conuma rivers with large production facilities (Fig. 5.19). However, the consequences of this shift are not as dramatic as they could be, given that the DFO now relies on a more systematic escapement monitoring program for general assessment purposes.

FIGURE 5.19. Percent of cumulative WCVI chinook escapement across streams.
Stream numbers ranked by escapement levels (greatest to lowest) for the top 60 streams. Overlapping curves for some decades omitted for purposes of clarity.



Naturally-spawning chinook escapement levels along the WCVI appear to be greater than those of the mid-1980s, but the separate effects of reduced exploitation, changes in hatchery production, variable ocean survival (and other factors) still cannot be determined with certainty. This situation could be improved by assigning additional populations to coded-wire tagging. This would provide more information on survival and exploitation rates, which in turn could help determine if the WSP requirements can be met for all CUs under certain levels of survival and exploitation. Until this is done, it might be advisable to restrict fishing measures to compensate for low ocean survival rates that may persist for years to come. Restrictions should be maintained until the recovery of natural populations is evident. New international treaty obligations with the US may further reduce fishing effort levels on the WCVI to protect chinook populations heading to US destinations. This should have some effect on WCVI populations as well, so continued monitoring of these natural systems will likely help determine the impacts of such restrictions. And given the uncertain contributions of hatchery programs to neighbouring wild populations, and the apparent spatio-temporal variation in ocean survival, it would be advisable to routinely monitor the composition of spawning populations (origin, age, sex) in several natural spawning populations along the WCVI.

ACKNOWLEDGEMENTS

Several fishery managers, scientists, biologists, and technicians working for various agencies in British Columbia (DFO, PSC, ONA, PSF, PFRCC, MoE, and others) provided key pieces of information to update this report. The Council wishes to express its sincere gratitude to all of you, and especially (by alphabetical order) to Alexander Argue, Ken Ashely, Richard Bailey, Steve Baillie, Robert Bison, Gayle Brown, Michael Chamberlain, Diana Dobson, Gordon Ennis, Erik Grundmann, Kim Hyatt, Leroy HopWo, Jim Irvine, Mike Lapointe, Diane Lake, Wilfred Luedke, Karin Mathias, Don Radford, Brian Riddell, Neil Schubert, Mel Sheng, Joe Tadey, Seaton Taylor, Arlene Tompkins, Pieter vanWill, Timber Whitehouse, Howie Wright and Patrik Zetterberg.

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GLOSSARY

Assessment—an evaluation of the productivity of a fish population conducted to determine the minimum an optimal number of spawners required, and determine the maximum allowable harvest rates on the population.

AUC—the "Area-under-the-Curve" method used to provide estimates of spawner abundance based on a series of visual surveys conducted over a certain period.

Catch year—the calendar year in which a catch occurs.

Coded-wire tag—a 1.0 x 0.1 mm piece of metal that is laser etched to show an alphanumeric code. These are inserted into the nose cartilage of salmon for stock identification purposes.

COSEWIC—the Committee on the Status of Endangered Wildlife in Canada.

CU—a Conservation Unit, defined under the Wild Salmon Policy of Fisheries & Oceans Canada, as a group of wild salmon sufficiently isolated from other groups that, if extirpated, is very unlikely to recolonise naturally within an acceptable time frame, such as a human lifetime or a specified number of salmon generations.

DFO—the Canadian Department of Fisheries and Oceans, also referred to as Fisheries & Oceans Canada. It is the federal agency responsible for managing Pacific salmon and their habitats.

ECVI—the east coast of Vancouver Island.

Enhancement—man-made alterations to natural habitats or application of artificial culture techniques that will lead to increased abundance of juvenile salmon.

Escapement—the number of fish escaping from a fishery. The escapement from all fisheries is the spawning escapement (i.e., the fish reaching their natal spawning stream).

Escapement goal—a management target, the number of fish desired on the spawning ground. The goal maybe established based on maximizing yield, habitat capacity, or historical precedent.

ESSR—Excess Salmon to Spawning Requirements, a management target, the number of fish desired on the spawning ground. The goal maybe established based on maximizing yield, habitat capacity, or historical precedent.

Exploitation rate—the portion of all adults returning to their natal streams that are captured in a fishery. Usually determined for a spawning or brood year in order to account for mortalities over all ages.

FOC—Fisheries & Oceans Canada, previously known as the Department of Fisheries and Oceans, the federal government agency responsible for managing most Pacific salmon and their habitats.

GVRD—Great Vancouver Regional District.

Habitat—area in which an organism would naturally be found; the place that is natural for life and growth of the organism.

Habitat capacity—the number of organisms that can make maximum use of the available habitat (may refer to spawning capacity for adults or rearing capacity of juveniles).

Harvest rate—the percent of the abundance of fish in a fishing area (defined by gear, location, and timing) that are killed in that fishery. Also used to describe the percent of a single age class harvested by all fisheries, e.g., catch of Age-3 Coho salmon.

Homing—the ability of salmon to undertake long distant migrations to sea and return to the stream where they were produced (i.e., their natal stream).

Index stream—a stream selected as being representative of other streams in an area.

Index stock—a spawning population of fish that is monitored as representative of other populations of the same species in a proximal geographic area or habitat.

Line—used as in a line of descent or linage; for pink and sometimes coho since annual returns are mainly associated with one spawning season; e.g., the odd year-line of pink salmon accounts for the fact that spawning only occurs every other year because they have a two-year life cycle. A line in coho usually assumed a three-year life cycle, despite the fact that some [few generally] return as 2 year olds (old), and some return as 4 year old.

Monitoring—sampling of a stream or salmon population on a continuing basis; tracking and reporting on conditions of the environment and salmon.

PBS—the Pacific Biological Station located in Nanaimo, British Columbia.

Pacific Scientific Advice Review Committee (PSARC)—scientific peer review process for stock assessment and scientific information to be used by Fisheries and Oceans Canada.

Precautionary management—erring on the side of caution and conservation; the greater the uncertainties are the more that harvests and other impacts should be reduced to diminish conservation risks to the stock.

Population—a localized spawning group of fish that is largely isolated from other such groups. In Pacific salmon, these groups maybe adapted to their local environment due to the high fidelity of homing to their natal streams. The term often refers to salmon of one species that occupies a watershed.

Production—the total number of fish produced from one or several populations.

Productivity—the rate of production per parent in a population. Frequently expressed as a ratio between the parent and the number of adult progeny they produce.

Rate of adult return—is used as a measure of productivity, and determined by the number of mature progeny produced from the number of spawning salmon in the parent generation. Mature progeny are fish returning to their natal streams, i.e., next generation of adults.

Return year—the year that salmon return to fresh water for spawning.

Salmon life stages—*alevins* emerge from eggs and reside in the gravel; *fry* emerge from the gravel and maybe reside in freshwater or migrate to the sea; *parr* are juveniles that reside and grow in freshwater; *smolts* are a transition phase from freshwater parr to seaward migrants and early The period of these stages differs between salmon species.

Spawning year—the year in which eggs were fertilized, may also be referred to as the brood year.

Statistical area—one of 30 coastal regions delineated for the purposes of accounting for catch by area and/or general locations of fisheries, streams, etc.

Stock—a genetically similar group of fish, usually returning to a specific geographic area and/or time period.

Stock assessment—evaluation of the productivity of a stock as a basis for deciding escapement goals and sustainable exploitation rates. These analyses provide the basis for conservation, management, and restoration strategies.

Sustainable exploitation rate—the percent of the production that can be harvested at an escapement level and provide sufficient spawners to replace that level of production in the next generation.

Survival rate—portion of the juveniles migrating to sea that survives to adult stages (usually determined by the sum of catches and escapements from a spawning year). Marine survival rate refers to survival of salmon entering the sea to adult stages but frequently also includes a period of freshwater downstream migration before sea entry.

Terminal harvest rate—the portion of a population's returning adults that are killed in fisheries that largely affect just on that population.

Total run—the sum of catches and spawners (all mature fish returning) for a population and spawning year.

Wild—as defined under the Wild Salmon Policy of Fisheries & Oceans Canada, this includes salmon that completed their entire life cycle in the wild, and are the offsprings of naturally spawning salmon that have also continuously lived in the wild.

WSP—the Canadian Policy for the Conservation of Wild Pacific Salmon, commonly referred to as the Wild Salmon Policy of Fisheries & Oceans Canada.

WCVI—the west coast of Vancouver Island.

Yield—at a specified level of production, yield is the number of fish that can be harvested that are in excess of the number of fish required, on average, to replace the production in the next generation.

APPENDIX A

TABLE A.1. Recent trends in production of Fraser River sockeye by stock (data provided by the PSC).

Main stock attributes are listed with comments on recent and long-term production trends (+ is increasing production, - is decreased production, NE is no long-term trend, and UNK is unknown). For stocks with cyclic abundance trends, the largest return year is noted. Increased production in 9 stocks, no long-term change in 7, and decreasing production in 14 (total n=30).

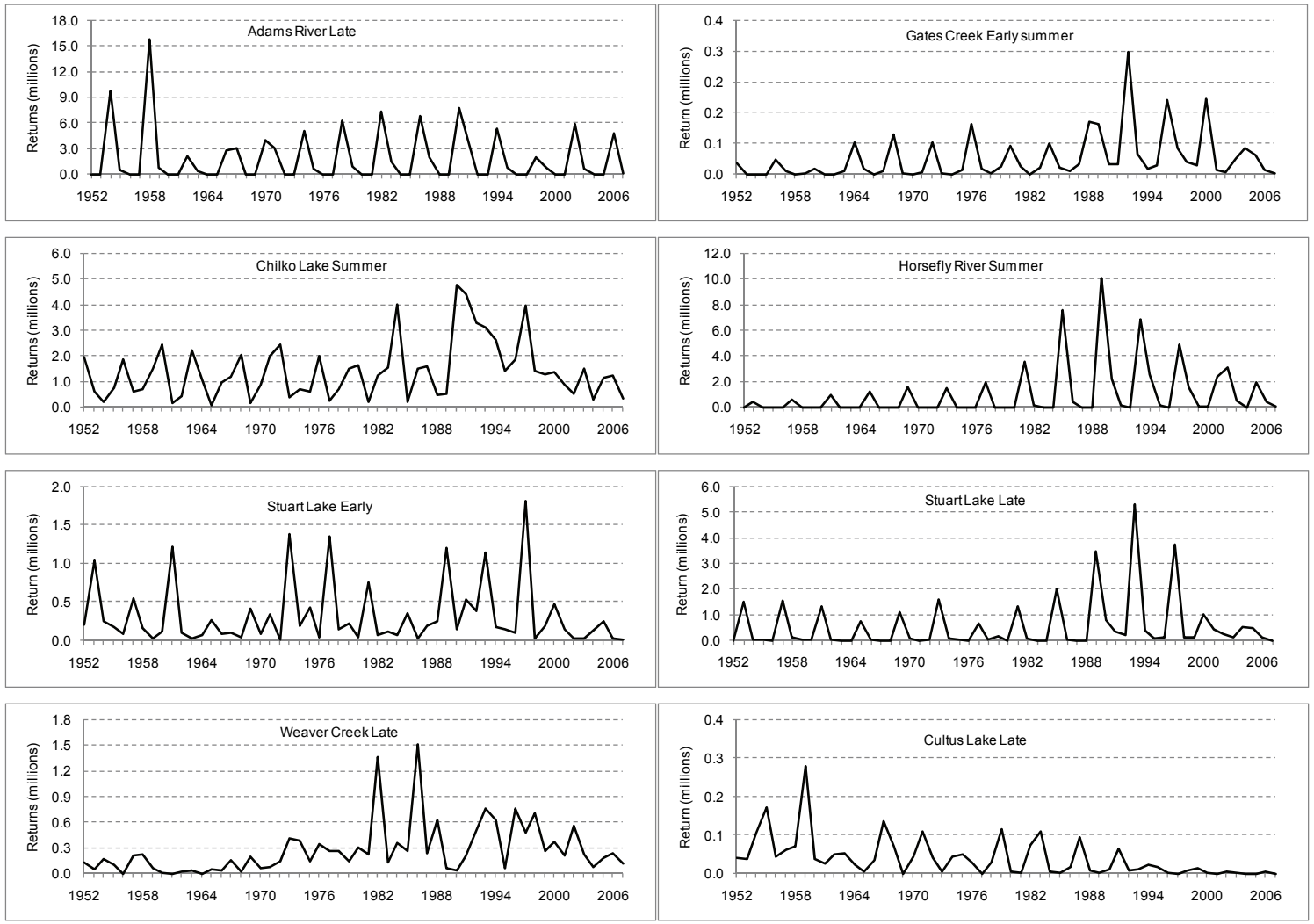
Stock Name	Timing Group (MU)	Main tributary system	Years of Surveys	Comment	Trend
Adams River (lower section). Appendix Fig. B.1	Late Summer	South Thompson River, flows into Shuswap Lake	1952–2007	Strong 4-year cyclic pattern with largest returns on the 2006 cycle year. Historically the largest single sockeye population. Stock impacted by late-run sockeye issue resulting in high levels often-route and pre-spawn mortality in some years.	(-)
Adams River (upper section)	Early Summer	South Thompson River, flows in to Adams Lake	1986–2007	Very large production in 2000 related to enhancement efforts, but has since declined. No long-term trend in production evident.	NE
Anstey River	Early Summer	South Thompson River, Shuswap Lake, Anstey Arm	1990–2007	Production strongest on 2006 cycle year, lower, but significant production also on 2007 cycle.	(+)
Birkenhead River	Late Summer	Lillooet River, flows into upper Lillooet River	1952–2007	No cyclic pattern evident decreased production through 1990s. Very poor production in 2007, likely due to effects of flooding on egg-to-fry survival of 2003 brood.	(-)
Bowron River	Early Summer	Upper Fraser River, above Prince George	1952–2007	Earlier cyclic pattern no longer evident, long term decline in production, recent production quite depressed triggering conservation concerns.	(-)
Cayenne River Momich River	Early Summers Late Summers	Upper Adams Lake, South Thompson River	1992–2007	Very large production in 2000 related to upper Adams enhancement efforts, but has since declined. No long-term trend in production evident.	NE
Chilko River. Appendix Fig. B.1	Summers	Chilcotin River, mid-Fraser River	1952–2007	Cycle pattern with largest returns on the 2004 cycle through 1984, but pattern has broke down since, perhaps due to effects of lake enrichment during the 1980–90s. Recent production declined from record high in the early 1990 to about 1 million sockeye annually due to an extended period of poor marine survival. Higher production forecast for 2009 from record abundant smolt outmigration in 2007.	(-)
Chilliwack Lake	Early Summer	Chilliwack River, lower Fraser River	1978–2007	Small stock but with increased production in recent years. Production strongest on the 2004 cycle year.	(+)

Stock Name	Timing Group (MU)	Main tributary system	Years of Surveys	Comment	Trend
Cultus River Appendix Fig. B.2	Late Summers	Lower Fraser River	1952–2007	Cyclic pattern with largest abundance on the 2005 cycle year has broken down since 1991, recent production very depressed, assessed by COSEWIC as endanger in 2001? Recovery efforts have been hampered by late-run sockeye mortality issues. Returns from hatchery mitigation measures have made up increasing fractions of the total production in recent years.	(-)
Eagle River	Early Summers	Shuswap Lake, South Thompson River	1989–2007	Limited data, very strong production on 2006 cycle year, but limited production in other years.	(-)
Fennel Creek	Early Summers	North Thompson River	1966–2007	Relatively small stock without cyclic production, no long term trend in production but recently increasing.	(+)
Gates Creek & spawning channel Appendix Fig. B.1	Early Summers	Flows into Anderson Lake, east of Lillooet	1952–2007	Production strongest on dominant 2004 cycle year. Long term trend in production has increased, although recently has declined.	(-)
Harrison River	Late Summer	Outflow of Harrison Lake, lower Fraser River	1952–2007	No cycles in production but recent increasing trend is reversing a period of decline despite fact stock appears to be affected by Late-run sockeye mortality issues.	(+)
Horsefly River Appendix Fig.B.1	Summers	Flows into Quesnel Lake and then Quesnel River	1952–2007	Highly cyclic production with largest abundance on the 2005 cycle year. Returns on the 2006 cycle increased until 2006 when a poor return resulted following two record escapements in 2001 and 2002. Some evidence of large escapements and resulting fry abundances depressing fry growth and subsequent survival of the 2002 brood. Production has recently declined from record levels in early 1990s.	(-)
Lower Shuswap River	Late Summers	South Thompson, flows into Mara Lake	1952–2007	Largest returns on 2006 cycle year but very low production otherwise in other years.	(+)
Mitchell River	Summers	Upper Quesnel Lake	1981–2001	Strong production cycle in 2006 year following rapid increases since the mid 1980's. Returns on the 2006 cycle increased until 2006 when a poor return resulted following two record escapements in 2001 and 2002. , no long-term trend.	NE
Nadina River & spawning channel	Early Summers	Flows into Francois Lake, upper Nechako River	1952–2007	Production has been quite variable but very strong on 2004 cycle, no long-term trend is evident.	NE
Nahatlatch River	Early Summers	East of Fraser canyon	1976–2007	Small stock, but production has strongly decreased in recent years.	(-)
Pitt River + hatch.	Early Summers	Upper Pitt Lake, lower Fraser River	1952–2007	No cyclic pattern in abundance, but recently production has been improving compared to the previous declining trend.	(+)

Stock Name	Timing Group (MU)	Main tributary system	Years of Surveys	Comment	Trend
Portage Creek	Late Summers	Between Anderson and Seton lakes	1953–2007	Relatively small stock with variable production. Current population is a result of eggs transplanted from Lower Adams River in the 1950's. Decreasing trend in production has been evident in recent years related to late-run sockeye issue.	(-)
Raft River	Early Summers	Upper North Thompson River	1952–2007	Relatively small stock but with stronger production in 2004 cycle year.	(+)
Scotch Creek	Early Summers	Shuswap Lake, South Thompson River	1980–2007	Greatest production on the 2006 cycle year, with very limited production on other years. Recent cycle years have remained strong.	(+)
Seymour River	Early Summers	Upper Shuswap Lake, South Thompson River	1952–2007	Greatest production on the 2006 cycle year, but other years have limited production. Declining trend in production over recent years.	(-)
Stellako River	Summers	Flows into Nechako River, upper Fraser River	1952–2007	No cyclic pattern in production. Production has declined in recent years.	(-)
Stuart River (early run group) Appendix Fig. B.2	Early Stuart	Stuart River, above Prince George (32 spawning streams)	1952–2007	Largest returns previously occurred on the 2005 cycle line, but production has drastically declined since 1997 when the success of upstream migration was reduce during a high flow event in the mainstem Fraser.	(-)
Stuart River (late timing group) Appendix Fig. B.2	Summers	Stuart River, above Prince George (7 spawning streams)	1952–2007	Largest returns on 2005 cycle year but production has declined substantially through early 2000s. No long-term trend is evident. Both Early and Late Stuart has been subject of research efforts to determine causes of recent declines.	NE
Taseko River	Early Summers	Flows into Chilko River and then Chilcotin River	1986–2007	Two best years of production observed in 1992 and 2006, but overall production has been quite variable. No long-term trend is evident. Turbid water conditions pose challenges for visual surveys of spawners.	NE
Weaver Creek & spawning channel Appendix Fig. B.2	Late Summer	Harrison River, lower Fraser River	1952–2007	Long-term trend is positive but recent production has been declining associated with late-run sockeye mortality issues.	(-)
Widgeon Creek	Late Summer	Lower Fraser River slough, Pitt Lake	1996–2007	Relatively low and variable production. No obvious trend in total returns, but visual surveys of spawners show pattern of low abundance since 1991. Potential conservation concern.	NE
Big Silver Creek	Late Summer	Flows into Harrison Lake, lower Fraser River	1977–2007	Relatively small stock, but production has increased over the past 10 years.	(+)

APPENDIX B

FIGURE B.1. Total annual adult sockeye returns by return year for major Fraser River stocks.



APPENDIX C

TABLE C.1. Principal sockeye stocks from small lakes along the islands and mainland of the Strait of Georgia region.
Watershed codes from BC Provincial Fisheries Inventory system.

Spawning Stream and Lake	Location (Watershed code)	Assessment and population size	Frequency of assessments
Fulmore River and Lake	Port Neville area (900-521100)	Returns of 2,000 to 4,000 until 1980s but now reduced to approx. 1,000.	Monitored every year 1953–1985 but infrequently since, 2001 return recorded as unknown.
Glendale Creek and Lake	Knight Inlet (900-569800-08600)	Original estimates recorded as 750-3,500 but reduced presently. Average return in past decade only 107 fish.	Very little information recorded since 1962. Past decade average based on only 3 entries. 2001 return recorded as unknown.
McKenzie (Sound) River and Lake	Kingcome Inlet (900-712900)	Population size recorded as 1,000 to 15,000 until late 1970's. Since then average returns only a few hundred per year. Improved to over 1,000 in 2000.	Escapement was recorded every year until 1980 but frequency reduced by one half since. No data yet recorded for 2001.
Heydon Lake & Creek	Loughborough Inlet (900-477600)	Up to a few thousand returns until mid-80's. Survey data not very reliable until weir counts conducted since 2000. Escapement since has average 3000 sockeye. Counts relatively stable since, with the dominant age group being 5_3.	Escapement was recorded every year until 1980s but frequency reduced by one half since. Counting weir operated in 2000–01, 2003–08.*-
Phillips Lake	Phillips Arm (900-447800)	A few thousand to now several thousand annual returns. 2007 return recorded as 1,500. Recent status low but stable.	One of two coastal lake systems with escapements recorded in each year since 1953. Majority of sockeye spawn in the Clearwater tributary.
Village Bay Lake and Clear Creek	Quadra Island (905-291000-76900)	No sockeye recorded until 1970 and increased through 1980s. Poor returns recently (except in 1997). No returns since 2003 with possible extirpation (Fig. 4.3).	Limited monitoring during the 1990s and no data obtained in 2001. A fence installed in X was not used in 2008 given lack of returns in recent years.
Ruby Creek and Sakinaw Lake	Lower Jervis Inlet (900-147300)	See Fig. 4.3	Data recorded for every year since 1953.
Tzoonie River and Lake	mid-Jervis Inlet (900-19500)	Escapements prior to 1970 were 400–7500 annually. No sockeye recorded after 1970.	Since 1970, records indicate none observed or Unknown since 1970.
Quatse River and Lake	Port Hardy Area	Typical run is 500–5000, but 2006–08 estimates are 1328, 773, 1764. Earliest run timing in the area (start May, ends early July).	Sockeye known to inhabit this system but no accurate numbers in past years. DIDSON counters used for monitoring recently.

APPENDIX D

TABLE D.1. Summary of spawning escapements in the Inner South Coast Chum population aggregate, based largely on data compiled by Ryall *et al.* (1999) for 1953–1997.
Does not include summer stocks (e.g., Ahnuhati R.).

Stock group by region	Location	Escapement status	Frequency of surveys	General trend in escapements
Seymore/ Belize Inlet	Northernmost region of the ISC chum, mainland inlet in lower Queen Charlotte Sound	Region has 19 relatively small populations, overall escapement has only averaged 22,000 based on 1953–97, stock not harvested in Clockwork fisheries	12 of 19 populations surveyed at least once in every 2 years up to 2003. Coverage reduced since 2003 due to funding constraints.	Slight decline over survey period. No information on escapement trends for recent years.
Upper Vancouver Island	North end of Island down to Cluxewe River	Region has 8 chum systems but escapements very depressed since the 1970s with total escapement currently in the hundreds.	2 of the 8 populations surveyed at least once in every two years	Long term decline in escapements, Slight improvement in recent years, but survey coverage reduced.
Kingcome Inlet	Mainland area, lower Queen Charlotte Sound	Region has 16 chum systems, total escapement currently only a few thousand and less than 1% of management goal.	4 of the 16 populations surveyed at least once every 2 years. Each of these was historically of moderate size.	Long term decline in escapements except during mid 1970s. Some improvements since 2000.
Bond & Knight Inlets	Mainland area, upper Johnstone Strait	Region has 25 chum systems, total escapement currently several thousand but less than 10% of management goal.	6 of the 25 populations surveyed at least once every 2 years. Most small populations not surveyed. Larger populations surveyed more consistently.	Steady long term decline in escapement, with lows during the 1990s. Some improvements since 2000.
Johnstone Strait	Vancouver Island, Port McNeill to Campbell River (streams do not include Quinsam or Campbell rivers)	Region has 16 chum systems including the Nimpkish River, that accounts for >90% of total escapements over the past two decades.	6 of the 16 populations surveyed at least once in every 2 years.	Total escapements have been declining slowly over time. Recent survival rates are very low, especially in the Nimpkish watershed that used to produce 90% of area returns.
Loughborough & Bute Inlets	Mainland area, mid Johnstone Strait	Region has 35 chum systems including major production in the Southgate River (3 to 4 streams account for >90% of total escapement). Trends in smaller systems are highly variable.	7 of the 35 populations surveyed at least once in every 2 years. Some of the larger populations have not been surveyed since 2003 due to funding constraints. These include the Southgate and the Homathko at the head of Bute Inlet.	Trend is relatively stable over the regular survey period, but no recent information on the state of the most important populations due to the recent reduction in survey coverage.
Mid Vancouver Island	Vancouver Island, Campbell River to Nanoose Bay	Region has 36 chum systems including 3 major hatcheries . Hatchery production makes up >90% of the total production in this area.	Survey coverage was substantially reduced from >20 of the 36 systems to only 8 in recent years.	Improving trend since the late 1980s. Insufficient information to determine trends for smaller systems due to reduced survey coverage.

Stock group by region	Location	Escapement status	Frequency of surveys	General trend in escapements
Toba Inlet	Mainland area, upper Strait of Georgia	Region has 16 chum systems	4 of the 15 populations surveyed at least once in every 2 years. Coverage of some large producers (e.g., Theodosia) are too infrequent to monitor trends.	Some signs of improvement since the 1990s. But very limited returns recorded since 2000. Trends unclear given recent reduction in survey coverage.
Jervis Inlet	Mainland area, central Strait of Georgia	Region has 36 chum systems, escapement quite consistent over time. Five systems account for most returns. Many other systems also show consistent returns over time.	Survey coverage reduced since 2000. Only 15–17 of the 36 populations have been surveyed consistently.	Increasing trend but significant declines in mid 1990s. Slight improvements since 2000.
Lower Vancouver Island	Vancouver Island, Nanoose Bay to Crofton	Region has 18 chum systems including the Nanaimo River, which accounts for about 80% of the total production.	Survey coverage greatly reduced since 2004, and now includes only 1 tributary to the Nanaimo River. Only one of the 18 populations surveyed at least once in every 2 years.	Regional trend is driven in recent years by the Nanaimo River escapements, which have been improving slowly since the 1990s.
South Vancouver Island	Vancouver Island, Crofton to Port Renfrew (excludes streams at Port Renfrew)	Region has 6 chum systems with strong returns to Cowichan, Chemainus and Goldstream rivers.	Survey coverage has been reduced in recent years, and now includes only 2 systems. DIDSON counters used since 2007 because visual estimates considered unreliable due to turbidity problems.	Increasing trend over time, but highly variable escapements in recent years.
Howe Sound & Sunshine Coast	Mainland area, central Strait of Georgia	Region has 56 chum systems but Squamish watershed accounts for vast majority of returns.	7 of the 56 populations surveyed at least once in every 2 years. Survey coverage severely reduced in recent years compared to the pre-1990 levels.	Trends uncertain due to low survey coverage historically, coupled with further reduction in recent years. Some evidence of declining escapement in the 1990s, and improvements since 2000.
Burrard Inlet	City of Vancouver	Region has 13 chum systems but Indian River is the only significant producer.	Survey coverage has been reduced periodically, and now focuses only on the main producer (Indian R.).	Total escapements have been steadily declining since the late 1990s.
Fraser River	Fraser River, south Strait of Georgia	Region has 121 chum systems with recorded escapements and 7 have average annual escapements >10,000 chum.	41 of the 121 populations surveyed at least once in every 2 years. Many others surveyed during >40 of the past 45 years. Numerous small populations infrequently inspected.	Escapements increased since the 1980s, few localized systems show declining escapements.
Boundary Bay	Mainland area, south of Fraser River	Region has only 4 small chum systems	Only the Campbell River has been surveyed often (39 of 55 years). Not surveyed recently.	No long term trend given very small population size and inconsistent surveys.

APPENDIX E

TABLE E.1. Sockeye salmon systems along the west coast of Vancouver Island that have access to rearing lakes.
Watershed codes from BC Provincial Fisheries Inventory system.

Spawning Stream and Lake	Location (Watershed code)	Assessment and population size	Frequency of assessments
Cheewhat Lake	Outer SW Vancouver Island (930-070100)	Returns of 2,000 to 5,000 during late 1980s but only recent escapement value was 1,000 in 2000. Spawning habitats have deteriorated recently, the planned restoration activities are uncertain.	Escapement records before the mid-1980s are dubious, and only one survey was conducted since the end of the Lake Enrichment program surveys.
Hobiton Lake	Tributary to Nitinat Lake (930-071700-20600)	Generally less than several thousand spawners, present production less than historical, no improvement in escapement monitoring.	Previously a Lake Enrichment study site. Fence built in 1996 for enumeration is now managed by the local FN band. Escapement data quality has varied over time.
Kennedy Lake & River, Clayoquot River, Cold Creek, Muriel Lake and Creek (off Clayoquot Arm of lake)	Clayoquot Sound (930-306400)	Average escapements to total system recorded at 50,000 during 1950s. Very little directed fishing. Escapements of the lake and rivers populations have declined lately (<20,000).	No directed surveys for the lake and river populations. Annual surveys were required at various sites in this lake system but survey methods changed over time. Evidence of abundance shift from Clayoquot Arm beach spawners to Kennedy River. Muriel Lake is considered to be a distinct population. Acoustic trawl surveys for both Muriel and Kennedy are ongoing. Lower Kennedy River RST operated during the last few years.
Hesquiat Lake and River	North of Clayoquot Sound (930-461400)	Small population and limited escapement records. First monitored in 1968, and spawning levels varied from 18 to 850 until 1982.	Escapement record very limited. No sockeye recorded since 1982 and most records are 'None observed' or 'Not Inspected'.
Megin Lake and River	Clayoquot Sound (930-413500)	Relatively small population with several hundred to 2,000 spawners on average since 1953. No long-term trend is evident in escapement values.	Little survey effort directed on sockeye, with most conducted in the lower river reaches below the lake. Visual enumeration not very accurate because of high tannin levels in the water.
Muchalat Lake & River, plus Oktwanch River	Gold River in Nootka Sound (930-511600-42100)	Moderate size sockeye populations, with reported escapements averaging ≈10,000 from the 1970s through the mid-1990s.	Escapement records since the mid-1990s very limited, and escapements since 2001 have been relatively low (≈600 reported 2001).
Zeballos River and Lake	Upper Espinosa Inlet (930-582200)	Infrequent records of sockeye before the late 1970s, numbers peaked in mid-1990s (x thousands), but 2001 escapement was only ≈500.	Infrequent records before mid-1970s but consistent records through the 1990s.

Spawning Stream and Lake	Location (Watershed code)	Assessment and population size	Frequency of assessments
Park River and Lake	Lower Espinosa Inlet (930-615900)	Outer coast lake with consistent records of several hundred spawners before 1985, with a peak of 4,000 spawners that year.	Consistency of escapement surveys is unknown, but since 1985, only 3 spawning records available (20–100).
Owossitsa Creek and Lake	Lower Espinosa Inlet (930-483000-57000)	Outer coastal lake, similar enumeration history to Park Lake except last year of substantial escapement was recorded in 1980 (≈2,000).	Consistency of surveys is unknown, but escapement surveys infrequent since 1985 and spawners only recorded in 1 year (125).
Jansen Lake and River	Kyuquot Inlet (930-692100)	Coastal lake with similar enumeration history to Park and Owossitsa lakes. Historical records indicate at least twice the escapements levels as the two others.	Last year of escapement record in 1985. Surveys conducted infrequently since, and escapement only recorded in 1992 (50). Records for most other years show 'Not Inspected'.
Power Lake and River	Kyuquot Inlet (930-732300)	Records for 1953–1968 indicate escapement levels of 1,500 to 3,500. Lower and more variable escapements recorded since 1968.	Records after 1968 are mainly 'None reported' or 'Not inspected'. Last substantial escapement record was 1,000 for 1991.
Canoe Creek and Lake	Brook's Peninsula (930-780600)	Very small population on the north shore of the Brooks peninsula but no record of sockeye spawners since 1963.	Records indicate that this population has not been monitored since 1970.
Mahatta Creek and O'Connell Lake	Quatsino Sound (930-823900)	Early records escapements of about 4,000 during the 1950s. Stock has declined to a few hundred in the 1990s. No record for 2001.	While substantial decline is indicated in the escapement records, the comparability of the surveys is unknown.
Marble River and Lakes	Quatsino Sound (930-865200)	Large lake system, but no evidence it ever supported a large population. Records indicate mean escapements of several hundred since 1953.	Surveys less frequent since 1980s and escapement estimates are lower. Ability to detect a true decline in escapement for a small population in a large system problematic, so the reliability of the trends is uncertain.
Fisherman River and William and Brink Lakes	Cape Scott (930-992000)	Records indicate average escapements of 2000–3000 during the 1950s. No records after 1963.	Records for each year since 1970 are 'Not Inspected' or 'Unknown'. Current status is unknown.

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