ASSESSMENT OF STATUS AND FACTORS FOR DECLINE OF SOUTHERN BC CHINOOK SALMON: INDEPENDENT PANEL'S REPORT

FINAL REPORT

Prepared for

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Executive Summary

As part of the broader initiative to address concerns about the current status of Chinook salmon in southern BC, Fisheries and Oceans Canada (DFO) and the Fraser River Aboriginal Fisheries Secretariat (FRAFS) organized a scientific workshop and an independent science panel to evaluate the relative importance of factors that may have affected the abundance and productivity of southern BC Chinook salmon. Working with ESSA Technologies, DFO and FRAFS designed and facilitated a workshop, held May 22-24, 2013 in Richmond, BC. A science panel was commissioned to provide an independent review of the evidence presented and to provide recommendations for future research priorities. This project was predominantly funded by the Pacific Salmon Commission's Southern Endowment Fund, with additional funding and support provided by FRAFS and DFO. This work is also concurrent with both preparations for the upcoming assessment of southern BC Chinook salmon by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and ongoing efforts to implement Canada's Policy for the Conservation of Wild Pacific Salmon (DFO 2005).

This Executive Summary highlights key observations, conclusions, recommendations, and identified information gaps for each topic that was discussed at the workshop and subsequently investigated by the Panel.

Geographic Scope of the Study

The scope of this study was substantial, involving spawning locations for Chinook salmon from the head of the Fraser River downstream to the Strait of Georgia, the mainland inlets of the Strait of Georgia and Johnstone Strait, and including all streams on Vancouver Island. These streams had been organized into 35 Conservation Units under Canada's Wild Salmon Policy capturing extensive diversity in life history traits, ocean migration patterns, and histories of fishing impacts. DFO had also categorized these streams by the quality and consistency of annual surveys to enumerate spawning populations, and assigned qualitative categories for their interactions with hatchery programs.

Departmental records account for about 400 Chinook spawning sites in southern British Columbia but these are not each a functional population. Populations may be composed of local networks of spawning sites that in aggregate make up an effective population (usually within a single watershed in these analyses). Other individual sites may have spawners intermittently or have consistent observations of very small numbers of fish (set at < 25 fish per year). Such small populations may also have irregular Departmental records and are subject to greater uncertainty in observation for a variety of reasons, including (but not limited to) less survey effort, variation in timing of surveys and visibility conditions, etc. However, based on the Departmental review for DFO (2013), analyses in this review were based on 157 time series (involving 226 spawning sites) of Chinook spawning estimates within 35 Conservation Units in southern BC (**Table ES-1**). These time series were assessed as having persistent records of spawners (i.e., sites have records for greater than 50% of years) within a period of verified records (1995-2012), or as being extirpated. The latter was defined as having had a persistent record of spawners in the past but have more recently declined to very small numbers or no recent observations at all. Readers should note that extirpated is an assessment of spawning records in this context and should not be used to assume a population is extinct as no direct investigations of their present state were conducted. Also, eight sites have been excluded from this review where extensive supplementation has occurred using non-native source populations (i.e., source populations from outside the CU), regardless of the persistence of recent escapement records.

Further, within the Persistent sites, the streams were also categorized based on the extent of enhancement activity within them: (Unknown levels, assumed to be low to no enhancement but could include some level of straying), Low enhancement, Moderate enhancement, High levels, and 8 sites included stock transfers between Conservation Units, designated as High-Cross_CU).

Limitations and Realistic Expectations

There are substantial constraints and limitations on the information available to address the objectives of the workshop and this report. Chinook salmon are subject to a complex array of human and natural drivers, and limited resources are available to understand these multiple dimensions and their interactions. Chinook salmon occupy a variety of freshwater and marine habitats across broad geographic range, and each habitat represents a complex system of biotic and abiotic factors that vary over time and space. Due to insufficient information being available prior to the workshop, it was not possible to quantitatively assess the relative likelihood of different factors in contributing to recent trends in southern BC Chinook salmon stocks. Readers should expect that the report will provide an objective, independent evaluation of the information presented at the workshop, identification of key uncertainties and data gaps, and recommendations for reducing those uncertainties.

Status and Trends

Observations and conclusions:

Spawner abundances of most Conservation Units (CUs) of Chinook salmon in Southern B.C. have decreased substantially over the most recent 3 fish generations (about the last 12 years). For spawning sites that were categorized by DFO as having a "low or unknown" level of enhancement activity, which occurred in 21 CUs, 13 of those CUs showed more than a 50% decrease in spawner abundance in the last 3 generations, 7 of which declined more than 70% and one dropped by 97% (**Figure ST-1**, panel a). Five CUs showed increases and three CUs showed decreases between zero and 50%.

Table ES-1. Distribution of spawning sites used in this review by Conservation Unit. Source: Salmon Assessment, Science Branch, DFO.

Area	CU Index	CU Name	Adult Run Timing	Major Juvenile Type	Time Series for Analysis (Aggregated Sites)[1]
Fraser River Conservation Units					
Fraser-Lower	CK-03	LFR-fall	FA	ocean	1
	CK-04	LFR-spring[2]	SP	stream	1
	CK-05	LFR-UPITT	SU	stream	1
	CK-06	LFR-summer	SU	stream	1
	CK-07	Maria	SU	ocean	1
	CK-9000	(P)HatchX-LFR	FA	ocean	1
Fraser-THOM	CK-13	STh-0.3	SU	ocean	4 (1)
	CK-14	STh-1.3	SU	stream	2
	CK-15	STh-SHUR	SU	ocean	2
	CK-16	STh-BESS	SU	stream	4
	CK-17	LTh	SP	stream	6 (3)
	CK-18	NTh-spr	SP	stream	2
	CK-19	NTh-sum	SU	stream	5
	CK-82	Adams-upper	SU	ocean	1
Fraser-Upper	CK-08	NAHAT	SP	stream	1
	CK-09	Portage	FA	stream	1
	CK-10	MFR-spring	SP	stream	12 (7)
	CK-11	MFR-summer	SU	stream	6 (2)
	CK-12	UFR-spring	SP	stream	27 (6)
Coastal Conservation Units					
Columbia R	CK-01	OK[3]	SU	stream	1
GS+OK	CK-02	BB	FA	ocean	1
	CK-20	SC+GStr[4]	FA	ocean	6 (14)
	CK-21	Goldstr	FA	ocean	1
	CK-22	CWCH-KOK	FA	ocean	1 (4)
	CK-23	NanR-spr	SP	stream	1
	CK-24	midEVI-sum	SU	ocean	2 (1)
	CK-25	midEVI-fall	FA	ocean	2 (2)
	CK-27	QP-fall	FA	ocean	4 (2)
WCVI/NEVI/USC	CK-28	SC+SFj[5]	FA	ocean	10
	CK-29	NEVI	FA	ocean	5 (1)
	CK-31	SWVI	FA	ocean	20 (20)
	CK-32	NoKy[6]	FA	ocean	21 (3)
	CK-33	NWVI	FA	ocean	2 (2)
	CK-34	HOMATH	SU	stream	0
	CK-35	KLINA	SU	stream	1 (1)

1. This column contains the number of time series of escapement estimates defined as persistent (i.e., estimates of sufficient quality are available for 50% or more of years between 1995-2011) or extirpated (i.e., numbers of fish have dwindled to the extent that no fish are observed within the spawning period or are so sparse that the site is no longer inspected). These time series have met or exceeded data quality and completeness criteria and are considered adequate for representation of trends in abundance.
2. Two systems (Alouette River and Stave River) composing the Lower Fraser-spring CU are categorized as extirpated. The original native spring runs have been lost and while Chinook currently spawn in these rivers, they originate from another CU with a fall, ocean-type life history pattern.
3. CK-01 (Okanagan) is grouped with the Coastal CUs for convenience even though the fish in this CU enter or exit the marine environment in a geographically distinct location relative to the other Chinook salmon CUs in southern British Columbia.
4. Three systems (Skwawka River, Toba River and Tzoonie River) in the South Coast-Georgia Strait CU have been categorized as extirpated. Historical records of observed fish show that Chinook salmon spawned annually in these systems (most notably in Toba River) but numbers dwindled and records of zero observed spawners in more recent years suggest extirpation or very low current abundance. These systems could possibly be categorized as data deficient but whether categorized as extirpated or data deficient, their contribution to an aggregate escapement time series for the CU from 1995-2012 is either very small or zero.
5. Three systems (Ahnuhati River, Southgate River and Teaquahan River) in the South Coast-Southern Fjords CU have been categorized as extirpated. Historical records of observed fish show that Chinook salmon spawned annually in these systems in modest to substantial numbers (most notably in Southgate River) with regular annual surveys. The reported numbers dwindled with records of zero observed spawners in more recent years suggesting extirpation or very low current abundance These systems could possibly be categorized as data deficient but whether categorized as extirpated or data deficient, their contribution to an aggregate escapement time series for the CU from 1995-2012 is either very small or zero.
6. Three systems (Deserted Creek, Eliza Creek and Park Creek) in the Southwest Vancouver Island CU have been categorized as extirpated. Historical records of observed spawners are infrequent and low for Eliza Creek. Records for the other two systems were modest but regular until the early 1980s when reports of no spawners became more common. DFO biologists consider these systems to be extirpated or at very low abundance.

For these data sets that are the least confounded by hatchery contributions, Fraser and Thompson Rivers stocks with stream-type juvenile life-history (i.e., overwinter in rivers and then go to sea as yearlings) represent the majority of those cases with decreasing spawner abundance in the last 3 generations.

Longer-term data back to the 1970s show that many southern B.C. stocks apparently started to recover from low spawner abundance after harvest rates were reduced after the 1985 Pacific Salmon Treaty was implemented. However, several of those stocks have again subsequently dropped to low abundance over the last 3 generations, adding to the concern that stimulated the organization of this workshop and expert panel.

In 4 of the 5 stock groupings of southern B.C. Chinook salmon (Fraser River Late, Lower and Upper Strait of Georgia, and West Coast of Vancouver Island), marine survival rates have decreased substantially from their highs in the 1970s or 1980s to their lows in the 1990s and 2000s. Regions outside of southern B.C. also had decreased survival rates, but in several cases, there was a temporary increase in the late 1990s and early 2000s followed by a decline. The marine survival rates describe the proportion of juveniles leaving their freshwater habitat that are alive after their first winter at sea. These proportions are estimated via the extensive coast-wide coded-wire tagging (CWT) program and a cohort reconstruction model.

Indices of life-cycle productivity from spawners to adult recruits were generated by the Pacific Salmon Commission's (PSC) coast-wide Chinook model, but they are of uncertain relevance to naturally spawning fish because many of these "model stocks" include large, temporally varying, and/or unknown fractions of hatchery fish in ocean catches and spawning escapements. Normally, catches and escapements that result directly from hatchery releases are excluded from standard stock-recruitment analyses designed to assess performance of naturally-spawning fish. Despite these concerns about interpreting these life-cycle productivity indices, they tend to be positively correlated with the time series of CWT-derived marine survival rates for stocks in the same region, i.e., they tend to show generally similar, but certainly not identical, time trends.

Life-cycle productivity decreased substantially over time for Lower Strait of Georgia and Robertson Creek Chinook salmon, but only slightly, though steadily, for the Fraser Late stock. Other Southern BC stocks show either no trend in productivity indices, or slight increases. Numerous stocks outside of Southern B.C. have also shown a decrease in productivity, especially since the late 1990s or early 2000s, including central and western Alaska stocks. The latter Alaskan stocks had high-quality spawner and recruit data that were not confounded by hatchery contributions.

Comparisons across Chinook salmon stocks of time series of the age-2-cohort marine survival rates show a tendency for an underlying trend of shared variation from Oregon through B.C., and even into some Alaskan stocks. That shared trend shows increasing survival rate from ocean-entry year 1995 to around 2000, decreasing until 2005 and then a partial reversal. However, in many stocks, there also are stock-specific sources of year-to-year variation that mask that underlying trend.

Southern B.C. Chinook stocks exhibit temporal patterns in life-cycle productivity, and to a lesser extent age-2 cohort survival rate, that are shared to various degrees across a large spatial area from Oregon up through western Alaska. Thus, it seems likely that there are large-scale processes influencing Chinook productivity.

Critical information gaps:

Sufficient data for assessment were available for about one half of the spawning sites reported. While this could be a sufficient sample if statistically designed, DFO spawner data reflect a poorly quantified contribution of hatcheries and other enhancement methods to total spawners, and a limited time series. The information gaps regarding hatchery contributions in particular, as discussed under the Hatchery section, seriously impede the analysis of status and trends in natural spawning Chinook populations, and most especially the identification of causes of those trends.

DFO is still in the process of validating Chinook spawner data collected prior to 1995. We strongly encourage the completion of this validation on all earlier data because longer-term trend data are essential for understanding patterns of change in abundance over time and space.

Catch data for some Chinook stocks are incomplete because they do not include all components of freshwater harvest and/or because there is incomplete accounting for recreational fishery catches.

Additional CWT indicator stocks are needed, especially for Upper Fraser River spring Chinook salmon stocks, which have a yearling juvenile life history and offshore ocean distribution pattern, and which appear to have had the most dramatic recent declines in spawning escapements.

With many confounding factors involved in explaining time trends in abundance of spawners, CWT studies are the best means to estimate marine survival, rates of maturity, ocean distribution, and total exploitation rates over the life of Chinook salmon. It is therefore critical that these CWT data series be established for indicator stocks with life history types that are currently under-represented, such as stream-type spring Chinook for which adults and immature fish have an offshore ocean distribution.

In many cases, data on age-at-return, body size, and sex composition are inadequate for analysis and must be included in future annual monitoring.

HARVEST

Observations and conclusions:

Very substantial reductions in total BC catch of Chinook salmon (originating from BC, Alaska, Oregon and Washington) occurred from 1975 to 1995; catch has been relatively steady post-1995 (**Figure ST-2).** More relevant to this review is a substantial decline in total coast-wide ocean catches of Chinook *originating from southern BC streams* (**Figure H-8).** Most of the decline in total catch has been attributable to reduced commercial fishery landings. Commercial landings were roughly twice sport fishery landings from 1975 to 1980, whereas today they are approximately equal (**Figure H-5**).

Ocean distribution patterns for southern BC Chinook can be grouped into three distinct types: far-north-migrating, local-distributed, and offshore. Far-north migrating stocks contribute to Alaskan fisheries, whereas locally-distributed stocks do not. Offshore-type Chinook are vulnerable primarily as returning mature adults in coastal areas on approaches to natal streams.

Total exploitation rates are the fraction of adults harvested in fisheries over a brood year's complete life span, and are computed based on CWT recovery data for indicator stocks. Total exploitation rates of southern BC Chinook stocks declined substantially over brood years 1973-1993 for both Far-north migrating and locally-distributed stock types, from an average of approximately 75% to an average of about 45%. Rates in the range of 70% to 80% are likely well above those that would have achieved maximum sustainable yield (MSY) during periods of average productivities. Total exploitation rates for all three ocean distribution types have been similar since about the 1993 brood year and have ranged from about 25% to 50%. Despite these dramatic reductions in total exploitation rates and ocean fishery landings, many stocks have experienced declines in spawning escapements over the past three generations.

Mean CWT-based estimates of survival from release to ocean age 2, a proxy for marine survival conditions for most stocks, were relatively high for far-north-migrating and locally-distributed stock types over brood years 1973 to 1993, but since then have been much lower.

The relatively long and steady period of low marine survivals that have been experienced by most southern BC Chinook stocks suggests that there has probably been a corresponding decrease in stock-specific productivities. In the Harvest section we show, for illustrative purposes, that if current stock-specific productivities have been reduced to one half of the past "average productivities", then recent exploitations rates could exceed MSY total exploitation rates that would be appropriate for many stocks currently, despite the substantial reduction from past much higher rates. If this were the case, then even the reduced exploitation rates could still be a contributing cause to the recent declines in escapements. Reductions in stock-specific productivities may not have been as great as 50%, however, and in our recommendations in the Harvest section we provide suggestions for methods that might allow more rigorous assessment of stock-specific changes in productivity from their long-term average values.

Critical information gaps:

The limited number of indicator stocks, especially for the offshore ocean distribution type (stream-type spring Chinook), limits the level of assurance with which estimates of total exploitation rates for indicator stocks can be used to infer likely exploitation rates for untagged stocks of interest. Inconsistency in estimated total exploitation rates for Dome Creek (no longer tagged) and Nicola River spring Chinook is also of concern. It is important to have at least one additional indicator stock for the offshore ocean distribution type, with a strong preference for the upper Fraser region.

Quantitative abundance estimates (rather than qualitative indexes) of spawning escapements and freshwater harvests are lacking for most southern BC Chinook CUs, thereby ruling out formal stock-recruitment analyses for estimation of stock-specific productivities and assessment of possible temporal changes in productivities. Watershed and habitat-based methods for estimating productivities likely have merit, but they are less desirable than stock-recruitment analyses, in particular because they do not allow incorporation of marine survival rates as a factor that may influence recruitment production.

We note the critical role that estimates of total exploitation rates and marine survival rates, based on tag recoveries of CWT releases of indicator stocks, have played in our assessment of the possibility that harvest (and also ocean environment) may be a continuing serious stressor on southern BC Chinook. It is critical that such estimates are available in the future.

Freshwater Habitat

Observations and conclusions:

Southern BC Chinook salmon CUs vary in size, and CUs often contain many spawning groups as well as a large number of watersheds. For freshwater mortality to be a driver of trends in abundance or productivity within or among CUs, it must operate at a large spatial scale comparable to that observed for covarying populations or CUs, or it must operate on a habitat that is used by all populations at some point in their life cycle (i.e., for mainstream rearing habitats or during downstream migration). For this report, the Panel examined stressors that cause variation at the CU level, and could potentially extend to multiple CUs for cases with adjacent CUs.

There is little evidence from the literature to support the hypothesis that large-scale environmental forcing across broad geographic areas such as the southern BC region can cause coherence in abundance or survival of salmonids during the spawning and freshwater rearing stages. The impacts of large-scale environmental factors appear to be "translated" to effects on stream biota by the nature of the catchment, with effects depending on variation in both catchment attributes and freshwater life history strategies.

The mortality of adult salmon (particularly sockeye) migrating upstream in the Fraser River has become much more common in the past 2 decades, and is coincident with a rise in river temperature to critical levels related to climate change (Martens et al. 2011). Mortality at the spawning areas is also observed. Many summer run Chinook salmon populations migrate during the period of peak river temperatures, and they are exposed to increasingly stressful temperatures > 18^{o}C (Hague and Patterson 2009). Because this mortality occurs directly on returning fish, it could be a contributor to trends in adult Chinook abundance. This mortality is not currently estimated.

From a population perspective, habitat degradation can cause a decline in salmon abundance through two mechanisms: a) continuous deterioration of freshwater habitats coincident with declines in salmon productivity, and/or b) interactions between human-induced declines in habitat quality and other stressors, whereby populations from poorer freshwater habitats are more vulnerable to other stressors later in their life history, such as harvest or deteriorating marine conditions.

The major developments in watersheds that produce Chinook salmon in the southern BC region were largely completed 50 or more years ago (e.g., agriculture, flood control dykes, modifications to estuaries, water withdrawals in the Thompson drainage, major hydroelectric facilities). Human activities which have continued to increase include urbanization, forestry, Mountain Pine Beetle, and changes in land cover, but there is no readily available means to track these changes and compare them to trends in Chinook salmon abundance or productivity. No correlations were found between recent trends in escapement and a set of "pressure indicators" developed under the Wild Salmon Policy. Indicators were a snapshot of potential stressors, some of which are based on recently collected data; however those indexing changes in land use are over 20 years old. This lack of correlation may reflect weaknesses in the pressure indicator data (i.e., inappropriate or imprecise indicators), the consequences of variability in survival through non-freshwater components of the life cycle, a lack of vulnerability of Chinook salmon in larger rivers to the habitat stressors that the pressure indicators are attempting to measure or improvements in standards of practice for many industries and activities in recent years.

Flow and water temperatures are impacted by flow regulation installations at many sites, particularly on Vancouver Island. Those rivers also have major hatcheries making it difficult to elucidate the impacts of environmental conditions on wild / natural fish production or abundance.

There are few consistent trends in environmental variables over the past 15 years (3 generations), except for increases in mid-summer air temperatures in some regions, and the increased incidence of stressful high (>18° C) river water temperatures. These could have an effect on survival during upstream migration, survival after exposure to in-river fishing gear, and reproductive success.

We conclude that there are no obvious freshwater environmental drivers that could explain recent trends in Chinook salmon spawner abundance.

Critical information gaps:

Tracking the role of freshwater habitat changes in the production of juvenile Chinook salmon in SBC is extremely difficult given the diversity of Chinook salmon life histories and habitat use within the region. Establishing a long-term monitoring program for juvenile stages is challenging given the size of the rivers, and the diversity of habitats that a single population can use. Appropriate management of land and water use, and activities in and around water can ensure habitats remain functional over time.

There is likely a more direct link between river temperatures and flow conditions and the survival and reproductive success of adults migrating upstream to their natal areas (e.g., Strange 2012). In light of projections of warming temperatures in many rivers during the migration of spring and summer run Chinook salmon (Patterson, et al. 2009; Hasler et al. 2012), the monitoring of river temperature and migration and reproductive success is warranted as this can allow for in-season adjustment of fisheries in response to adverse environmental effects. This approach is currently being used for Fraser River sockeye salmon and could readily be adapted for Chinook salmon populations where high temperatures are problematic.

MARINE HABITAT

Observations and conclusions:

As noted in the Status and Trends section, workshop presentations documented declines in abundance of spawners between 1995 and 2012 for most stocks of SBC Chinook salmon across CU aggregates (**Figure ST-1**). These declines have occurred despite substantial reductions in harvest rates and large differences between CUs in the scale of anthropogenic habitat alterations and enhancement activities. The general declines in spawner abundances across CUs suggest that mortality causing the decline occurred in habitat shared by SBC stocks.

Graphs of actual survival rates suggest that much of the decline in survival conditions for BC Chinook salmon occurred following the 1980s; survival rates have been generally low since then (**Figures H-11, ST-3**).

Not all SBC Chinook salmon stocks have shown a pattern of decline in marine survival (**Figures MH-1**, **ST-3**). Chinook salmon from the Thompson summer CU and other salmon stocks with early (prior to May) or late (July or later) entry timing into the Strait of Georgia have fared better than those with the more common May/June entrance timing, suggesting that temporal differences in marine conditions can have strong effects on early marine survival.

Climate indices show cyclic variation over time and influence conditions in salmon marine habitats. The North Pacific Gyre Oscillation (NPGO) shown in **Figure MH-5** has exhibited a pattern since 1995 similar to the widely shared trend in marine survival derived from dynamic factor analysis (**Figure ST-11**); the correlation coefficient (r) between the two time series on those figures is 0.78.

Physical and biological oceanographic conditions can vary greatly at regional and local scales (**Figure MH-6**). Such differences result in differences in primary and secondary production in terms of quantity of the production, prey types, and timing of prey availability. Synchrony of entry timing, distribution, and migration of juvenile Chinook salmon with phytoplankton blooms and secondary production peaks may be critical for growth and survival (**Figure MH-7**).

Top-down predation processes may be a major factor in salmon survival under certain conditions. A number of marine mammal populations in SBC have increased dramatically in recent decades. Some conservation units of Chinook salmon may be more vulnerable to opportunistic predation by marine mammals because of marine mammal distribution. Simulation modeling indicates that commensurate with the increased abundance of marine mammals, mortality rates of Chinook salmon from marine mammal predation increased in 1990 to a relatively stable but higher level than occurred from 1960 through the 1980s (**Figure MH-10**). Exploitation rates of Chinook salmon have declined substantially from the 1970s to the present (**Figure H-13**). As a result, marine mammal predation may now be a more significant mortality factor than fishery removals for SBC Chinook salmon, while total mortality rates due to both marine mammal predation and fishing is considerably less in recent years than pre-1990 (**Figure MH-10**). Because total mortality rates from both these sources have declined substantially from approximately 1980 through 2003, it is unlikely that these factors were driving the general decline in

SBC Chinook abundance since 1995. However, the higher rate of marine mammal predation in recent years may indeed affect the ocean abundance of Chinook salmon during periods of low stock productivity, and inhibit recovery of depressed stocks through depensatory mortality.

No consistent association was found between Chinook salmon marine survival and major blooms of harmful algae (**Figure MH-11**). Data presented at the Workshop indicated no effect of pink salmon juveniles on marine survival of SBC Chinook salmon (**Figure MH-12**).

The Panel concluded that conditions in the marine environment during the first year of marine residency of SBC Chinook salmon were very likely a key driver in recent trends in survival and productivity. Both local and basin-scale oceanographic conditions are affecting marine survival. There is strong evidence of direct effects of local marine conditions on the survival of Chinook salmon, especially in the Strait of Georgia. Differences in marine survival in relation to migration timing demonstrate the adaptive value of the wide diversity in life-history strategies of SBC Chinook salmon. It is not clear whether the large-scale effects reflect atmospheric and oceanographic conditions that similarly influence local marine conditions encountered by juvenile Chinook salmon across a wide geographic range, or whether they are the result of later mortality in shared ocean habitats.

This conclusion is consistent with the findings of the expert panel reviewing the decline of Fraser River sockeye salmon and the disastrous sockeye return in 2009 (Peterman et al. 2010). They also concluded that ocean conditions inside the Strait of Georgia were likely a major causal factor in the long-term declines in Fraser sockeye productivity and very likely to be a major factor in the extremely low productivity associated with the 2009 return.

Critical information gaps:

The Panel has identified the first year of ocean residency of SBC Chinook salmon as the life history phase most likely to explain the decline in productivity and recruitment of these fish. Better understanding of the ecological processes affecting this life history phase could contribute to 1) identification of limiting factors; 2) development of strategies to mitigate or compensate for such factors; and 3) improvement of forecasting models for adaptive management of salmon fisheries and escapements. To achieve these objectives, the Panel recommends continued support and improvement of long-term, integrated oceanographic and ecological research in the Strait of Georgia and coastal WCVI.

Essential to the Panel's conclusion on the importance of marine conditions to the status of SBC Chinook salmon was the capability to track marine survival for a number of indicator stocks of Chinook salmon. This capability depends on a robust system of coded-wire tagging of hatchery smolts, and intensive sampling for tags in salmon fisheries and returns to hatcheries and spawning areas. Maintenance of the coded-wire system is crucial to monitor marine survival and annual variation that can be associated with marine environmental factors.

Coded-wire tagging of selected wild stocks should also be considered to provide information on marine survival for CUs that are not represented by hatchery indicator stocks.

Forecasting of Chinook salmon is an important component of coastwide management. Pre-season forecasts provide managers and users insights into the potential scope of harvests and management constraints to meet escapement goals. Improved understanding of factors in the marine environment affecting salmon survival may provide opportunities to improve standard forecast models. Monitoring may also identify factors associated with the marine survival of Chinook salmon that can then be used to directly forecast survival or year-class strength.

Salmon in the ocean are vulnerable to natural mortality processes throughout their lives. Both the magnitude and variability of mortality at various ages or life-stages contribute to the survival of a year class of Chinook salmon. Instantaneous and annual mortality rates are generally assumed to be much higher and more variable for smaller, younger fish, and much lower for older age classes. Better estimates of mortality rates and their interannual variability (through various types of tagging studies, stock identification work, modeling, and retrospective analyses) would give insight into the mechanisms affecting marine survival.

Hatcheries

Observations and conclusions:

The panel was not provided with adequate information to allow a comprehensive assessment of the degree to which hatchery programs could have contributed to the apparent widespread decline in abundance of southern BC Chinook salmon stocks. Considerable information gaps along with limited data quantifying potential effects of enhancement on natural populations, made it challenging to conduct our assessment. Nevertheless, we did find that there are causes for concern in specific CUs.

While the need to safeguard wild salmon populations is laudable and essential, the DFO Wild Salmon Policy's (WSP) definition of wild salmon is difficult to apply from a practical monitoring and evaluation perspective and is more conservative than definitions used elsewhere in the Pacific Northwest.

The WSP clearly establishes a foundation and a need for managing hatcheries in a manner that is consistent with conservation of wild salmon populations. Even with limited information our assessment raises very serious issues concerning the compatibility and coordination of certain aspects DFO's Salmonid Enhancement Program (SEP) with the objectives of the WSP. The WCVI and Georgia Strait CU hatchery programs appear to be operating at serious odds with sound wild salmon population conservation principles as well as the WSP. The basis for this assertion is that serious risks to "wild" populations are being created by the very high hatchery proportions in the enhanced populations, the corresponding extremely low proportions of wild salmon that they imply, and the indication of extensive straying of hatchery fish into "wild" unenhanced populations. Other concerns include the absence of essential information and high degree of uncertainty related to hatchery benefits and risks, and the lack of demonstrated adaptive management changes in the hatchery program in response to developments in other agencies managing hatchery production.

Clearly the hatchery risks vary considerably between CU groups. In the Middle-Upper Fraser River, Thompson River, and Lower Fraser CU groups, hatchery programs have been reduced to levels where risk is small and additional hatchery monitoring and evaluation efforts would yield little contribution to understanding hatchery impacts in these CUs. In contrast, hatcheries appear to be a major factor influencing many aspects of Chinook salmon natural population ecology and dynamics in the Georgia Strait and WCVI CU groups. Although the WCVI CU group appears to have the most relevant data, a substantial expansion in monitoring and evaluation of hatchery programs and natural populations is needed to provide data for essential high-priority metrics (as described in the Hatcheries section of this report, Section 7).

There is a clear need for a thorough and critical programmatic assessment, including evaluation of the role hatcheries serve, the consistency with which hatchery programs meet WSP goals, an accounting of the contributions of hatchery-produced fish to fisheries, and the benefits and risks of the hatchery releases for wild stocks. We recommend an independent comprehensive assessment of hatchery programs within the SBC Chinook salmon domain, using previous review processes conducted elsewhere as a template (e.g. Columbia River basin, HSRG 2009; Puget Sound, HSRG 2004; California, CA HSRG 2012). Such an assessment would provide a basis for assessing consistency with the WSP and for hatchery reform.

There appears to be limited integration of information between SEP and the assessment programs responsible for data collection and analyses of the hatchery and natural population performance information. Development of integrated assessment teams from multiple disciplines (including hatchery evaluation, population dynamics, stock assessment, harvest, and genetics) would accelerate implementation of our recommendations for interdisciplinary collaboration in data analyses, and integrated management and sharing of data. Implementation of our recommendations would provide the essential information needed for future assessments and help to identify the essential actions needed to reform hatchery operations.

<u>Critical information gaps</u> (most relevant to the Georgia Strait and the WCVI CUs, which appear to be the most affected by hatchery programs):

In general there was very limited information to address the highest priority questions, and to assess the degree to which hatcheries have been a stressor and contributor to observed declines in SBC Chinook salmon. This paucity of information was consistent and somewhat alarming for the harvest augmentation, supplementation, and wild stock indicator hatchery programs. Based on information presented to the Panel at the workshop, it appears that the Salmonid Enhancement Program is largely operating in isolation, independent of other evaluation and management programs. The Panel was provided with a draft of the DFO SEP Biological Risk Assessment Framework for Enhancing Salmon in the Pacific Region in early July following the workshop. Panel members were informed that the framework provides guidance for collecting data for some of the important metrics for which no data were presented or provided. However, there were no examples of hatchery program risk assessments provided based on the Framework guidance.

Given the number and diversity of hatchery programs, their broad geographic area of influence and the large number of natural populations, it is clear that it would be logistically challenging to extensively monitor all hatchery programs and natural populations within these CU groups. A stratified standardized monitoring framework might be used to provide data that could be aggregated upward for inference to the CU and CU group level. Hatchery programs could be stratified according to program type, program size, broodstock sources and management, Chinook race (spring, summer, fall) and rearing-release strategies. All of these factors have been shown to influence hatchery effectiveness and potential impacts to natural populations. Within each constructed stratum, randomly selected or representative populations and hatchery programs could be monitored carefully for the key metrics identified in the Hatchery section of this report.

The proportion of natural-origin broodstock (pNOB) and the proportion of hatchery-origin spawners in nature (pHOS) are believed to be important factors influencing the fitness of natural spawners because they are an indication of the dominant selecting environment influencing the aggregate natural spawner population. The Proportionate Natural Influence (PNI) metric developed by Busack et al. (2006) integrates pNOB and pHOS to index the degree of influence of the hatchery environment on the mixed hatchery and natural-origin spawners. In areas of southern BC where enhancement occurs there is a need to: a) document the number of natural and hatchery-origin broodstock collected and spawned annually in different SBC Chinook CUs; b) determine the total number of natural and hatchery spawners in nature within target populations; c) estimate pHOS, pNOB in spawning populations and in hatchery broodstocks, respectively; d) determine annual and mean generational PNI values to characterize the dominant selection environment; e) assess stray rates and distribution of strays; and f) determine the degree of genetic introgression of hatchery strays into unenhanced natural populations.

In addition to the above information, scientists and managers also need to conduct comparative studies to: a) determine the age-structure of hatchery and natural-origin fish within target populations; b) estimate and compare adult recruits-per-spawner productivity for hatchery and natural spawners (to assess the full life cycle survival advantage provided by taking natural-origin adults into the hatchery program); c) assess differences in age-structure, adult run timing and spawner distributions between hatchery and natural fish as well as changes in these attributes through time; and d) assess changes in productivity of enhanced populations relative to unenhanced reference populations.

It is important to identify and select reference natural populations that have minimal or no hatchery influence but that share common characteristics with the hatchery enhanced population (e.g., race, geographic location, ocean migration patterns, etc.). Scientists should monitor abundance and productivity in these reference populations to provide spatial and temporal comparisons with enhanced populations. In addition, unenhanced natural populations can be used to monitor hatchery fish straying within a stratified framework (distance from enhanced population, within and outside adult migratory pathways), determining hatchery and natural-origin abundance, pHOS, hatchery stock-specific stray sources, stray abundance and distribution, and stray rates. This would require a significant expansion of marking and tagging (perhaps using genetic methods) beyond the current approach of applying coded-wire-tags only to indicator stocks.

Finally, it is important to expand the current genetics monitoring program to better assess the genetic characteristics of "wild" unenhanced populations, the degree of hatchery stock introgression into "wild" populations, and the origin of broodstock in programs collecting adults in lower river reaches and bays near the ocean. This work should include an evaluation of the influence of seapen acclimation on stray rates and distribution.

PATHOGENS

Observations and conclusions:

Laboratory studies and observations from captive (farmed or hatchery) Chinook salmon have shown that pathogens and disease can cause mortality, but evidence of population level impacts in southern BC Chinook salmon is much more limited. Thus the extent to which pathogens contribute to variation in Chinook production both between populations and over time is not known. Monitoring of wild populations and estimation of impact of disease is largely non-existent in BC (also see, Hershberger et al. 2013).

Higgins et al. (workshop presentation and handout, May 2013) acknowledged the "potential impacts on salmon populations can occur directly through mortality of individuals or indirectly through changes in various performance parameters including, but not limited to, swimming ability, growth, and reproduction, ". However, they did not have any quantitative evidence regarding the distribution, magnitude and frequency of either direct or indirect impacts. There was acknowledgement that three pathogens (*R. salmoninarum, A.salmonicida, and V. anguillarum*) have "the potential to contribute to changes in Chinook salmon productivity".

Regarding the risks of open net-pen salmon aquaculture to wild Chinook salmon, Higgins et al. stated that "we expect that there is a low risk of transmission of pathogens from farmed Atlantic salmon to wild Chinook salmon because of differences in susceptibility to various disease organisms as well the related husbandry practices that minimize the occurrence of disease in farmed salmon." They also suggested that there was minimal risk of infection from aquaculture reared Chinook salmon due to their small numbers within the industry currently.

Given the limited information provide to the Panel[1], the Panel cannot draw any conclusions on whether pathogens and associated diseases contributed to the reduction in Chinook production in southern BC. If exposed to contagions, a number of the pathogens identified may cause reduced growth and even mortality of Chinook salmon individuals in natural habitats. The fact that freshwater hatcheries and aquaculture sites must use vaccinations to control the few diseases that occur in a culture environment

[1] Following the workshop, the Panel was provided an informative reference on this topic:

http://assets.worldwildlife.org/publications/172/files/original/Salmon_Aquaculture_Dialogue_%E2%80%93Working_Group_Report_on_Salmon_Disease_SalmonY.pdf?1344873463 suggests that disease could be a significant mortality factor. But extension of experience in cultured populations to natural populations and their productivity is uncertain. Extension to natural populations would require exposure of individuals to infective agents, environmental conditions allowing for expression of the disease, and a lack of compensatory mechanisms (i.e.; mechanisms that could compensate for small to moderate losses due to disease).

Critical information gaps:

Monitoring and reporting of pathogens and disease occurrence in hatcheries and natural populations is inadequate and should be improved. Monitoring for microbes known to be pathogenic in Chinook salmon is a first step in the identification of infectious agents and the potential risk of disease in Chinook salmon populations.

Interpreting the presence of pathogens in terms of the risk to natural populations, however, requires more research into the dynamics of disease expression, interactions with environmental conditions (particularly in light of climate change effects), and the potential role of hatcheries in the persistence of pathogens and risk of transmission to natural populations. Further, we know that different species and populations of Pacific salmon have different susceptibilities to specific pathogens, and that different strains of a pathogen can have very different virulence in expression of disease; these complications make these studies multi-factorial and requiring specialized research facilities.

The Panel also recommends more in-depth consideration of the interaction of salmon farms with the hatchery and natural populations of Chinook salmon. These studies should be integrated with surveillance of wild salmonids and environmental conditions, but the abundance and concentration of aquaculture fish in southern BC generates public concern for the extent of risk posed by them. Concern about the potential interaction between cultured and wild will simply continue without direct investigations.

Climate Change

Observations and conclusions:

Given the numerous and interconnected pathways that changes in climate (meaning trends in climate patterns as opposed to cycles or random variation in annual conditions) could affect production of Chinook salmon in southern BC, it is highly likely that climate variation and change has been a factor influencing productivity in the past and will have increasing impacts in the future. Effects are likely mediated through changes in temperature (Ferrari et al 2007, Morrison et al 2002), stream flow volume and seasonality (Dery et al 2012), reductions in glaciers (Stahl et al 2008, Schiefer et al 2007[2]),

[2] Glacier recession in BC accounts for 8.3% of the global contribution from mountain glaciers and ice caps to sea level change. The recent rate of loss in southern BC Coastal mountain glaciers (17 km^3 / annum) is approximately double the rate of the previous two decades!

pathogens and non-indigenous species, and contaminants (Walker and Winton 2010, Noyes et al 2009, Sanderson et al 2009, Harvell et al 2002), plus changes in the marine environment (Rensel et al 2010, Mooney et al 2009, Moore et al 2008).

In southern BC, most assessments of climate change have been within the Fraser River and largely focused on mainstem temperature and flows due to impacts on upstream migration rate and survival of sockeye salmon. These assessments show an earlier freshet in the Fraser (over half of the Fraser flow volume passes Hope in the lower Fraser Basin before July 1st), and a significant increase in summer temperatures, with the largest increase of 1 °C for the summer minimum temperature (Patterson et al 2007).

Climate change likely has had an impact on southern BC Chinook through a number of these pathways over the past two decades, but evidence presented at the workshop does not allow for estimation of mortality impacts. We can conclude though that most if not all southern Chinook populations have faced increasingly stressful thermal conditions during return migrations in recent decades. Evidence presented also projected environmental change in the future (impacts projected to 2050s relative to a base period of 1961-1990). We can anticipate increased stress on SBC Chinook under these projections.

While climate change effects on southern BC Chinook salmon are highly likely given the diversity of possible interactions, there are no conclusions that can be drawn from the materials presented. A thorough analysis of past and potential future impacts of climate change on Chinook should consider the diversity of life history types of Chinook in southern BC (not all types will be equally affected), the complex topography of southern BC and diversity of stream types involved, and the potential for behavioural adaptation of Chinook to change. Each of these factors limits what can be concluded at a broad geographic scale, as has been determined in more in-depth (or localized) evaluations (Isaak et al 2012, Thorne and Woo 2011, Fleming et al 2007, Tolimieri and Levin 2004).

Critical information gaps:

The ability to monitor environmental change and variation and Chinook salmon production must be critically assessed and improved. Throughout the material presented and the Panel's deliberations, the need for a strategic plan and monitoring design was apparent.

The effects of climate change can occur throughout the life cycle of Pacific salmon. Assessing the effects of climate change over time on salmon needs to also account for the other factors that will impact Chinook salmon, including: annual variation in freshwater and marine survival; exploitation including total fishing mortality by age; quantitative monitoring of spawning escapements by age (including losses during up-stream migration, retention of eggs and pre-spawning mortality of females), and hatchery-produced first-generation returns. This level of detailed assessment information is costly and will require the designation of 'indicator stocks or populations' that are strategically placed to represent the major life history types of Chinook salmon (i.e., consistent with Step 3 of Strategy 1 of Canada's Wild Salmon Policy (DFO 2005).

The complexity of BC's topography, diversity of life history types for BC Chinook salmon, and the numerous pathways for climate change to impact Chinook production argues for a new and more holistic approach to monitoring and salmon assessment related to climate change. The effects of climate change or variation will be pervasive across Pacific salmon throughout BC and the Yukon. The assessments described above should be conducted by an interdisciplinary team involving government departments, academia, First Nations and NGOs. This may be a more appropriate model for integrated research, monitoring and evaluation than the current approach of assessment by the few persons in different departments and institutions today. Ideally, DFO should lead this initiative to maintain a focus on BC's Pacific salmon resources since Pacific salmon integrate many of the ecological factors that may be impacted.

Our Charge and Overall Conclusions

This Panel was asked to report on the following topics:

1) Review status and trends of southern BC Chinook salmon Conservation Units (CUs) and associated component populations.
2) Synthesize evidence and associated insights regarding:
    a) The impact, relative importance and potential for mitigation of factors hypothesized to limit the productive capacity of Chinook salmon originating from southern BC rivers; and
    b) The future risks associated with climate change and potential adaptation strategies.
3) Recommend additional research and monitoring to address gaps and support future planning.
4) Review existing management/assessment tools that could be used to incorporate risks into a management decision making framework and offer suggestions for improvement.

The Panel's report addresses items (1) through (3) with the exception that analyses presented did not focus on "associated component populations", which was assumed to include multiple streams and sites within streams within CUs. DFO's trend analyses provided to the panel consider the sum of spawning escapements across streams within CUs but did not consider variation between streams or sites. The Panel comments on data needs required to address tem (4) but don't otherwise address this topic.

A short summary of our findings is as follows. The abundances of Chinook salmon spawning in many Conservation Units (CUs) in southern BC have declined substantially over the past 3 generations, but the clearest indication of this decline is within the Fraser River and not as apparent in other regions. However, the Panel could not attribute particular causes to the declines other than inferring that low early marine survivals (based on recoveries from coded-wire tagged indicator stocks) have been a primary contributing factor and there have likely been contributions (to varying degrees across CUs but not quantified) from each of the other factors considered at the workshop (harvests, freshwater habitats, hatcheries, pathogens, and climate change and variation).

Limitations of information. The Panel based its report on materials provided for the Southern BC Chinook Science Workshop (May 22-24, 2013) and follow up discussions with scientists from the Department of Fisheries and Ocean. There were substantial constraints and limitations on the information available to address the objectives of the workshop in this report. However, the report presents an objective, independent evaluation of the materials provided for the workshop and subsequently, identifies key uncertainties and data gaps, and provides recommendations based on our collective experience across a number of organizations and regions. While other information may exist that can help to reduce uncertainties identified in our report, this information was not available to the Panel during the May to September 2013 period within which we did our work. Regardless of the state of information provided, we believe that critical commentary that generates discussion is an important contribution of independent and external review.

Southern BC (SBC) Chinook salmon are subject to a complex array of human and natural drivers, and occupy a variety of freshwater and marine habitats across broad geographic ranges. Over time, Chinook developed life history strategies best suited to the environmental conditions faced by individual populations that now determine the units of production within SBC (i.e., individual CUs). Management and assessment of these units becomes a complex task of monitoring the abundance of Chinook, as well as the biotic and abiotic variables that determine their abundance through time. Add to this, the fiscal and logistical limitations of annual monitoring programs, and the reasons for variability in data quality and completeness becomes more understandable. Consequently, it was not possible for scientists making presentations at the workshop, or for the Science Panel, to quantitatively assess the relative likelihood of different factors contributing to trends in the abundance and productivity of southern BC Chinook salmon stocks. The Panel has, however, identified factors that likely contributed to the decline in spawning abundance over the past 12 to 15 years.

Trends in SBC Chinook Abundance and Productivity. The Panel concurs that spawner abundances in most Conservation Units (CUs) of Chinook salmon in Southern B.C. have decreased substantially over the most recent three generations (about the last 12 years). For spawning sites that were categorized by DFO as having a "low or unknown" level of enhancement activity, which occurred in 21 CUs, 13 of those CUs showed more than a 50% decrease in spawner abundance in the last 3 generations. Five CUs showed increases. It is notable that data sets that are the least confounded by hatchery contributions, i.e., the Fraser and Thompson Rivers stocks with stream life-history types (which overwinter in rivers and then go to sea as yearlings), represent the majority of those cases with decreasing spawner abundance. They constitute 12 of the 13 CUs with more than a 50% decrease and 12 of the 16 that show any decrease in the last 3 generations.

Southern B.C. Chinook stocks exhibit temporal patterns in life-cycle productivity, and to a lesser extent age-2 marine survival rate, that are shared to some extent across a large spatial area from Oregon up through western Alaska. Thus, it seems likely that there are large-scale marine processes influencing Chinook productivity. However, stock-specific deviations in survival rates and productivity (**Figures ST-3**, **ST-6**, **ST-7**) from the shared trends **(Figures ST-11**, **ST-15**) indicate that there are other key factors affecting productivity that are not shared across a wider group of stocks. That is, local processes causing variation in productivity are also prominent. Any consideration of mechanisms causing changes in survival rate and life-cycle productivity must recognize variation on both local and large scales.

Harvest. The above-described declines in spawning escapements have occurred during a period of substantial reductions in ocean harvest on SBC Chinook (**Figure H-8**), and significantly reduced total exploitation rates since the mid-1990 brood years (**Figure H-13**); patterns in terminal harvest rates do not account for patterns of decline **(Figure H-9** to **H-11**). The inconsistency between declining escapement trends for many SBC Chinook CUs with stable or decreased total exploitation rates in fisheries may reflect (1) under-estimated mortalities (for example, unaccounted for incidental mortalities in fisheries or increased natural mortality rates such as increased predation by marine mammals), and/or (2) accurate total exploitation rates but reduced productivities of most Chinook CUs, as reflected by declining marine survival rates. If the latter possibility is true, then even the reduced exploitation rates may remain too high to sustain Chinook production for some CUs (see section 4.4).

Habitats. Habitat considerations included freshwater and marine habitats. Chinook salmon use freshwater and estuary habitats for spawning, rearing and migration and there is little doubt that changes in those habitats will affect the productivity of the populations that use them. However, there was no evidence presented to suggest that the variation in patterns of decline or increase observed in recent years among CUs is related to land-use activities including forestry, urban development, and linear developments (roads, pipelines) and water uses. However, for marine habitats, the Panel concluded that the marine environment during the first year of marine residency of SBC Chinook salmon was very likely a key driver of recent trends in survival and productivity. Both local and larger scale oceanographic conditions are likely involved. There is strong evidence of direct effects of local marine conditions on the survival of Chinook salmon, especially in the Strait of Georgia. Differences in marine survival in relation to migration timing demonstrate the adaptive value of the wide diversity in life-history strategies of SBC Chinook salmon. It is not clear whether the large-scale effects reflect atmospheric and oceanographic conditions that similarly influence local marine conditions encountered by juvenile salmon across a wide geographic range, or whether they are the result of later mortality in shared ocean habitats. On general principle, however, smaller fish have higher natural mortality rates, which helps to support our primary research recommendation is to focus on early marine periods.

Hatcheries. The panel was not provided with adequate information to allow a comprehensive assessment of the degree to which hatchery programs could have contributed to the apparent widespread decline in abundance of southern BC Chinook salmon stocks. However, there are a number of factors that indicate that hatchery programs have likely had a negative effect on the productivity and viability of natural populations in some CUs. The effect appears to be highly variable between CU groups, ranging from little or no impact (in most Fraser River CUs) to substantial risks (Vancouver Island). In the Vancouver Island region, the magnitude of annual releases, high proportion of CUs enhanced, broodstock history and management, straying, and genetic changes, all contribute to the likelihood that hatcheries are a significant stressor to CUs in this region, to a point of being incompatible with Canada's Wild Salmon Policy (see section 7.1). Similar to recent intensive hatchery reviews in the Pacific Northwest United States (references provided in text), the Panel recommended an independent programmatic assessment including evaluation of the role hatcheries serve, the consistency with which hatchery programs meet Wild Salmon Policy (WSP) goals[3], and more quantitative accounting of the contributions of hatchery-produced Chinook to fisheries and natural spawning streams.

Pathogens. Laboratory studies and observations from captive (farmed or hatchery) Chinook salmon have shown that pathogens and disease can cause mortality, but evidence of population-level impacts on southern BC Chinook salmon is much more limited. Thus the extent to which pathogens contribute to variation in Chinook production both between populations and over time is not known. Monitoring of wild populations and estimation of impact of disease is largely non-existent in BC (also see, Hershberger et al. 2013). The Cohen Commission drew similar conclusions with respect to Fraser sockeye (see Volume 3, Cohen 2012). Until such information is collected, pathogens remain a *possible* contributor to Chinook declines; filling this gap is seen as a critical uncertainty and need for assessment.

Climate. Given the numerous and interconnected pathways that changes in climate (meaning trends in climate patterns as opposed to cycles or random variation in annual conditions) could affect production of Chinook salmon in southern BC, it is highly likely that climate variation and change has been a factor influencing productivity in the past **and will have increasing impacts in the future**. For example, changes in freshwater thermal regimes can generate large changes in size and timing of outmigration of smolts, factors directly related to their marine survival.

Research Priorities. Throughout our review the panel was frequently confronted with limited information over time and space. The highest priority follow up from this review would likely be for DFO and collaborating entities to undertake a critical review of assessment data available and needs, and related research. Chinook salmon have a complex life history and cover extensive areas during their life cycle. It is consequently a significant challenge to establish a comprehensive assessment and management framework for this species. However, if the task is to monitor the status of CUs ***and explain causation***, then an integrated evaluation of status, ocean conditions, hatcheries, pathogens, freshwater habitat, and harvest for SBC Chinook requires a more strategic design for future evaluation frameworks that should be scaled to a monitoring level that will be maintained annually.

The Panel identified several critical research topics which must be addressed in this future evaluation framework:

- studies of the early marine survival of Chinook in the Strait of Georgia and west coast of Vancouver Island;
- interactions of hatchery and wild Chinook and development of hatchery performance metrics, particularly concerning the contribution of hatchery salmon to naturally spawning populations of Chinook on Vancouver Island; and

[3] The Panel noted the difference between "natural origin" salmon as used in U.S. policy and "wild salmon" as used in Canada's WSP. While the definition of wild salmon is more protective of genetic diversity in Pacific salmon, the definition is difficult to monitor (see **Figure Hat-1** in this report). Metrics for natural-origin salmon have been developed for hatchery evaluations in the Pacific NW United States but focus on first generation returns from hatcheries.

- studies of natural mortality of Chinook salmon after recruitment to fisheries, particularly related to marine mammals. This specific recommendation is made because cohort models, based on coded-wire tag recovery data and critically important in Chinook assessments coast-wide, have assumed the same ocean natural mortality rates since the models were developed in the early 1980s. Natural mortality rates are applied by age during cohort reconstructions and directly affect estimates of fishery exploitation rates, age-at-maturity values, and marine survival estimates of each cohort. Error in these estimates will then directly affect advice for management.

Finally, because the need for more quantitative evaluations of complex systems will likely increase, the Panel strongly recommends the department consider of new more collaborative and inclusive processes to meet these needs. Funding pressures on government agencies and increased demands for information suggests that reliance on the Department of Fisheries and Oceans alone is likely an untenable situation that will result in limited monitoring of Chinook abundance, productivity, and habitats in CUs. DFO should integrate the strengths and resources of First Nations, universities, and other NGOs and communities within one assessment and monitoring framework; this is likely the only reasonable response to meet future demands. Many of the information needs (e.g., for habitat conditions and climate change, and annual variations in environmental conditions) could be improved through the establishment of an integrated network of communities (in the broad sense of inclusion) to support the department and help maintain abundant and productive Chinook salmon populations.

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1 Introduction

1.1 Overview

Chinook salmon are very important to the people of British Columbia -- ecologically, economically, and socially. However, many Chinook salmon populations in southern BC have shown decreases in spawning abundance or repeatedly low numbers of spawners, especially over the last fifteen years. These patterns have caused broad concern among user groups and fishery managers regarding the current and future status of southern BC Chinook salmon and the provision of sustainable fisheries.

As part of the broader initiative to address these concerns, Fisheries and Oceans Canada (DFO) and the Fraser River Aboriginal Fisheries Secretariat (FRAFS) organized a scientific workshop and an independent science panel to evaluate the relative importance of potential factors that may have affected the abundance and productivity of southern BC Chinook salmon. Working with ESSA Technologies, DFO and FRAFS designed and facilitated a workshop, held May 22-24, 2013 in Richmond, BC. A science panel (Expert Advisory Panel) was commissioned to provide an independent review of the evidence presented during the workshop and to provide recommendations for future research priorities. This project was predominantly funded by the Pacific Salmon Commission's Southern Endowment Fund, with additional funding and support provided by FRAFS and DFO.

1.2 Southern BC Chinook Strategic Planning Initiative

The Southern BC Chinook Science Workshop was a key step in the Southern BC Chinook Strategic Planning Initiative led by DFO and FRAFS. The initiative is under the direction of the Southern BC Chinook Planning Committee that has participants from First Nations, DFO, the recreational and commercial fishing sectors, NGOs and the Province of BC. The Southern BC Chinook Technical Working Group, with technical representatives from the same organizations, has provided technical and analytical support to the initiative and this workshop.

The objective of the Southern BC Chinook Strategic Planning Initiative is:

> *To develop an Integrated Strategic Plan that accounts for the biological status of southern BC Chinook conservation units, their habitat and the ecosystem, that addresses the causes of any declines, and identifies the management actions necessary to remedy their status where possible. This initiative will depend on the collaboration of First Nations, interest groups and DFO to identify rebuilding actions related to fisheries management, salmonid enhancement and habitat restoration.*
>
> *Deliverables from this process will provide guidance to annual Integrated Fisheries Management Plans, fish culture production plans, habitat restoration work plans and community partnership agreements where possible. It may also inform Pacific Salmon Treaty discussions between Canada and the United States.*

This strategic plan will be developed in a manner consistent with Strategy 4 of the Wild Salmon Policy, the [DFO's] Rebuilding Guidelines of the Precautionary Approach Framework and the Species at Risk Act.

–Southern BC Chinook Strategic Planning Initiative Terms of Reference, 2013

The results of the workshop and the present report are expected to provide a valuable input into the Southern BC Chinook Strategic Planning Initiative.

1.3 Objectives

The objectives for both the workshop and this report are:

1) Review status and trends of southern BC Chinook salmon Conservation Units (or management units where applicable) and associated component populations.
2) Synthesize evidence and associated insights regarding:
   a) The impact, relative importance and potential for mitigation of factors hypothesized to limit the productive capacity of Chinook salmon originating from southern BC rivers?
   b) The future risks associated with climate change and potential adaptation strategies?
3) Recommend additional research and monitoring to address gaps and support future planning.
4) Review existing management/assessment tools that could be used to incorporate risks into a management decision making framework and offer suggestions for improvement

1.4 Workshop Approach

The Planning Committee determined that a science workshop and an independent science panel would be the best forum for presenting and evaluating the most relevant evidence available on the status and trends in southern BC Chinook salmon and potential factors contributing to those observed patterns. The agenda (**Appendix I-1**) was organized by thematic topic areas: status and trends, harvest, freshwater habitat, marine habitat, hatcheries, pathogens, and climate change. Instead of having a series of disjoint presentations from multiple authors, teams of DFO scientists worked to synthesize the existing data and research within each thematic area into one or two integrated presentations. The goal was to cover the breadth of potential stressors and drivers within each topic and the evidence available to address workshop objective 2 above. Each team was also instructed to provide a short handout to summarize the most important elements of their presentations, which was distributed to participants prior to the workshop. Prior to the workshop, DFO scientists also prepared a template for the "stressor-threat matrix" (organizing stressor information by CU, by life stage) to be used during the workshop as a framework for discussions around specific threats facing different CUs.

Prior to the workshop, data for two indicators were sent to all scientists who presented evidence at the workshop concerning potential causes of changes in southern B.C. Chinook. Those indicators were the juvenile-to-age-2 cohort marine survival rate, which came from the CTC's CWT analyses, and historical abundances of spawners and the resulting adult recruits, which came from stock reconstructions done with the Pacific Salmon Commission's (PSC) Chinook coast-wide model. This pre-workshop step aimed to provide a shared set of data that everyone could attempt to explain with their focal hypotheses about causes such as changes in freshwater or marine habitats, pathogens, or hatcheries.

The workshop was attended by 66 participants, from across the geographic range of southern BC Chinook salmon, including DFO scientists, DFO managers, technical representatives from First Nations, non-governmental organizations and the Province of BC, and members of the Panel. Each presentation on a thematic area was followed by a discussion period, with substantial time (almost 50%) allocated for questions, first from the Panel then from all participants. During the second afternoon, workshop participants divided into subgroups for focused discussion on either: 1) one of the thematic topic areas (e.g., harvest) presented and its potential impact across all/many CUs, or 2) the potential impacts of all relevant stressors across all of the CUs in one of the regional groupings (e.g., Middle & Upper Fraser). The subgroups working on the latter (stressors within a CU grouping) used the "stressor-threat matrix" to guide their discussions and populated the template with information or uncertainties as appropriate[4]. All of the subgroups reported back to the entire group in plenary discussion.

The presentations and handouts were made available to all of the participants following the workshop.

1.5 Independent Advisory Panel

The independent advisory panel (the Panel) commissioned by the workshop planning committee consists of six senior scientists from academic, government and non-government institutions. These scientists were chosen according to relevant expertise in stock assessment, population dynamics, freshwater habitat ecology, early marine processes, fisheries oceanography, climate change, hatchery influences, and ocean-salmon interactions. The knowledge base of the selected scientists also represents a broad geographic range, comprising extensive experience with Chinook salmon populations from Alaska to California.

The Panel consists of:

Dr. Brian Riddell[5] (Chair) Pacific Salmon Foundation, BC

Dr. Mike Bradford, Fisheries and Oceans Canada (DFO) and Simon Fraser University, School of Resource and Environmental Management, BC

[4] All of the inputs for the "stressor-threat" matrix were collected by DFO and compiled into a single document, providing a foundation for further work on populating the matrix.
[5] Dr. Brian Riddell was previously the Canadian chair of the Chinook Technical Committee of the Pacific Salmon Commission for almost 20 years.

Dr. Rich Carmichael, Oregon Department of Fish and Wildlife, NE-Central Oregon Fish Research and Monitoring, OR

Dr. David Hankin, Department of Fisheries Biology, Humboldt State University, CA

Mr. Alex Wertheimer, NOAA Fisheries (retired), Auke Bay Lab, AK

Dr. Randall Peterman, Simon Fraser University (retired), School of Resource and Environmental Management, BC

The Panel was commissioned to provide an independent review of the information and analyses presented during the workshop, documented in a written report.

To fulfill this role, the Panel reviewed all of the background materials available ahead of the workshop, attended the workshop, asked questions of the presenters, engaged in discussion periods, and participated in the Panel session following the workshop. After the workshop, the Panel prepared its report, including multiple iterations of reviewing and further revising. The draft report was submitted to the workshop planning committee and lead presenters for comments, to ensure clarity of communication and to check for errors in fact. Extensive review comments were provided and have each been considered by the Panel.

1.6 Report Structure

The structure of the remainder of the report is as follows:

Section 2 provides background and context for the rest of the report, including a description of southern BC Chinook salmon life histories, information on the spatial stratification of southern BC Chinook salmon, and a high-level summary of the Wild Salmon Policy.

Section 3 examines the status and trends in the abundance, productivity and escapements of southern BC Chinook salmon, to the extent that data are available and of sufficient quality to allow such analyses. This section aims to describe "the patterns we seek to explain", that is, characterizing the nature of the observed patterns in southern BC Chinook salmon that the factors discussed in subsequent sections may be contributing to. The limitations of data availability and quality are discussed explicitly.

Sections 4 to 9 evaluate the available evidence on the potential factors that may be contributing to the observed patterns. These factors are organized into six themes: harvest (**4**), freshwater habitat (**5**), marine habitat (**6**), hatcheries (**7**), pathogens (**8**), and future climate change (**9**). Each section follows a similar structure:

- discussing the plausibility and realism of the proposed mechanisms;
- summarizing the key evidence presented at the workshop on this stressor, including the spatial extent, stratification, and/or retrospective analyses performed;
- drawing conclusions on the relatively likelihood of this factor explaining the observed patterns in the status and trends within the Conservation Units (CUs) of southern BC Chinook salmon

- identifying critical information gaps and providing recommendations for research priorities to reduce those uncertainties

Appendices provide additional details on particular topics as necessary.

1.7 Limitations and Realistic Expectations

There are substantial constraints and limitations on the information available to address the objectives of the workshop and this report, both in terms of whether information was available for the workshop and whether such information exists at all. Given the complexity and constraints briefly summarized below, it is unrealistic to expect that the report to confidently ascribe causative factors to those observed patterns. Readers should expect that the report will provide an objective, independent evaluation of the information presented at the workshop, identification of key uncertainties and data gaps, and recommendations for reducing those uncertainties.

Chinook salmon are subject to a complex array of human and natural drivers, and limited resources are available to better understand these multiple dimensions and their interactions. Chinook salmon occupy a variety of freshwater and marine habitats across broad geographic ranges. Each habitat represents a complex system of biotic and abiotic variables that vary over time and space. Consequently, the variables of interest may have sparse or inconsistent data or no data at all. Due to insufficient information being available prior to the workshop, it was not possible to quantitatively assess the relative likelihood of different factors in contributing to recent trends in southern BC Chinook salmon stocks. In some cases, the lack of knowledge impedes the Panel's ability to even make recommendations and will impede future considerations also.

2 BACKGROUND

2.1 OVERVIEW OF BC CHINOOK SALMON LIFE HISTORY STRATEGIES

Southern BC Chinook salmons are typically grouped by their life history, run timing, spawning geography, and/or marine migration patterns. Compared to other salmon, Chinook salmon have the greatest variety of life histories and life spans (from 2 to 7 years). The two major life histories for Chinook are stream-type and ocean-type, based on the length of time they spend rearing in their freshwater habitats before migrating to their marine rearing habitats. The three run timing groups for returning adults are spring, summer and fall. Southern BC Chinook salmon can also be grouped based on the spatial patterns of their marine migration behavior – far north migrating, offshore, or locally-distributed. Although differences in adult run timing, marine distribution and spawning geography do not perfectly correspond with the two life history types, each of these life history types do share some broadly similar characteristics.

For stream-type Chinook salmon, adults typically return to freshwater in spring or early summer to migrate to their spawning grounds. The fry that emerge in the following spring spend one or more years rearing in freshwater before migrating to their marine rearing areas. Smolts generally do not remain in the estuaries for very long, sub-adults will rear in coastal waters for a limited period but usually migrate offshore. In North America, stream-type life history traits are more commonly found in northerly and interior headwater populations of Chinook (Healey, 1991). In southern BC, most of the stream-type Chinook stocks occur in the interior watersheds of the Fraser and Thompson rivers and mainland inlets of the Strait of Georgia (glacial systems).

For ocean-type Chinook salmon, adults will return to freshwater in late summer and fall to migrate to their spawning grounds. The fry that emerge in the following spring spend less than one year (typically only 2-6 months) rearing in freshwater before migrating to estuarine areas, where they will remain for 1-3 months. Sub-adults subsequently rear in coastal waters (continental shelf areas). In southern BC, most of the ocean-type Chinook stocks are found on Vancouver Island and in the coastal watersheds of the Strait of Georgia, and in the Fraser River (both the lower Fraser River and Thompson basin).

2.2 THE WILD SALMON POLICY

Concern about decreases in Chinook salmon abundance in southern B.C. exists within the broad context of Canada's Policy for the Conservation of Wild Pacific Salmon (The Wild Salmon Policy, or WSP; DFO, 2005). The overarching goal of this policy is to:

Restore and maintain healthy and diverse salmon populations and their habitats for the benefit and enjoyment of the people of Canada in perpetuity.

Canada's Policy for the Conservation of Wild Pacific Salmon (June 2005) provides a broad management framework for the conservation and use of Pacific salmon. The policy was developed after a decade of extensive consultations and reviews, and involves six strategies to protect and manage Pacific salmon (Irvine 2009, http://www.pac.dfo-mpo.gc.ca/publications/pdfs/wsp-eng.pdf).With respect to the present report, two of the important components of the Wild Salmon Policy are:

1) the focus on using CUs as the primary unit for monitoring and assessment, and

2) the definition of "wild" salmon.

Under the Wild Salmon Policy, wild salmon are to be maintained by identifying and managing conservation units (CU). CUs are intended to reflect the geographic and genetic diversity within BC Chinook salmon. Salmon within a CU are more genetically similar than between CUs and the diversity of spawning populations within a CU is believed essential for maintaining the resilience of salmon to local perturbations over time. The Wild Salmon Policy states that the status of CUs will be monitored, assessed against appropriate benchmarks, and reported publicly. The Wild Salmon Policy aims to maintain all of the identified CUs, but recognizes that there will be exceptional circumstances where this may not be possible.

The Wild Salmon Policy defines "wild" salmon as follows:

> ***Salmon are considered "wild" if they have spent their entire life cycle in the wild and originate from parents that were also produced by natural spawning and continuously lived in the wild.***
>
> *Salmon that originate directly from hatcheries and managed spawning channels are not considered wild in this policy, and are called "enhanced" salmon. This term is sometimes also applied to salmon that originate from other enhancement activities, such as habitat restoration and lake enrichment, since their rate of production has been augmented. However, the reproduction of these fish has not been altered, and therefore they are deemed "wild" in this policy. The requirement in the definition that a wild salmon must complete more than one full generation in the wild safeguards against potential adverse effects resulting from artificial culture.* – *DFO (2005, p. 1, emphasis added)*

The Wild Salmon Policy also states that habitat protection and salmon enhancement should specifically focus on sustaining wild salmon, emphasizing an integrated approach to habitat management that will link fish production with watershed and coastal planning initiatives. Additionally, the Wild Salmon Policy asserts that salmon management should incorporate ecosystem considerations, including indicators of freshwater ecosystem status and ocean climate studies of marine survival and condition. These components should be integrated into the annual assessments of abundance that guide harvest planning.

2.3 Stratification of Southern BC Chinook

The southern BC Chinook population group can be stratified in several different ways, including life history type (as described above), eco-typology, and genetics. Ultimately, these dimensions have been used by DFO to inform the development of Conservation Units (CUs) for Chinook salmon (Holtby and Ciruna 2007).

Conservation Units, as put forth in the Wild Salmon Policy (DFO, 2005), are the primary stratification of southern BC Chinook salmon for the applied purposes of monitoring, assessment and management. The Wild Salmon Policy defines CUs as a group of wild salmon that are isolated enough that natural recolonization would be unlikely within a reasonable time frame if the group was lost from the population (see WSP summary). At the time of the workshop, the spatial description of southern BC Chinook salmon consists of 35 CUs **Figure B-1** shows the geographic delineation of the 17 stream-type CUs and **Figure B-2** shows the geographic delineation of the 18 ocean-type CUs. For the purposes of the workshop and this report, these 35 CUs were grouped into five geographic areas to facilitate their evaluation and the generation of recommendations within the constraints of the workshop process (i.e., it was not feasible assess every CU individually). The current definitions of the CUs and the five regional groups used during the current process are included in **Appendix I-2**.

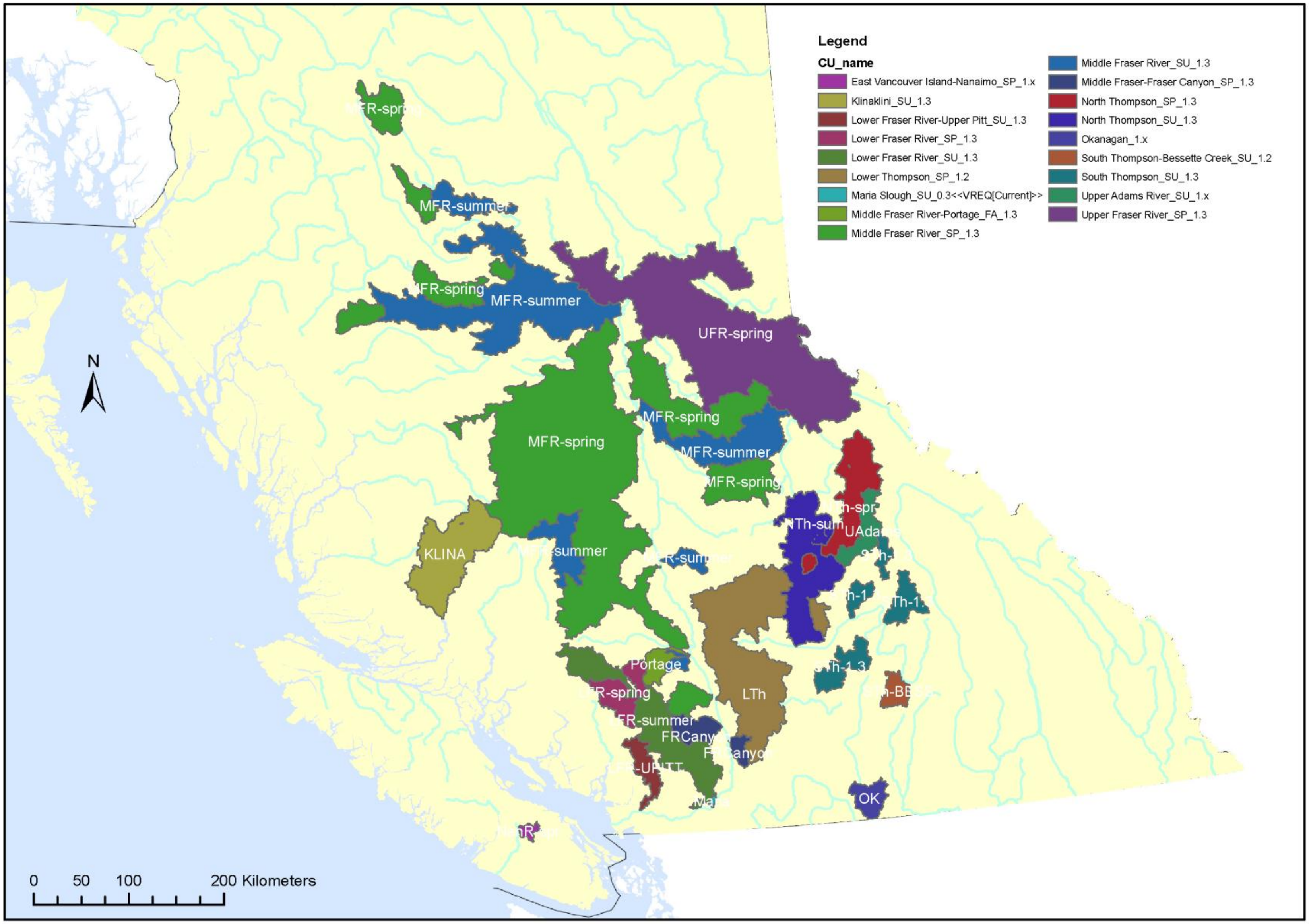


Figure B-1. Southern BC Chinook salmon Conservation Units – stream-type. CUs based on definitions as of May 17, 2013. Source: Gayle Brown, DFO.

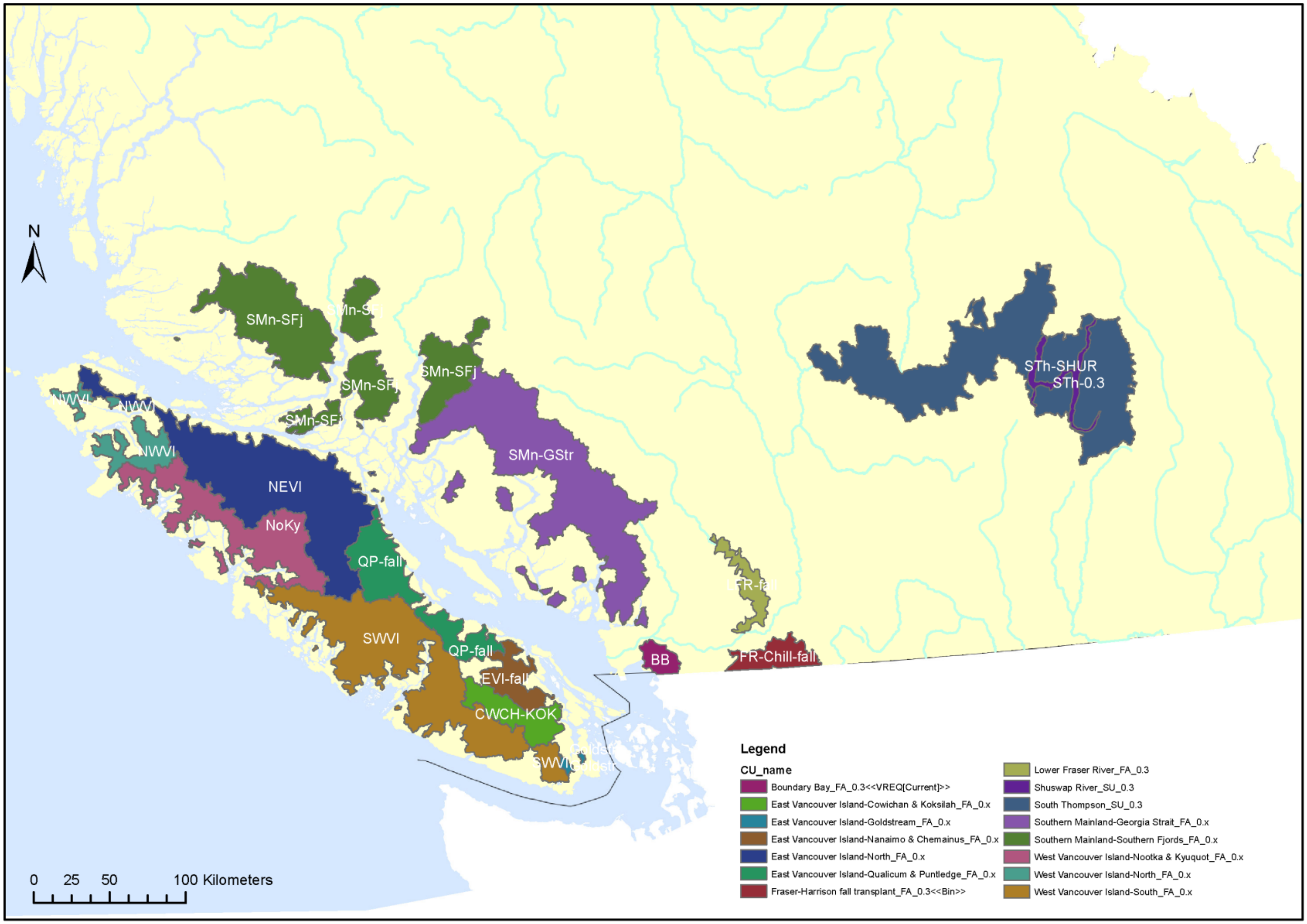


Figure B-2. Southern BC Chinook salmon Conservation Units – ocean-type. CUs based on definitions as of May 17, 2013. Source: Gayle Brown, DFO. The blue STH-SHUR area should extend downstream of the Nicola River; this is an inaccuracy of the DFO map and not related to the Panel (C. Parken, pers. Comm.)

2.4 A Brief History of Chinook Salmon Management

The history of Chinook salmon management has been one of controversy for about 50 years, and largely caused by inadequate information, competition to catch the fish first, and the development of large-scale hatchery production. The source of the controversy can largely be reduced to three factors:

a. The biological diversity of Chinook from California through Alaska and their extensive ocean migrations results in large mixtures of populations vulnerable to ocean fisheries and competition to harvest the fish first. Chinook salmon are sequentially exposed to multiple fisheries and over two to three ages before they mature and begin their return migration to natal streams.
b. This diversity in Chinook is also expressed in extensive life history variation and uses of freshwater habitats in varying degrees of disturbance. This combination naturally results in a range of population productivities (progeny produced per adult spawner) and associated differences in harvest rates that sustain production in the different wild or naturally-reproducing populations.
c. In addition, with improvements in hatchery practices and diets in the 1950s and 1960s, the production of hatchery Chinook exploded in an effort to address management issues by simply producing more fish to harvest (Lichatowich 2001). Unfortunately, as these Chinook mixed with the naturally-produced Chinook in the sea, fishing rates increased to harvest the inflated abundance leading to excessive exploitation of naturally produced Chinook.

However, by the late 1960s and through the 1970s, the effect of excessive fishing rates were becoming evident on the natural spawning grounds and felt by in-river fishers as their catches declined and they were increasingly regulated (i.e., catches reduced) to sustain local spawning populations.

As users were pressured to reduce harvests, however, a fourth serious limitation became apparent. The information available to assess the state of Chinook salmon and manage these complex fisheries was very limited. Assessments were typically dependent on trends in spawning escapements and the cause of those trends was assumed to be over-fishing – but which fisheries, how excessive was the harvest rate, and who should reduce their harvest first? The last question initiated the first major change in ocean fisheries and stimulated the development of more quantitative stock assessments.

Change began with the Boldt Decision[6] (1974) in the United States that ultimately required federal fishery managers to allow for equal harvest between Treaty tribes and other users, and that Treaty

[6]http://wdfw.wa.gov/fishing/salmon/BoldtDecision8.5x11layoutforweb.pdf

United States v. Washington, 384 F. Supp. 312 (W.D. Wash. 1974), was a 1974 US District court case (the so-called Boldt decision) that reaffirmed the right of Treaty tribes in Washington and Oregon to act as "comanagers", alongside the state, of salmon and to share the total harvestable surplus of stocks passing usual and accustomed places.

tribes should be provided opportunity to harvest in their "usual and accustomed places". Fishery managers were now faced with reducing ocean catches to deliver allowable catches to specific Tribal locations. While this ruling clearly affected U.S. citizens, it was also fully understood that Canadian fisheries were the major user of many US Chinook salmon populations in the ocean fisheries (**Figure B-3**). Ocean fisheries had competed for Chinook coast-wide since the 1920s, but by the late 1970s, Canada clearly had the largest ocean catches of Chinook salmon …but which Chinook were being caught?

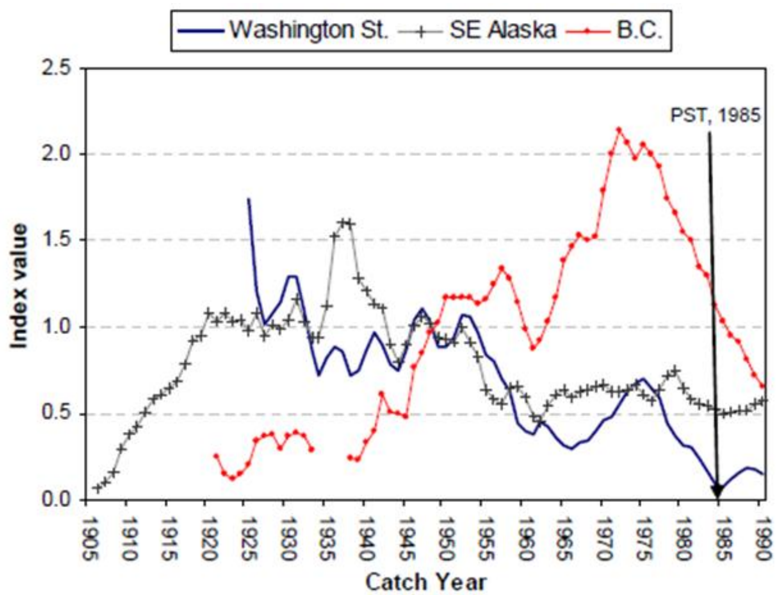


Figure B-3. Trends in the reported catches of Chinook salmon by ocean troll fisheries (1905-1990) in Washington State, British Columbia, and SE Alaska. Trends are relative to the average catches during 1946-1950 to account for differences in landing records and smoothed (3-pt moving averages) to show time trends more clearly. The vertical bar indicates the 1985 signing of the Pacific Salmon Treaty between the United States and Canada. Historical data compiled by B. Riddell. Figure and caption from ISAB 2005[7].

Ironically, the solution to understanding the fishing impacts on naturally-produced Chinook salmon came from a tool developed to allow assessment of the effectiveness of hatchery production. Micro-pieces of magnetic wire that were uniquely coded (coded-wire tags) were inserted into the snout of a fish to enable the identification of groups of fish released from specific hatcheries on specific dates and at specific locations (Jefferts et al. 1963). Each Chinook marked with a coded-wire tag (CWT) was identified by removing the adipose fin (clipped) before their release. Since 1975, fishery agencies coast-wide had agreed to sample 20% of their Chinook catches to recover the heads of clipped Chinook so that tags could be recovered and decoded. These CWT recovery data w provided information on where specific hatchery production was being harvested and what hatchery contributions to fisheries were, but

[7] www.nwcouncil.org/fw/isab2005-4/

the data had never been applied to fisheries management or assessment of natural production. That changed with the insight that a marine fisheries statistical model could be applied to coded-wire tag data (Cohort analysis, J Pope 1972)[8]. The first full documentation of cohort analysis using coded-wire tag data was provided by the Chinook Technical Committee (CTC) of the Pacific Salmon Commission in 1987[9]. **Figure B-4** represents the data required to apply cohort analysis. It begins with recovery of tags in the oldest aged spawners and works backwards until we can estimate the number of Age-2 Chinook before any fishing mortality occurs.

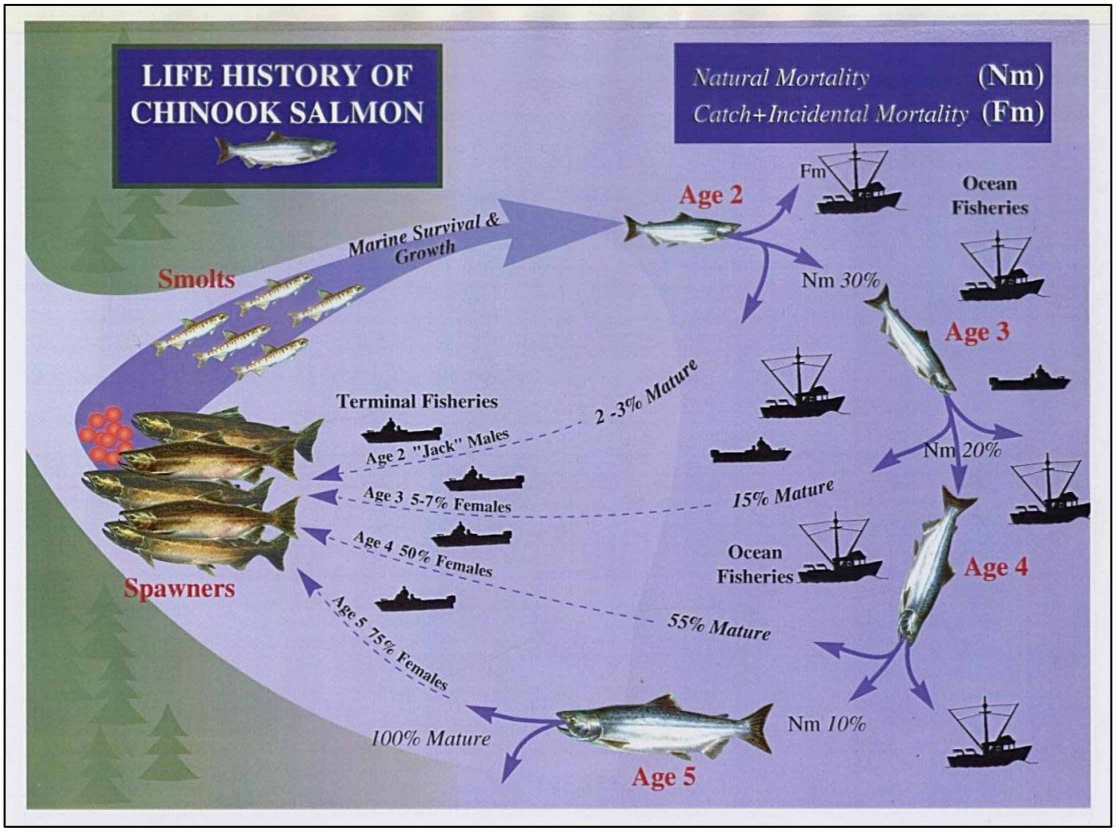


Figure B-4. Schematic of Chinook salmon fates and reconstruction of 'cohorts' to Age-2 pre-fishery abundance. Marine survival is estimated as the Age-2 Cohort (estimated number of Chinook salmon per tag group) divided by the numbers of smolts released (number tagged per CWT group). Chart produced by Val Luedke for Dr. B. Riddell.

The application of CWT cohort analysis to hatchery Chinook data provided estimates of exploitation rate by fishery and age, the distribution of catches, maturity rates by age, and survival rates from release to age 2 for each brood year tagged. The accuracy of these estimates depends on the accuracy with which

[8]Pope, J.G., 1972. An investigation of the accuracy of Virtual Population Analysis using cohort analysis. ICNAF Res. Bull. 9, 65–74. Also available in D.H. Cushing (ed.) (1983), Key Papers on Fish Populations, p. 291–301, IRL Press, Oxford, 405 p.

[9] Available at: http://www.psc.org/pubs/TCCHINOOK88-2app2.pdf

ocean and freshwater catches and spawning escapement escapements are estimated for a specific CWT group. In most situations, the numbers of Chinook belonging to a CWT group that stray to freshwater systems other than the system of release are poorly known, but have been assumed to be minor for fish released from their natal stream.

Once these analyses were conducted on recoveries from coded-wire tagged hatchery Chinook, the estimated parameters were assumed by fisheries managers to apply to local natural populations believed to be represented by these tagged hatchery fish. Representation was assumed based on similarity in abundance trends over time, similarity in return run-timing and in age-at-maturity. However, it was not assumed that the hatchery and associated wild populations share common marine survival rates. Further, if the escapement to the natural populations is estimated quantitatively, then we can apply the estimated exploitation rates by age for the indicator stock and estimate the Age-2 pre-fishery recruitment (i.e., the cohort) for the natural population(s). Combining data from the indicator hatchery stock and the natural spawning escapement, one can in theory reconstruct a stock/recruitment function for the natural population and determine the spawning objective and sustainable harvest rate for the management of natural stocks (see Riddell and Starr 1987, DFO 1999).

The first estimates of total exploitation rates (rates of removal expressed over the entire life cycle) for southern BC Chinook populations showed immediately that total exploitation rates of many Chinook stocks exceeded rates sustainable by natural populations. This finding supported the need to reduce ocean harvest impacts under the Pacific Salmon Treaty. In Canada, Healey (1982) was the first to document the decline in the number of spawning Chinook salmon but he was less certain about the extent of reduction in exploitation rates that would be required to restore spawning populations of naturally produced Chinook in southern BC.

In 1982-83, nature intervened with an extreme El Nino event (Mysak 1986, Pearcy and Schoener 1987) that resulted in extremely poor survival for Canada's indicator stock for the west coast Vancouver Island Chinook (Robertson Creek Hatchery, **Figure B-5**; Appendix D, CTC 2012) and extremely poor catches off Washington and Oregon. This one El Nino event was a significant stimulus in completing the Treaty between the United States and Canada Concerning Pacific Salmon, 1985. It had become obvious that Canada and the United States needed to collaborate on the management of Chinook because neither country had full control over this highly migratory species.

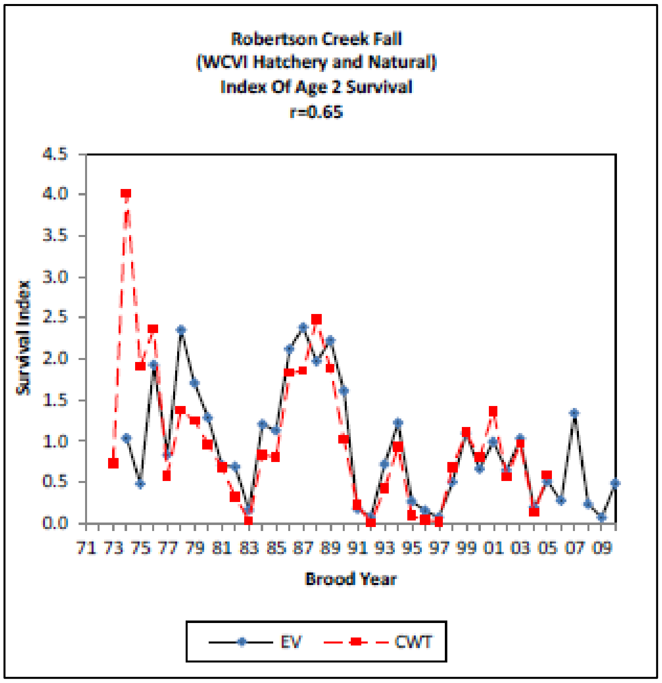


Figure B-5. Estimated marine survival rate for Robertson Creek Hatchery Chinook by spawning year (Brood Year, juveniles are released to sea in the following spring). Note the zero survival value for the 1983 Brood Year. CWT = values estimated directly from observed coded-wire tags. EV = the environmental value estimated during the calibration of the CTC coast-wide Chinook model Source: Figure D28, Appendix D, CTC 2012.

Since then the management plan in the Chinook chapter of the Pacific Salmon Treaty has evolved from fixed upper limits on catch in specific ocean fisheries to agreements on allowable harvest rates in fisheries for specific ranges of mixed-stock Chinook abundances forecasted annually by the Chinook Technical Committee (Aggregate Abundance-based Management regime, AABM). Fundamentally, the Treaty sets *upper limits* on the impact of a country's ocean fisheries on aggregate Chinook production from both countries. However, if a country meets the Treaty limits at the forecasted abundance, then it does not have to reduce its fisheries further for the conservation of specific stocks unless specific individual stock criteria are not met and the country of origin requests additional action (Chapter 3, Annex IV, Pacific Salmon Treaty, 2008). Consequently, the Treaty has enabled substantial reductions in the total exploitation rate on many Chinook stocks, but actions beyond Treaty limits usually remain the responsibility of the country of origin.

Both domestically and under the PST, Canada has also taken significant measures to reduce non-landed, fishing associated mortalities (incidental mortalities, CTC 2004, 2011). Incidental mortalities result from the release of fish below size limits (in troll and sport fisheries), catch of juvenile salmon in purse seines, and catch of Chinook in all gears during non-retention periods (the latter may also be referred to as by-catch). Each fishing gear has some associated mortality that is not reflected in the observed landed catch. In the 1970s and 1980s, these non-reported mortalities likely resulted in a 30% or greater loss (depending on fish size, gear type, and fishing locations) due to fishing than was reflected in recoveries of coded-wire tags (CTC 1987). Assessments conducted by the CTC now present fishery exploitation rates for Landed Catch (observed catch data and CWT sampling only) and the Total Exploitation Rate that accounts for *estimates* of associated incidental mortalities as well (**Figure B-6**, Appendix E, CTC 2012). While these incidental mortalities have been substantially reduced, losses due to incidentally mortalities remain a concern.

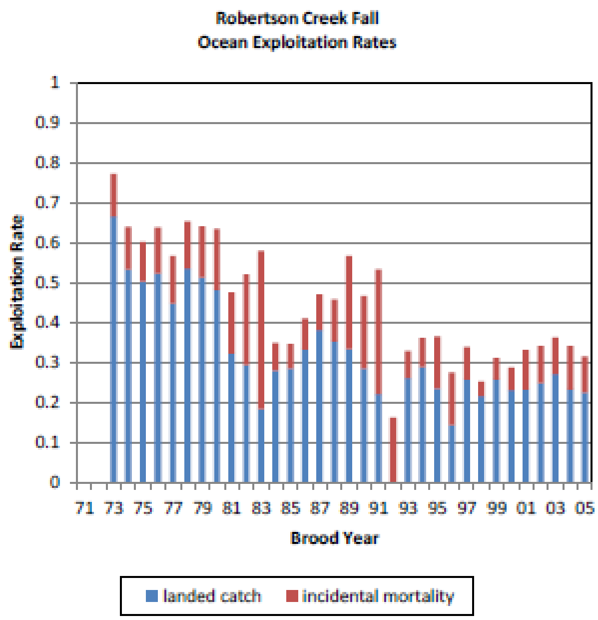


Figure B-6. Exploitation rates over all ocean fisheries for the Robertson Creek Hatchery Chinook by brood year. The figure presents total exploitation based on observed (and sampled) landed catches (blue column) plus the estimated non-reported incidental mortality for each brood year of Chinook production. Source: Figure E28, Appendix E, CTC 2012.

Did the changes to management practices (reductions in exploitation rates and incidental mortality) increase spawning escapements to southern BC Chinook populations? Initially, most of the spawning escapements did respond positively but not all. **Figure B-7** provides a summary of some populations through southern BC; three are key indicator populations (Cowichan River, Harrison River, and the Somass River, the latter contains the largest Chinook hatchery production in Canada). The other examples presented are indices of several populations within three major Chinook production regions: west coast Vancouver Island (index of six naturally spawning streams), Upper Fraser River spring Chinook (an index of 12 streams), and Thompson River summer Chinook (an index of 8 streams). These data were extracted from the data files provided by DFO Stock Assessment. Each line is a 3-point moving average[10] of annual returns expressed as standardized deviations calculated within the 1982-2012

[10] A 3-point average was applied as the vast majority of spawning Chinook are composed of 3 age classes, excluding Jack Chinook from escapements. This averaging is not intended to be a generational average, merely a smoothing function of catch and escapement trends.

period. Averaging will emphasize the trend in Chinook returns but it masks the inter-annual variation in spawning numbers. However, what is likely most striking is that each trend line is quite different.

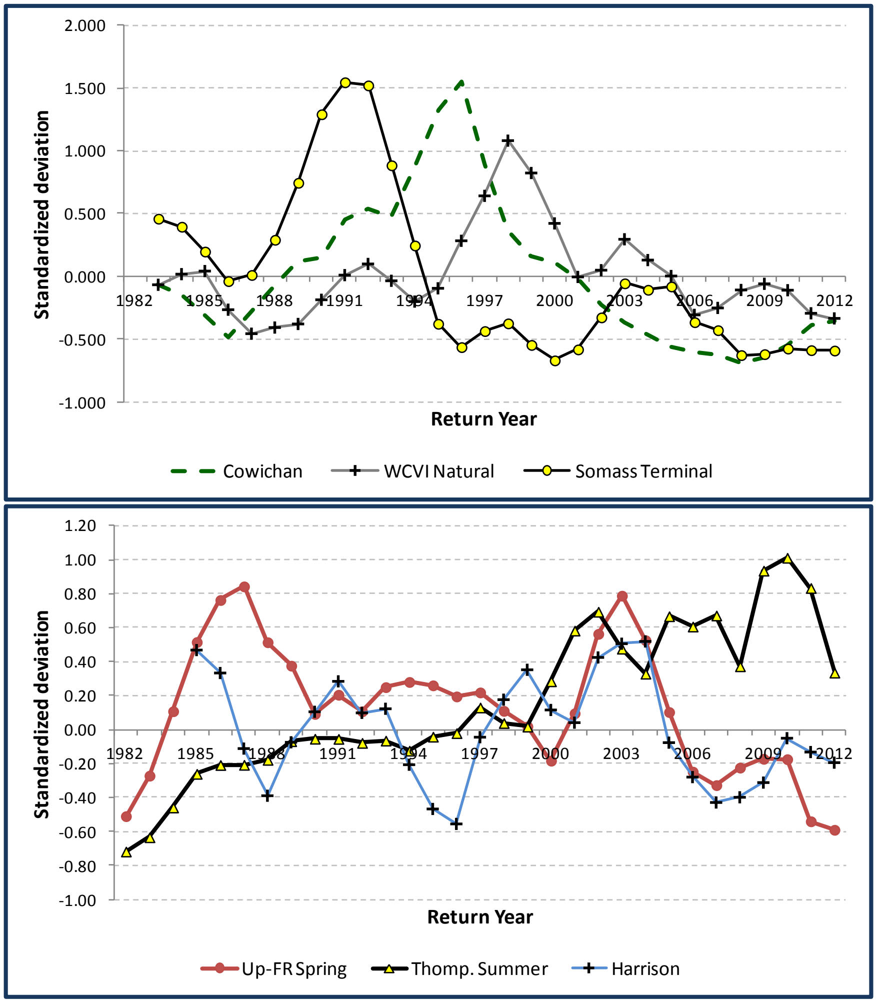


Figure B-7. Average annual returns for 1982-2012 for six Chinook populations in southern BC, including three key indicator populations (Cowichan, Harrison, and Somass rivers) and three other major production regions (west coast Vancouver Island, Upper Fraser spring Chinook, and Thompson River summer Chinook). Returns are expressed as standardized deviations of a 3-pt moving average of annual returns. For five of these six trend lines, the most common feature is the declining returns since about 2000.

So after substantial changes to the management of ocean and river fisheries for Chinook salmon, the abundance of Chinook salmon seems to have returned to levels of spawning escapements that generated coast-wide concern for Chinook salmon in the early 1980s.

Answering why this occurred now may be an even more difficult question than it was 30 years ago. Over-fishing was the first consideration at that time but given the changes in fishing pressures and practices since then, it is difficult to start from that premise. However, we cannot preclude fishing pressures as a contributing factor. The allowable fishing impact on a Chinook population is related to the productivity of the population in their current environmental conditions. If habitat effects, climate change, and hatchery interactions (for example) have reduced the productivity of the naturally produced Chinook populations in southern BC, then total mortalities associated with present patterns of fishing could still contribute to these declining escapement trends. This review will address several potential contributing factors: harvest, freshwater and marine habitats, hatcheries, pathogens, and climate change. But as will be observed, there is frequently inadequate information to draw conclusions and still more to learn.

3 Status and Trends – "The patterns we seek to explain"

3.1 Indicators

The Introduction briefly described the general situation for Chinook salmon populations in Southern British Columbia (SBC). This section elaborates further by presenting data on time trends in indicators of biological status (spawner abundance, survival rate, and productivity), as well as changes in Chinook catches. Data on other Chinook populations outside of SBC are also presented to place the SBC situation into a broader context.

One key objective of the workshop was to examine various mechanisms that could have caused the historical changes in biological indicators. We therefore first describe how those indicators have changed, not only over time, but also among stocks in different spatial locations. This information is important because causal mechanisms that can explain similarities and differences among Chinook stocks over time both and space can provide more convincing sources of evidence than mechanisms that just explain the temporal change over time in one local stock.

There are many complexities, details, and nuances to the Southern B.C. Chinook salmon data that warrant further inquiry, but there was very limited time for the Panel's work. Hence, the Panel drew its conclusions based on information presented at the workshop and various documents, as well as its own experience, rather than conducting its own additional analyses (with a few exceptions).

3.1.1 Indicator #1: Field-observed Spawner Abundance

Background

Estimates of Chinook spawner abundance from field surveys are available from DFO for the 35 "Conservation Units" (CUs) in Southern B.C. (**Table ST-1**; **Appendix STA-1**). Although some of these data sets begin in the 1950s, DFO staff have only verified these data back to 1995. Thus, that is the period for which DFO has the greatest confidence in the data. Spawner abundances include both natural-origin spawners and, if present, hatchery-origin spawners, as well as adults taken for hatchery broodstock. Natural and hatchery fish are not separated in these spawner data because in most cases, "only a small portion of fish have clipped adipose fins to externally indicate that they are hatchery fish" (Gayle Brown, DFO, personal communication, 21 June 2013). These spawner data thus reflect a poorly quantified influence of hatcheries and other enhancement methods. The vast majority of the spawner data are based on visual survey methods and have unknown accuracy or precision, and do not include returns of Age-2 Jack male Chinook due to their small size and difficulty of enumeration.

Trends

The most important observation that stimulated this workshop is that spawner abundances (S) of most CUs of Chinook salmon in Southern B.C. have decreased substantially over the most recent 3 fish generations (**Figure ST-1**). All except four of those 35 CUs have an average generation time of 4 years (last column of **Table ST-1**), so most results in **Figure ST-1** cover the last 12 years in the records. For spawning sites that were categorized by DFO as having a "low or unknown" level of enhancement activity, which occurred in 21 CUs, 13 of those CUs showed more than a 50% decrease in spawner abundance in the last 3 generations, 7 of which declined more than 70%, and one dropped by 97% (**Figure ST-1**, panel a). Five CUs showed increases. For these data, DFO assumed that the "unknown" category of enhancement most likely means little or no enhancement (Gayle Brown, DFO, personal communication, 24 May 2013). The percent changes shown in **Figure ST-1** were calculated from a linear regression through $\log_e$-transformed annual escapement estimates (summed within each CU) over the last 3 generations, with the most recent year being 2012, as described in **Box 1**.

Box 1. Calculation of 3-Generation Trend (Holt et. al. 2009)

1. Calculate generational average of $\log_e$(spawner abundance) from the time series based on the CUs generation time (i.e., 3, 4, or 5-year moving averages of $\log_e$[escapement estimates]). This averaging reduces the influence of random interannual variation.
2. Fit a simple linear regression to the $\log_e$-transformed time series and then back-transform to arithmetic scale to report annual escapement in terms of actual numbers of fish.
3. Calculate the percent change over 3 generations on the back-transformed results:

$$\%\ change\ over\ 3\ generations = \frac{y_n - y_1}{y_1} \times 100$$

where the starting and ending points of the back-transformed fitted regression line (based on a 3-generation period) are Y_1 and Y_n at times 1 and n, respectively (e.g., in the case of a 4-year generation time, n=12).

A similar result emerged in analyses of all spawning sites across the 35 CUs, regardless of the extent of enhancement (**Figure ST-1**, panel b). There, spawner abundance in 18 of 35 CUs decreased more than 50% in the most recent 3 generations, whereas 11 of them increased.

For the data sets that are the least confounded by hatchery contributions ("low or unknown" level of enhancement, **Figure ST-1**, panel a), Fraser and Thompson Rivers stocks with stream life-history types represent the majority of cases with decreasing abundance. Specifically, they constitute 12 of the 13 CUs with more than a 50% decrease and 12 of the 16 that show any decrease in the last 3 generations. Recall that stream life history means that juveniles overwinter in streams and go to sea as yearlings. The only exception to this association between stream life history and a large decrease in recent abundance is CU CK-35, Klinaklini, which had a 611% increase but also has highly uncertain data owing to turbidity in the glacier-influenced water. For the larger data set, which included all Chinook spawning sites regardless of the level of enhancement, many ocean-type stocks also had large reductions in spawners, whereas many others had large increases (**Figure ST-1**, panel b). Most of the stream-type Fraser and Thompson Rivers CUs consisted of spawning sites categorized as low or unknown enhancement, so for data that included all spawning sites, regardless of the level of enhancement, those CUs of course still showed a consistent decrease in abundance (**Figure ST-1**, panel b). A map of these same data clearly illustrates the above-described pattern of declining abundances of stream-type stocks in the Upper Fraser and Thompson River CUs, most of which had low levels of enhancement. (**Figure ST-1**, panel c).

The calculations summarized in **Figure ST-1** (panels a-c) were based on original data series that included missing values for spawner abundance in particular years. Those missing values were filled in with an algorithm by DFO when appropriate supplementary information was available (Gayle Brown, personal communication, 22 May 2013). However, even when those in-filled missing values were removed, creating a smaller data set, the general pattern of changes in abundance was similar to that described above. Specifically, for spawning sites without missing values that were categorized by DFO as having a "low or unknown" level of enhancement activity, which occurred in 10 SBC CUs, 9 CUs decreased in spawner abundance in the last 3 generations, with 5 declining more than a 50% (**Appendix Figure STA-1**, panel a). The majority of SBC Chinook stocks also had decreases in spawners for data that included all categories of extent of enhancement (**Appendix Figure STA-1**, panel b).

These reductions in spawner abundance since the mid-1990s have generated considerable concern among harvesters of Chinook salmon, conservation organizations, and the public. However, this 50-to-70% reduction in spawners only describes the last 3 generations (i.e., the last 9 to 15 years depending on the average generation time of a CU), and those trends may differ from trends over the much longer 30- to 40-year period for which there are records. This raises the potential for a "shifting baseline" problem (Pauly 1995), whereby we might reach incorrect conclusions about the status and trends of populations by only analyzing data over the last 15 years. In fact, empirical analyses have shown that trends in abundance starting with some historical baseline early in a data series (e.g., Mace et al. 2002) are more reliable predictors of future trends of Fraser sockeye salmon than just calculating changes in the last 3 generations (Porszt et al. 2012).

Unfortunately, the Panel was not provided with such long-term analyses because we were told at the workshop that DFO has only verified the Chinook spawner data from 1995 forward. Nevertheless, the Panel was provided with the long-term spawner-abundance data set, albeit unverified prior to 1995. A cursory review of it shows that spawner abundance over longer periods than the last 3 generations do not generally show as large of a percent decrease as during the last 3 generations, and some even show no change or even increases (**Appendix STA-1**). Examples of little or no change from the 1970s to 2011 are CU 10 (Mid-Fraser River Spring Chinook of **Appendix STA-1**) and CU 12 (Upper Fraser Spring Chinook), both of which showed large percent decreases since the mid-1990s (**Appendix STA-1**). Other examples, such as CU 19 (North Thompson Summers (age 1.3), still show a decrease from the 1970s to present, but less of a change than over the last 3 generations (**Appendix STA-1**).

Interpretation of these long-term data must be done carefully for two key reasons. First, changes in methods for estimating escapements have occurred over time for some stocks, which could account for some of the differences between older and more recent data. Second, harvest rates in the 1970s and early 1980s were too high to be sustainable (see Harvest section of this report) and resulted in low spawner abundance in many stocks (**Appendix STA-1**). Then the 1985 Pacific Salmon Treaty was implemented and exploitation rates decreased substantially (**Figure H-9** in Harvest section). However, despite those reduced harvest rates, only some stocks showed increased spawner abundance after 1985, others decreased, and others showed no apparent trend (**Appendix STA-1**). Many southern B.C. stocks that were apparently recovering from low spawner abundance after harvest rates were reduced have subsequently dropped to low abundance again over the last 3 generations, adding to the concern that stimulated the organization of this workshop and review panel.

3.1.2 INDICATOR #2: CATCHES

Background

Canadian Chinook salmon are caught not only in B.C. waters, but also in Alaska, Washington, and Oregon fisheries (see Harvest section). Similarly, many U.S.-bound Chinook are caught in B.C. waters. The Chinook Technical Committee (CTC), in conjunction with the relevant Canadian and United States agencies, has therefore developed elaborate procedures for sampling Chinook catches, conducting stock identification based on coded-wire tags (CWT, with some validation using DNA studies), and attributing fish caught back to their parental stocks of origin. However, catch data for some Chinook stocks are incomplete as a measure of fishing mortality because they do not include all recreational or First Nation catches, do not account for incidental fishing-related mortalities, and the accuracy of reported catches is frequently argued.

Trends

Catches of Chinook salmon have decreased dramatically since the mid-1970s (**Figure ST-2**). British Columbia fisheries have seen the greatest percent decline in catch compared to Alaska, Washington, and Oregon. These time trends reflect changes in both abundance and fishing regulations, which have generally become more restrictive in recent years as a result of regulations under both the Pacific Salmon Treaty and regional management authorities. Catch data are discussed further in the Harvest section later in this report.

3.1.3 INDICATOR #3: CTC'S CWT-DERIVED MARINE SURVIVAL RATES

Background

The third indicator of Chinook status that the Panel examined is the Chinook Technical Committee's "age-2-cohort marine survival rate", which reflects the proportion of juveniles leaving their freshwater habitat that are alive after their first winter at sea. By convention, this survival rate is referred to as the "age-2 cohort marine survival rate", although stream-type Chinook at this life-history stage are actually age 3 years (but with only one year at sea). CTC scientists from Canada and the U.S.A. have worked together since 1982 on many activities, including collecting and analyzing data from coded-wire-tags that have been inserted annually into millions of juvenile Chinook salmon from numerous west-coast stocks. Subsequent sampling of tagged and untagged adults is routinely done, both in the harvest and escapement. Among other benefits, this CWT program has produced a valuable time series of "age-2-cohort marine survival rates", which are based on recoveries of tagged and untagged adults of all ages and back-calculations of how many 2-year-olds must have been present in the cohort for each brood year (year of spawning), taking into account harvest in various fisheries, maturation rates, and natural mortality rates by age class. These marine survival rates were provided to workshop participants by the CTC and were derived from well-established but technically complicated methods that we do not describe here. For details of those methods, see CTC (1987). Although the CTC refers to these data series as "marine" survival rates, for a few indicator stocks, they technically include a short period of juvenile migration through fresh water to the ocean. Throughout this report, though, we use the widely used shorthand of "marine survival rates".

These data for age-2-cohort marine survival rates cover 13 Canadian Chinook Conservation Units (CUs) and 40 United States CWT "indicator stocks" (**Table ST-2**; **Figure ST-3**). In some stocks, these data go back to early 1970s brood years. Note that Chinook salmon in certain areas can live up to 7 years, so the marine survival rates of the final brood years of some data series are estimates from incomplete cohorts (shown with dotted lines in **Figure ST-3**). Those survival rates were estimated by the CTC based on partial returns from that cohort and past age distributions of returns. Nevertheless, as we show in a later sensitivity analysis, the main results of this "Status and Trends" section are not heavily influenced by those incomplete cohorts, which are only a small portion of the total time series.

Box 2. Transformations of CWT-based marine survival rate data

The CWT-based marine survival rate data were transformed in various ways to facilitate their interpretation and comparison with other stocks:

a) Log_e(marine survival rate)

b) 4-year moving average of log_e(marine survival rate)

c) Scaled values of log_e(marine survival rate) for each stock, where each series of scaled values has a mean = 0 and a standard deviation (SD) = 1. Such scaled values allow meaningful comparisons across stocks that have quite different average survival rates.

An example for Robertson Creek, West Coast Vancouver Island, illustrates the differences between the original indicator and its three transformations (**Figure ST-4**).

Trends

In 4 of the 5 stock groupings of Southern B.C. Chinook salmon (Fraser River Late, Lower and Upper Strait of Georgia, and West Coast of Vancouver Island), age-2-cohort marine survival rates have decreased substantially from their highs in the 1970s or 1980s to their lows in the 1990s and 2000s (**Figure ST-3**, panels a-e). The exception was Fraser Early (**Figure ST-3**, panel b) where stocks showed the highest survival rates for the 1990 and late 1990s brood years. Regions outside of Southern B.C. also had decreased survival rate, but in several cases, there was a temporary increase in the late 1990s and early 2000s followed by a decline (**Figure ST-3**, panels f-n).

Most of these CWT survival data series are for stocks where juveniles are released from hatcheries because it is more difficult and expensive to catch and tag large enough numbers of ***wild*** Chinook smolts from naturally spawning populations to generate reliable direct estimates of survival rate of wild fish. Nevertheless, CTC scientists assume that such hatchery-based marine survival estimates are useful indicators of survival conditions for naturally spawning Chinook populations

Note on effects of fishing

It is important to note that variation over time and across stocks in these estimated marine survival rates is <u>not</u> explainable by fishing rates. This is because survival rates are derived from estimates of the age-2 cohort divided by the number of CWT-tagged juveniles released. Age-2 is the age before recruitment to the fishery (for steam-type Chinook this would be Age-3 Chinook). The cohort reconstruction model explicitly accounts for the effects of fishing by incorporating age-specific harvest as estimated from CWT recoveries. Of course, fishing reduces the number of spawners, but it does not affect the juvenile-to-age-2 survival rate of the cohort that produces the fishable population in a given year. This distinction is important; mechanisms to explain changes in survival rate and biological productivity of Chinook salmon are in a separate category from harvest rates, which do not affect natural survival rate or biological productivity in the short term, yet cause immediate changes in spawner abundance and catches.

3.1.4 Indicator #4: Life-cycle Productivity

Background

Changes across years in adult recruits of a given population of Chinook salmon are obviously affected by spawner abundance and subsequent survival rates over the entire spawner-to-recruit life cycle. Here we describe various measures of what the CTC refers to as productivity (as distinct from the age-2-cohort marine survival rate described above). These productivity measures for the entire Chinook life cycle were produced from abundance estimates for spawners (S) and the adult recruits (R) that resulted from each brood year's spawning. The S and R data came from two sources. The first was Gayle Brown (DFO, personal communication, 25 April 2013) who provided estimates from the Pacific Salmon Commission's

(PSC) Chinook coast-wide model (CTC 2012a) for reconstructed historical abundances of spawners and the resulting adult recruits for 30 PSC model stocks (**Table ST-3**). These stocks spawn in areas from as far south as the Oregon coast and the Columbia River to as far north as Southeast Alaska. We also examined Chinook data from outside of Southern B.C. to determine whether changes in SBC Chinook populations are unique or whether other Chinook stocks show similar changes.

The indices of life-cycle productivity, as generated by the PSC coast-wide model's reconstructed spawners and adult recruits, are of uncertain relevance to naturally spawning fish because most of these 30 "model stocks" include large, temporally varying, and/or unknown fractions of hatchery fish in ocean catches and spawning escapements. Normally, catches and escapements that result directly from hatchery releases are excluded from standard stock-recruitment analyses that are designed to assess performance of naturally-spawning fish. Furthermore, most of these PSC model-based data for S and R reflect *aggregates* of Chinook stocks, rather than the *single* stocks that are the focus of typical stock-recruitment analyses. For these reasons, the life-cycle productivity measures should be interpreted carefully recognizing the inherent uncertainty in how well they represent single-stock dynamics. Just prior to completion of this report, we received a list of 9 of these PSC "model stocks" that were composed of at least 90% natural spawners, and whose dynamics therefore do not reflect confounding with hatchery or other enhancement contributions. We suggest that future analyses of productivities of PSC "model stocks" should focus on the following 9 wild stocks:

1. North/Central BC (NTH)
2. Fraser Early (FRE)
3. Harrison River Late Whites (subset of the Fraser Late group)
4. Alaska South SE (AKS)
5. Skagit wild (SKG), Washington
6. Lewis River wild (LRW), Washington
7. Washington coastal wild (WCN)
8. Lyons Ferry (LYF), Washington
9. Oregon coast (ORC)

The second set of S and R data covered Alaskan stocks that were not included in the above reconstructions from the PSC's coast-wide model and hence do not have the same concerns described for that model's output. These non-PSC data came from Alaska Department of Fish and Game files via personal communication in May 2013 from Eric Volk (Alaska Department of Fish and Game in Anchorage) and Matt Catalano (Auburn University, Georgia), who has collaborated with ADF&G on analyses of several Alaskan stocks. These Alaskan data cover 13 Chinook stocks in central and western Alaska and Southeast Alaska (other than the CTC's aggregate stock called Alaska South SE) (**Table ST-3**).

Box 3. Transformations of spawner and recruit data

From these data on abundances of spawners and recruits by year and stock, various productivity indices were generated by Brigitte Dorner (a contractor for the workshop, bdorner@driftwoodcove.ca) and Randall M. Peterman (a contractor prior to the workshop, as well as a panelist). Similar transformations were done to these S and R data as described above in **Box 2** for the CTC's CWT-based marine survival rate. As an example, data for Late Fraser River Chinook salmon illustrate the differences between time trends in the original S and R indicators and various indicators derived from them (**Figure ST-5**), calculated as:

a) Loge(R/S)

b) 4-year moving average of loge(R/S)

c) Scaled values of the 4-year moving average of loge(R/S) for each stock, where each series of scaled values has a mean = 0 and a standard deviation (SD) = 1.

d) In addition, a standard Ricker (1975) spawner-recruit model was fit to each set of S and R data, and annual residuals from the best-fit model were calculated. Each brood-year's residual thus reflects the influence of factors other than within-stock within-brood-year spawner abundance (i.e., other than the within-stock density-dependent effects). Factors potentially affecting the magnitude and sign of these residuals include predation, competition for limited food supply, mortality from pathogens, as well as marine and freshwater habitat-related processes that may influence survival at any life stage.

e) In the standard Ricker (1975) spawner-recruit model, the maximum rate of increase in abundance between generations is denoted by the Ricker 'a' parameter. We estimated a time-varying Ricker productivity parameter (denoted at) to describe the non-stationary feature of many of these Chinook stocks. Non-stationary productivity, which refers to a change over time in average productivity and/or its variance, is a feature that was already implied from the large decreases over time in many of the CTC's CWT marine survival rates (**Figure ST-3**).

   The time-varying Ricker at parameter was estimated using a Kalman filter procedure that had a random walk error term, which is a method that has proven effective at describing underlying time trends in salmon productivity in the presence of observation error (i.e., errors in estimates of spawner abundance and recruits) (Peterman et al. 2000; 2003). Smoothed time series estimates of the at parameter (called "Kalman filter at" here) illustrate the dynamic nature of productivity over time in the entire Chinook life cycle (example for Fraser Late in **Figure ST-5**).

f) Scaled values of the Kalman filter at for each stock, where each series of scaled values has a mean = 0 and a standard deviation (SD) = 1.

Trends

The Ricker residuals show (a) a clear decreasing trend only in the Lower Strait of Georgia Chinook (meaning that in most years, fewer adults are returning than expected from parental spawners), (b) a slight decrease in Fraser Late, and (c) the remaining SBC stocks' residuals vary around a constant mean (**Figure ST-6**). The other productivity indicator here, $\log_e(R/S)$, decreased since 1995 in the Upper Strait of Georgia and since the 1980s for Fraser Early, the latter possibly due to increased spawner abundance. For $\log_e(R/S)$, a value of 0 means that adult recruits are just replacing the number of parental spawners; positive values indicate an increasing population, and negative values a decreasing one. Hence, Fraser Early and Upper Strait of Georgia Chinook have been trending toward just replacing themselves in recent years. Numerous stocks outside of the Southern B.C. also show a decrease in both Ricker residuals and $\log_e(R/S)$, especially since the late 1990s or early 2000s (**Appendix Figure STA-2**).

Two smoothed versions of life-cycle productivity show underlying long-term trends more clearly than the other two measures of productivity because the year-to-year variations are reduced -- the 4-year moving average of $\log_e(R/S)$ and the Kalman filter estimate of the time-varying Ricker 'a' parameter (KF a_t). For all 5 component regions of Southern B.C. Chinook salmon, the 4-year moving average of $\log_e(R/S)$ decreased in the most recent years, if not even earlier (**Figure ST-7**). For some stocks, these values were decreasing toward just meeting replacement. The time-varying Ricker 'a' parameter decreased substantially for Lower Strait of Georgia and Robertson Creek, but only slightly though steadily for Fraser Late (**Figure ST-7**). In contrast, it generally increased for Upper Strait of Georgia and Fraser Early (**Figure ST-7**). Readers should interpret these trends for the Kalman filter estimates of the Ricker a_t parameter in terms of corresponding nonlinear changes in recruits per spawner, noting that the Ricker a_t parameter appears as an exponent, e^a, in the Ricker model. Thus, a change from a_t=2 to 1 is equivalent to a drop in recruits per spawner from 7.4 to 2.7.

Outside of Southern B.C., Chinook stocks show prominent and frequently similar trends for the 4-year moving average of $\log_e(R/S)$ and the KF a_t parameter. The North/Central B.C. stock and many areas of Oregon, Washington, and Alaska show high $\log_e(R/S)$ in the late 1990s and early 2000s, but declining since then and, for a few stocks, with an upswing in the last 3 brood years (**Appendix Figure STA-3**). Shared patterns in the Kalman filter a_t parameter are less obvious, but more stocks in those same regions show a tendency for decreasing Kalman filter a_t values than increasing values (**Appendix Figure STA-3**). Quantitative comparisons of these indicators are provided below in the section "Comparisons among Chinook salmon stocks". The productivity trends for Alaskan Chinook salmon were considered so worrisome that a public and scientific conference was organized on short notice for October 2012 (www.adfg.alaska.gov/static/home/news/hottopics/pdfs/agenda.pdf). Alaska has also developed a statewide Chinook Research Plan (ADF&G 2013). In addition, an Expert Panel was established to investigate the decline in the Arctic-Yukon-Kuskokwim (AYK) region of Alaska and produce a research action plan for that specific area (Schindler et al. 2013). Unfortunately, we received this report just as we were finalizing our own Panel report on the Southern B.C. Chinook, so it was not possible to incorporate information from it here. We therefore encourage readers to look at Schindler et al. (2013) for material that may be useful for the Southern B.C. Chinook situation.

3.1.5 Indicator #5: Contribution of Hatcheries and other Enhancement Methods

Abundance of adult recruits of many Southern B.C. Chinook salmon populations is driven by both the dynamics of wild populations and contributions from hatcheries as well as other enhancement methods such as seapens. Therefore, the percent composition of stocks that is natural vs. enhanced is an important indicator that could help scientists understand the causes of changes in abundance. Unfortunately, the Panel was only provided such data on 5 stocks for contributions from hatcheries and other enhancement methods (**Figure ST-8**). In 4 of those cases (excluding Cowichan), enhancement-derived fish constituted between 38% and 100% of escapements since 1991, averaging more than 60%. Thus, wild, natural-spawning fish tend to be in the minority for Robertson Creek on the west coast, and Big Qualicum, Puntledge, and Quinsam on the east coast of Vancouver Island. Hatchery data are discussed further in the "Hatchery" section later in this report.

3.2 Comparisons of Biological Indicators within and across Stocks

The next two sections (3.2.1 and 3.2.2) use the data described above to compare changes in the juvenile-to-age-2 cohort survival rate with changes in productivity of multiple Chinook stocks, and to compare each variable across stocks. The spatial and temporal changes in biological variables are what scientists are attempting to explain with particular causal mechanisms. The influence of harvesting on abundance of spawners is the focus of the next section of this report ("Harvest").

3.2.1 Comparisons between Marine Survival Rate and Life-cycle Productivity

The time series of CWT-derived marine survival rates for a given stock tend to be positively correlated with indices of life-cycle productivity for the same region, despite the concerns about interpreting the latter productivity indices of aggregate PSC stocks caused by hatchery contributions to spawners and recruits (**Table ST-4**). Across all 17 B.C. and non-B.C. stocks where there were time series of both variables, the highest median correlation is between the 4-yr-moving average of the CWT $\log_e$(survival rate) and the 4-yr-moving average of residuals from the best-fit Ricker model. That median correlation is 0.70 (**Table ST-4**, right-most column). For the 5 Southern B.C. stocks only, the median correlation between those same two variables is 0.86. Note that in several cases, the stock used for the CWT-based marine survival rates is not identical to the stock with the indicator for life-cycle productivity, because the latter are in many cases based on larger aggregates of stocks for which spawners and recruits were reconstructed from the Pacific Salmon Commission's Coast-wide model. Hence, part of the reason for differences between these two data series is that the particular groups of fish are not identical in each case. The relatively high correlation between full life-cycle productivity and estimated marine survival rates suggests, however, that marine rather than freshwater factors have had a strong influence on productivities over the years for which data are available.

3.2.2 Comparisons among Chinook Salmon Stocks

An important initial step in attempting to determine causes of changes in survival and productivity of Southern B.C. Chinook salmon is to ask how well correlated those time series are for these stocks. For instance, if all juvenile-to-age-2 cohort survival rate series are highly correlated from the west coast of Vancouver Island through the Strait of Georgia and Fraser River, then that would suggest that the most likely causes of changes in those survival rates are processes that either (a) operate in marine waters that are shared by those stocks during migration and rearing, and/or (b) operate at a large enough spatial scale to encompass all of those freshwater environments and cause delayed mortality in the marine stage. Such shared variation across salmon stocks has been observed in pink, chum, and sockeye salmon (Pyper et al. 2005). In contrast, if there is only a low correlation in age-2-cohort survival rate among stocks within Southern B.C., then that suggests that local, stock-specific causal mechanisms dominate. Analogous arguments hold for the life-cycle productivity indices, and also for comparisons across the larger west-coast region beyond Southern B.C. For hatchery stocks, there is of course no freshwater life stage to compare with wild fish, so any changes over time in the indices of hatchery stocks must be due to factors in the ocean (assuming that there are no time trends in practices such as brood-stock selection within hatcheries that affect survival).

3.2.2.1 Comparisons based on age-2-cohort survival rate

Correlations

We (which refers only to B. Dorner and R. Peterman in this section 3.2.2) first created a full correlation matrix by calculating the Pearson correlation coefficient between each pair of stocks that had time series for the CTC's CWT-based juvenile-to-age-2-cohort survival rate, for stocks from Washington up through Southeast Alaska. For these correlation analyses we used the 4-year moving average of that survival rate and aligned the data series from each stock to have the same ocean entry year to account for different life-history types of juveniles. Because of the workshop's initial focus on the most recent downward trends in Chinook abundance, we first present results for ocean-entry years 1995-2009, and then later discuss results for a sensitivity analysis with a longer period, 1981-2009.

Correlations between stocks in their age-2-cohort marine survival rates range from strongly positive to strongly negative, depending on the region. Even the Southern B.C. region alone shows this range of positive and negative correlations (**Figure ST-9**; see red box enclosing correlations between all pairs of Southern B.C. stocks), suggesting that even within this small region, quite different mechanisms may be affecting survival rates, which may reflect different freshwater habitats, enhancement effects, as well as different timing and locations of ocean entry. Correlations between SBC stocks and those from other regions are also not consistent, but tend to be slightly more positive than negative (**Figure ST-9**; see two black boxes enclosing correlations between SBC and all other stocks). All Fraser River stocks except Dome Creek show strong positive correlations with Oregon and Columbia River Chinook. As well, coastal Oregon, Columbia River, and coastal Washington stocks (i.e., not Puget Sound) show consistent positive pairwise correlations (**Figure ST-9**; lower left corner). The juveniles of these Oregon, Columbia River, and coastal Washington stocks all enter the ocean directly on the west coast, as opposed to Puget Sound, and their age-2 cohort survival rates are strongly positively correlated despite their diverse freshwater habitats, suggesting a dominant role of shared drivers in the ocean.

A regional summary of this detailed pairwise correlation matrix more clearly illustrates the general spatial patterns (**Figure ST-10**). Each cell in this table was created by first removing all diagonal pairwise elements from the matrix in **Figure ST-9** (which have correlations of 1.0) and then averaging the remaining pairwise correlations within that cell. The resulting average is shown in **Figure ST-10**. The slight tendency for positive average correlations among Southern B.C. stocks is reflected by the three positive but low-correlation cells. Some SBC stocks are also positively correlated with Southeast Alaska and transboundary rivers, but not with North and Central B.C. One feature of these regional averages that was not as clear from the detailed correlation matrix is the tendency for positive correlations in survival rate between West Coast Vancouver Island stocks and Columbia River, Washington coast, and Puget Sound stocks, as well as between Strait of Georgia and Columbia River (**Figure ST-10**). These positive correlations suggest shared drivers of change.

Dynamic Factor Analysis of Shared Trends

The correlation matrices quantify the strength of correlations or shared trends in survival rates among Chinook stocks, but to better understand the causes of these spatial and temporal patterns, the shared trends need to be quantified. To do this, we used Dynamic Factor Analysis (DFA), which is a powerful method for describing similarities in several sets of time series data (see **Box 4**).

Box 4. Dynamic Factor Analysis

Dynamic Factor Analysis (DFA) is a factor analysis for time series data that works even with missing data (unlike Principal Components Analysis) (Zuur et al. 2003). DFA is a regression for which independent variables (factors) are temporal patterns rather than the typical annual values of some variable. DFA uses Kalman filtering and smoothing to estimate parameters, and uses a standard model selection criterion (AIC_c) to compare the fit to data of each of several alternative models that differ in the number of underlying shared trends that are assumed to exist in the data. The best (lowest AIC_c) model reflects the number and temporal pattern of shared trends that are justified by the data.

The best DFA model for the CWT-based juvenile-to-age-2-cohort survival rate had one shared trend, which shows increasing survival rate from ocean-entry year 1995 to around 2000, decreasing until 2005 and then a partial reversal (**Figure ST-11**). The factor loadings or weights on that trend were almost uniformly positive for Chinook stocks from Oregon, the Columbia River, Washington, and B.C. (**Figure ST-12**); indicating that those stocks tended to share that temporal pattern to various extents -- the higher the loading value, the more a given stock's time trend in age-2-cohort survival rate resembles the generally shared trend of **Figure ST-11**. Southern B.C. stocks are among those with positive loadings on that overall shared trend (**Figure ST-12**). This result for SBC stocks reflects the results from the correlation matrix in which SBC stocks tended to be positively correlated with other, non-SBC stocks, especially from Oregon and Washington (**Figures ST-9**, 10). In contrast, Southeast Alaska has about as many stocks that do not share the DFA-derived overall general trend as share it (**Figure ST-12**).

3.2.2.2 Comparisons based on life-cycle productivity

Just as we did with the data on age-2-cohort marine survival rate, we calculated a pairwise correlation matrix for the Kalman filter estimate of life-cycle Ricker productivity, a_t. This is already a smoothed variable, so it was not necessary to take moving averages to make it comparable to the 4-year moving average of the CWT survival rate above. Recall that this analysis is based on spawner and recruit data and includes many more Alaskan Chinook stocks than for the analysis of CWT survival rates.

Both the detailed pairwise stock correlation matrix and the regional average matrix of Kalman filter a_t show more positive (blue) than negative (red) correlations (**Figures ST-13, ST-14**). Southern B.C. stocks tend to be more positively correlated with one another than negatively, with Strait of Georgia stocks being the strongest negative ones (**Figure ST-14**). The latter results for the Strait of Georgia are from only two time series from the PSC coast-wide model, GSQ (Quinsam in Upper Georgia Strait) and GST (natural stock, Cowichan and Nanaimo in Lower Georgia Strait). SBC stocks share common patterns in the Kalman filter a_t with stocks from northern and central B.C. and most of Alaska, although such a "northern" group was not apparent in the correlation matrices derived from the survival rate series because of the paucity of CWT data on Alaskan survival rates.

Strong positive correlations in the Kalman filter a_t are prevalent among northern stocks (from central and northern B.C. northward to western Alaska) and also among the coastal Oregon, Washington, and Columbia River stocks (**Figure ST-13**). Regional average correlations also reveal the shared patterns of time trends in productivity across many stocks ranging from Oregon up through Alaska (**Figure ST-14**), suggesting that there may be large-scale shared drivers of changes in productivity.

For life-cycle productivity, we did not conduct a Dynamic Factor Analysis on the Kalman filter estimates of the Ricker a_t parameter because the DFA applies a Kalman filter of its own. Instead, our DFA analysis used residuals from the stock-specific best-fit Ricker model. The best-fit model from the DFA for ocean-entry years 1995-2009 for these residuals had two shared trends, one increasing to 2002 and then decreasing, and a second trend with declining productivity starting around 2000 and continuing until a slight upturn in 2008 and 2009 (**Figure ST-15**). Both time trends had positive loadings for most stocks, with the first trend most prominent in B.C. and parts of Southeast Alaska, and the second trend most prominent in Washington and the rest of the Alaskan stocks (**Figure ST-16**).

The general conclusion is that there are shared time trends across stocks over a wide area well beyond southern B.C. alone. This conclusion emerged from not only the CWT-based marine survival rates but also the more problematic indices of life-cycle productivity derived from the PSC's coast-wide model. Even though the latter indices are much more uncertain because of the uncertain contributions from hatchery fish, they still suggest a spatially extensive trend of decreasing productivity over time and a concern about stocks of southern B.C. Chinook salmon in particular. The consistency of these results for the more reliable marine survival rates suggests that useful information is contained in the measures of life-cycle productivity, despite uncertainties in the latter.

3.2.2.3 Conclusions about among-stock comparisons

Southern B.C. Chinook stocks exhibit temporal patterns in life-cycle productivity, and to a lesser extent age-2 cohort survival rate, that are shared to various degrees across a large spatial area from Oregon up through western Alaska. Thus, it seems likely that there are large-scale processes influencing Chinook productivity. Such shared temporal patterns in productivity have also been observed in sockeye salmon (Peterman and Dorner 2012), as well as other analyses of Chinook salmon (Sharma et al. 2013). In fact, most non-Fraser River sockeye salmon from Washington to Alaska also show a temporary increase in productivity in the late 1990s and early 2000s (Peterman and Dorner 2012)

However, stock-specific deviations in survival rates and productivity (**Figures ST-3, ST-6, ST-7**) from the shared trends (**Figures ST-11, ST-15**) indicate that there are other key factors affecting productivity that are not shared across a wider group of stocks. That is, local processes causing variation in productivity are also prominent, in addition to the shared large-scale processes (Sharma et al. 2013). Research into mechanisms causing changes in survival rate and life-cycle productivity should therefore examine processes on both spatial scales.

3.2.2.4 Sensitivity analyses

We also conducted several sensitivity analyses to determine whether the conclusions drawn so far in this section remain valid for different assumptions or data sets.

1. To determine whether the trends in survival rate and productivity for ocean-entry years 1995-2009 reflect longer-term trends, we repeated our analyses with data starting in 1981. The resulting correlation matrices were similar to the original ones, but contained either slightly more and stronger positive correlations (for marine survival rate) or fewer positive correlations (for productivity) than in the 1995-2009 period (more details in **Appendix STA-4**). These changes were relatively small, though, and the general overall patterns remained.

2. To check whether incomplete cohorts affected results for the CWT-based marine survival rates, we repeated the among-stock correlations using only data up through ocean-entry year 2007 (instead of the initial 2009), which meant that marine survival rates for all except two of the 33 stocks were based on data from all adult age classes (**Appendix STA-4**). Results for this shorter data set produced correlation matrices that were very similar to the original ones. We therefore are confident that the general patterns of shared variation among Chinook salmon stocks in the survival rates are valid and were not affected by the incomplete cohorts.

3. We repeated the correlation analyses by aligning stock-specific data series by brood year instead of ocean-entry year to allow for shared freshwater influences (**Appendix STA-4**). The resulting correlation matrices for survival rate and productivity were similar to the original analyses, so there were no changes in overall patterns or conclusions.

3.3 Summary for the Status and Trends

- Spawner abundances of most Conservation Units (CUs) of Chinook salmon in Southern B.C. have decreased substantially over the most recent 3 fish generations (about the last 12 years). For spawning sites that were categorized by DFO as having a "low or unknown" level of enhancement activity, which occurred in 21 CUs, 13 of those CUs showed more than a 50% decrease in spawner abundance in the last 3 generations, 7 of which declined more than 70%, and one dropped by 97%[11] (**Figure ST-1**, panel a). Five CUs showed increases.

- For data sets that are the least confounded by hatchery contributions, Fraser and Thompson Rivers stocks with stream life-history types (which overwinter in rivers and then go to sea as yearlings) represent the majority of those cases with decreasing spawner abundance in the last 3 generations. They constitute 12 of the 13 CUs with more than a 50% decrease and 12 of the 16 that show any decrease in the last 3 generations.

- Longer-term data back to the 1970s show that many southern B.C. stocks had apparently started to recover from low spawner abundance after harvest rates were reduced after the 1985 Pacific Salmon Treaty was implemented. However, several of those stocks have again dropped to low abundance over the last 3 generations.

- Catches of Chinook salmon have been reduced dramatically since the mid-1970s but have been stable or increasing during the period of interest (1995-2012).

- In 4 of the 5 stock groupings of southern B.C. Chinook salmon (Fraser River Late, Lower and Upper Strait of Georgia, and West Coast of Vancouver Island), survival rate from juveniles to 2-year-olds (the cohort "marine survival rates"), which are estimated via an extensive coded-wire tagging (CWT) program, have decreased substantially from their highs in the 1970s or 1980s to their lows in the 1990s and 2000s. Regions outside of southern B.C. also had decreased survival rate, but in several cases, there was a temporary increase in the late 1990s and early 2000s followed by a decline.

- Indices of life-cycle productivity from spawners to adult recruits were generated by the Pacific Salmon Commission's coast-wide model, but they are highly uncertain because many of these "model stocks" include returns of hatchery fish that vary from year to year. Given this caveat

[11] The one CU is $SC+SF_j$ involving 6 time series with 3 categorized as Extirpated; the CU generally involves poor data quality and limited monitoring.

though, life-cycle productivity indices decreased substantially for Lower Strait of Georgia and Robertson Creek, but only slightly though steadily for the Fraser Late stock. Other Southern BC stocks show either no trend in productivity indices, or slight increases.

- Numerous stocks outside of the Southern B.C. also show a decrease in productivity, especially since the late 1990s or early 2000s, including central and western Alaska stocks that had spawner and recruit abundance data for naturally-produced Chinook, that were not confounded by hatchery contributions.
- The time series of CWT-derived marine survival rates for a given stock tend to be positively correlated with the indices of life-cycle productivity for the same region that were produced by the Pacific Salmon Commission's coast-wide model, despite the large uncertainty associated with those productivity indices.
- Comparisons across Chinook salmon stocks of time series of the age-2-cohort marine survival rates show a tendency for an underlying trend of shared variation from Oregon through B.C., and even into some Alaskan stocks. That shared trend shows increasing survival rate from ocean-entry year 1995 to around 2000, decreasing until 2005 and then a partial reversal. However, in many stocks, there also are stock-specific sources of year-to-year variation that mask that underlying trend.
- Southern B.C. Chinook stocks exhibit temporal patterns in life-cycle productivity, and to a lesser extent age-2 cohort survival rate, that are shared to various degrees across a large spatial area from Oregon up through western Alaska. Thus, it seems likely that there are large-scale processes influencing Chinook productivity.

3.4 Chapter Tables and Figures

3.4.1 *Tables*

Table ST-1. Descriptions of groups of Southern British Columbia Chinook salmon, delineated by area (see footnote), Conservation Unit (CU), and life-history type (including adult run timing, the main type of juvenile life history -- where juveniles initially rear, and average duration of a full-life-cycle generation in years). Information provided by Gayle Brown (DFO, personal communication, 25 April 2013).

Area[1]	CU ID	CU_Acronym	Run timing	Main type juveniles	Avg. gen (years)
1-Fr-St	CK-04	LFR-spring	SP	stream	4
1-Fr-St	CK-05	LFR-UPITT	SU	stream	4
1-Fr-St	CK-06	LFR-summer	SU	stream	4
1-Fr-St	CK-08	NAHAT	SP	stream	4
1-Fr-St	CK-09	Portage	FA	stream	4
1-Fr-St	CK-10	MFR-spring	SP	stream	4
1-Fr-St	CK-11	MFR-summer	SU	stream	4
1-Fr-St	CK-12	UFR-spring	SP	stream	5
2-Th-St	CK-14	STh-1.3	SU	stream	4
2-Th-St	CK-16	STh-BESS	SU	stream	4
2-Th-St	CK-17	LTh	SP	stream	4
2-Th-St	CK-18	NTh-spr	SP	stream	4
2-Th-St	CK-19	NTh-sum	SU	stream	4
3-Th-Oc	CK-13	STh-0.3	SU	ocean	4
3-Th-Oc	CK-15	STh-SHUR	SU	ocean	4
3-Th-Oc	CK-82	Adams-upper	SU	ocean	4
4-Lfr-Oc	CK-03	LFR-fall	FA	ocean	4
4-Lfr-Oc	CK-07	Maria	SU	ocean	4
4-Lfr-Oc	CK-9000	(P)HatchX-LFR	FA	ocean	4
5-GS-Oc	CK-02	BB	FA	ocean	4
5-GS-Oc	CK-20	SC+GStr	FA	ocean	4
5-GS-Oc	CK-21	Goldstr	FA	ocean	3
5-GS-Oc	CK-22	CWCH-KOK	FA	ocean	3
5-GS-Oc	CK-24	midEVI-sum	SU	ocean	4
5-GS-Oc	CK-25	midEVI-fall	FA	ocean	3
5-GS-Oc	CK-27	QP-fall	FA	ocean	4
5-GS-Oc	CK-28	SC+SFj	FA	ocean	4
5-GS-Oc	CK-29	NEVI	FA	ocean	4
6-WCVI-Oc	CK-31	SWVI	FA	ocean	4
6-WCVI-Oc	CK-32	NoKy	FA	ocean	4
6-WCVI-Oc	CK-33	NWVI	FA	ocean	4
7-Misc-St	CK-01	OK	SU	stream	4
7-Misc-St	CK-23	NanR-spr	SP	stream	4
7-Misc-St	CK-34	HOMATH	SU	stream	4
7-Misc-St	CK-35	KLINA	SU	stream	4

[1]**Area Code:**

1-Fr-St:	All Fraser mainstem stream type including lower Fraser (includes the Birkenhead population CK-04)
2-Th-St:	Thompson stream type
3-Th-Oc:	Thompson ocean type; this group has a slightly different ocean timing compared to Lower Fraser ocean type
4-Lfr-Oc:	Lower Fraser ocean type
5-GS-Oc:	Georgia Strait ocean type; roughly sequenced from south to north; could be subdivided NS or EW if needed
6-WCVI-OC:	All WCVI ocean type
7-Misc-St:	The remaining non-Fraser stream types scattered through the region. Little data.

Table ST-2. Canadian Chinook salmon "Conservation Units" (CUs) and U.S.A. Chinook indicator stocks for which time series data exist on the CTC's CWT-based age-2-cohort marine survival rates. Data provided by Gayle Brown (DFO, personal communication, 25 April 2013).

Canadian Conservation Units (CU)			
CU	**Label**	**Stock**	**Region**
LFR-fall	HAR	Harrison	Fraser Late
(P)HatchX-LFR	CHI	Chilliwack/Harrison	Fraser Late
STh-SHUR	SHU	Lwr Shuswap R	Fraser Early
LTh	NIC	Nicola R	Fraser Early
UFR-spring	DOM	Dome Cr	Fraser Early
midEVI-sum	PPS	Puntledge	Hatchery Lower St. of Georgia
midEVI-fall	NAN	Nanaimo R.	Lower St. of Georgia
CWCH-KOK	COW	Cowichan	Lower St. of Georgia
QP-fall	BQR	Big Qualicum	Hatchery Lower St. of Georgia
NEVI	QUI	Quinsam	Upper St. of Georgia
SWVI	RBT	Robertson Cr	West Coast Vanc. Is. (WCVI)
BCR-BENT	ATN	Atnarko Su.	North & Central B.C.
KALUM-L	KLM	Kitsumkalum Su.	North & Central B.C.

U.S.A. indicator stocks		
Label	**Stock**	**Region**
SRH	Salmon River	Oregon coast
ELK	Elk River	Oregon coast
CWF	Cowlitz Fall Tule	Lower Columbia River
WSH	Willamette Spring	Lower Columbia River
LRW	Lewis River Wild	Lower Columbia River
LRH	Columbia Lower River Hatchery	Lower Columbia River
SPR	Spring Creek Tule	Middle & Upper Columbia R.
LYY	Lyons Ferry Yearling	Middle & Upper Columbia R.
LYF	Lyons Ferry	Middle & Upper Columbia R.
URB	UpRiver Brights	Middle & Upper Columbia R.
SUM	Columbia Summers	Middle & Upper Columbia R.
HAN	Hanford Wild	Middle & Upper Columbia R.
ELW	Elwha Fall Fingerling	Washington coast
HOK	Hoko Fall Fingerling	Washington coast
SOO	Sooes Fall Fingerling	Washington coast
QUE	Queets Fall Fingerling	Washington coast
GAD	George Adams Fall Fingerling	Southern Puget Sound
UWA	University of Washington Accel.	Southern Puget Sound
SQP	Squaxin Pens Fall Yearling	Southern Puget Sound
SPY	South Puget Sound Fall Yearling	Southern Puget Sound
SPS	South Puget Sound Fall Fingerling	Southern Puget Sound

WRY	White River Spring Yearling	Southern Puget Sound
NIS	Nisqually Fall Fingerling	Southern Puget Sound
STL	Stillaguamish Summer Fingerling	Northern Puget Sound
SSF	Skagit Summer Fingerling	Northern Puget Sound
SKY	Skykomish Fall Fingerling	Northern Puget Sound
SKS	Skagit Spring Yearling	Northern Puget Sound
SKF	Skagit Spring Fingerling	Northern Puget Sound
NSF	Nooksack Spring Fingerling	Northern Puget Sound
NKS	Nooksack Spring Yearling	Northern Puget Sound
SAM	Samish Fall Fingerling	Northern Puget Sound
UNU	Unuk Spring	Trans-boundary rivers
TAK	Taku Spring	Trans-boundary rivers
CHK	Chilkat Spring	Southeast Alaska (SEAK)
ANB	Alaska Neets Bay	Southeast Alaska (SEAK)
ALP	Little Port Walter	Southeast Alaska (SEAK)
AKS	Alaska Spring	Southeast Alaska (SEAK)
AHC	Alaska Herring Cove	Southeast Alaska (SEAK)
ADM	Alaska Deer Mountain	Southeast Alaska (SEAK)
ACI	Alaska Central Inside	Southeast Alaska (SEAK)

Table ST-3. Chinook salmon stocks for which annual spawner and adult abundance estimates were either reconstructed using the Pacific Salmon Commission's Chinook coast-wide model (top part of list) or obtained from the Alaska Department of Fish and Game (bottom). Data provided by Gayle Brown (DFO, personal communication, 25 April 2013).

Region	Stock Acronym	Stock Name	Source
Alaska-PSC	AKS	Alaska South SE	PSCs Chinook coast-wide model
B.C.	NTH	North/Centr	"
B.C.	FRE	Fraser Early	"
B.C.	FRL	Fraser Late	"
B.C.	RBH	WCVI Hatchery	"
B.C.	RBT	WCVI Natural	"
B.C.	GSQ	Georgia St. Upper	"
B.C.	GST	Georgia St. Lwr Nat	"
B.C.	GSH	Georgia St. Lwr Hat	"
Wash/Oregon	NKF	Nooksack Fall	"
Wash/Oregon	PSF	Pgt Sd Fing	"
Wash/Oregon	PSN	Pgt Sd NatF	"
Wash/Oregon	PSY	Pgt Sd Year	"
Wash/Oregon	NKS	Nooksack Spring	"
Wash/Oregon	SKG	Skagit Wild	"
Wash/Oregon	STL	Stillaguamish Wild	"
Wash/Oregon	SNO	Snohomish Wild	"
Wash/Oregon	WCH	WA Coastal Hat	"
Wash/Oregon	URB	UpRiver Brights	"
Wash/Oregon	SPR	Spring Creek Hat	"
Wash/Oregon	LRH	Lwr Bonneville Hat	"
Wash/Oregon	CWF	Fall Cowlitz Hat	"
Wash/Oregon	LRW	Lewis R Wild	"
Wash/Oregon	WSH	Willamette R	"
Wash/Oregon	CWS	Spr Cowlitz Hat	"
Wash/Oregon	SUM	Col R Summer	"
Wash/Oregon	ORC	Oregon Coast	"
Wash/Oregon	WCN	WA Coastal Wild	"
Wash/Oregon	LYF	Lyons Ferry	"
Wash/Oregon	MCB	Mid Col R Brights	"
Alaska	BLS	Blossom	Alaska Dept. of Fish and Game
Alaska	SIT	Situk	"
Alaska	ALS	Alsek	"
Alaska	DES	Deshka	"
Alaska	ANC	Anchor	"
Alaska	KAR	Karluk	"
Alaska	AYA	Ayakulik	"
Alaska	YUK	Yukon	"
Alaska	KSK	Kuskokwim	"
Alaska	GDN	Goodnews	"
Alaska	CHS	Chena Salcha	"
Alaska	UNA	Unalakleet	"
Alaska	NEL	Nelson	"

Table ST-4. (next page). Pairwise Pearson correlations between various forms of time series of CWT-based indicators of marine survival rate and indicators of productivity, the latter based on spawner (S)-to-recruit (R) data that were reconstructed using the Pacific Salmon Commission's coast-wide model (for years 1975-2010). The latter "model stocks" were paired with CWT stocks based on tables in Appendix A of Pacific Salmon Commission (2012). In the 5 shaded rows, there is more than one CWT survival rate data series that could potentially be associated with a model stock that had spawner-to-recruit data. Correlations in those shaded rows are based on the CWT series with the longest and/or most recent data, as shown in the first column.

		CWT-based indicator:	CWT Loge(SurvRate)	CWT Loge(SurvRate)	4-year moving avg. of CWT Loge(SurvRate)	4-year moving avg. of CWT Loge(SurvRate)
Stock or CU for CWT survival rate data	**Stock aggregate or stock for spawner-to-recruit data**	**Spawner-to- recruit indicator:**	Loge(R/S)	Ricker residuals	4-year moving avg. of Loge(R/S)	4-year moving avg. of Ricker residuals
SRH (Salmon R.)	Oregon Coast		0.68	0.32	0.85	0.54
LRW (Lewis R.)	Lewis R Wild		0.66	0.83	0.70	0.95
LYF (Lyons Ferry)	Lyons Ferry		0.19	0.20	0.68	0.79
URB (Upriver Brights)	UpRiver Brights		0.79	0.58	0.93	0.46
SUM (Columbia R. summer)	Columbia R. Summer		0.51	0.62	0.61	0.79
QUE (Queets fingerling)	WA Coastal Wild		0.28	0.34	0.24	0.36
SKY (Skykomish fingerling)	Snohomish Wild		0.37	0.57	0.80	0.91
STL (Stillaguamish fing.)	Stillaguamish Wild		0.07	0.05	0.12	-0.30
SKF (Skagit fingerling)	Skagit Wild		-0.32	-0.16	-0.05	0.18
NSF (Nooksack fingerling)	Nooksack Spring		0.40	0.41	0.68	0.70
CHI (Chilliwack/Harrison fall)	Fraser Late		0.76	0.83	0.61	0.86
SHU (L. Shuswap summer)	Fraser Early		0.35	0.25	0.34	-0.07
COW (Cowichan)	Georgia St. Lwr Nat		0.71	0.79	0.83	0.94
QUI (Quinsam)	Georgia St. Upper		0.66	0.53	0.70	0.52
RBT (Roberston Cr.)	WCVI Natural		0.94	0.93	0.98	0.93
KLM (Kitsumkalum summ.)	North/Central B.C.		0.50	0.33	0.59	0.16
AKS (Alaska South SE)	Alaska South SE		0.39	0.48	0.36	0.77
		Overall average:	**0.47**	**0.46**	**0.59**	**0.56**
		Overall median:	**0.50**	**0.48**	**0.68**	**0.70**
	For Southern B.C. only	**Average:**	**0.68**	**0.66**	**0.69**	**0.64**
		Median:	**0.71**	**0.79**	**0.70**	**0.86**

3.4.2 *Figures*

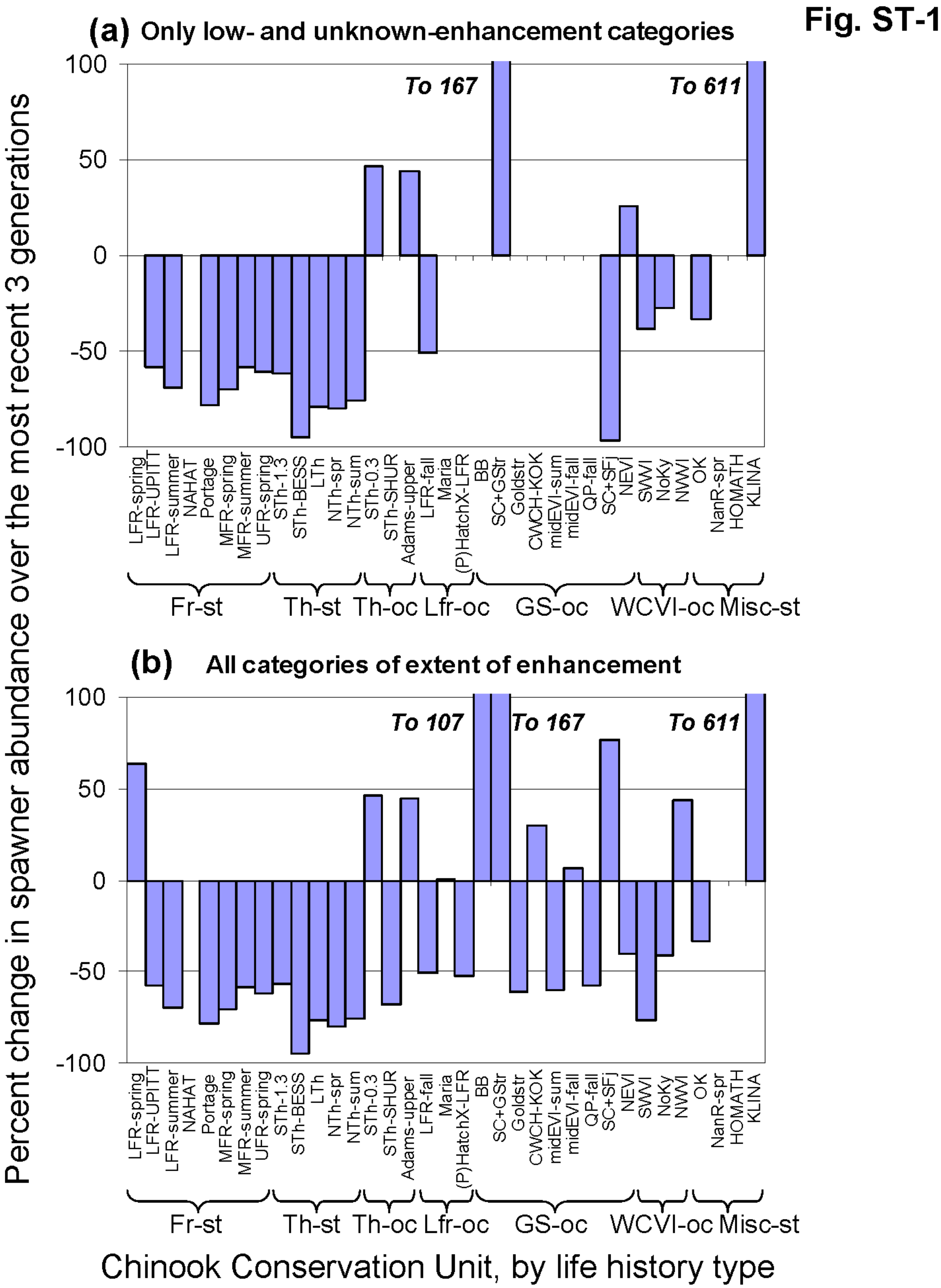


Figure ST-1. Panels (a) and (b). Full caption at bottom of figure.

(c)

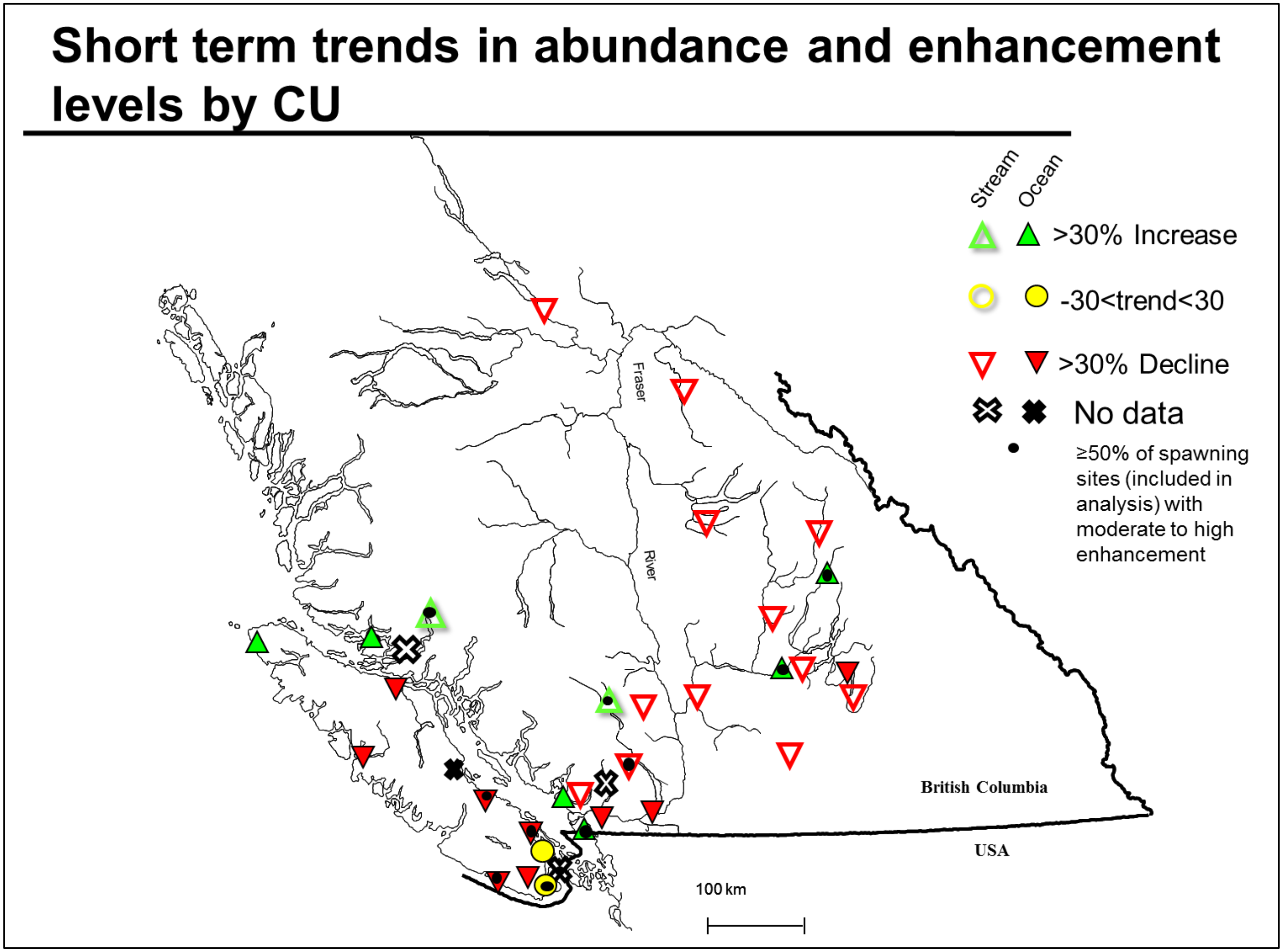


Figure ST-1. Panels a and b: Histograms show the percent change over the last 3 generations in abundance of spawners for 35 Conservation Units (CUs) for Southern British Columbia Chinook salmon, arranged by CU and type of life history. Depending on the particular CU, the generation time is either 3, 4, or 5 years; see "Avg. gen. (years)" column of **Table ST-1**. Data for spawning sites that were categorized as having a "low or unknown" extent of enhancement activity are shown in panel (a), organized by CU. Here, "unknown" most likely means little or no enhancement. In contrast, panel (b) is based on data for spawning sites across all levels of enhancement, including "moderate" and "high" categories. The map (panel c) shows the spatial distribution of Chinook salmon CUs, life history types, 3-generation abundance trends, and level of enhancement. Data source: Gayle Brown, DFO; map from David Patterson, DFO.

Fig. ST-2

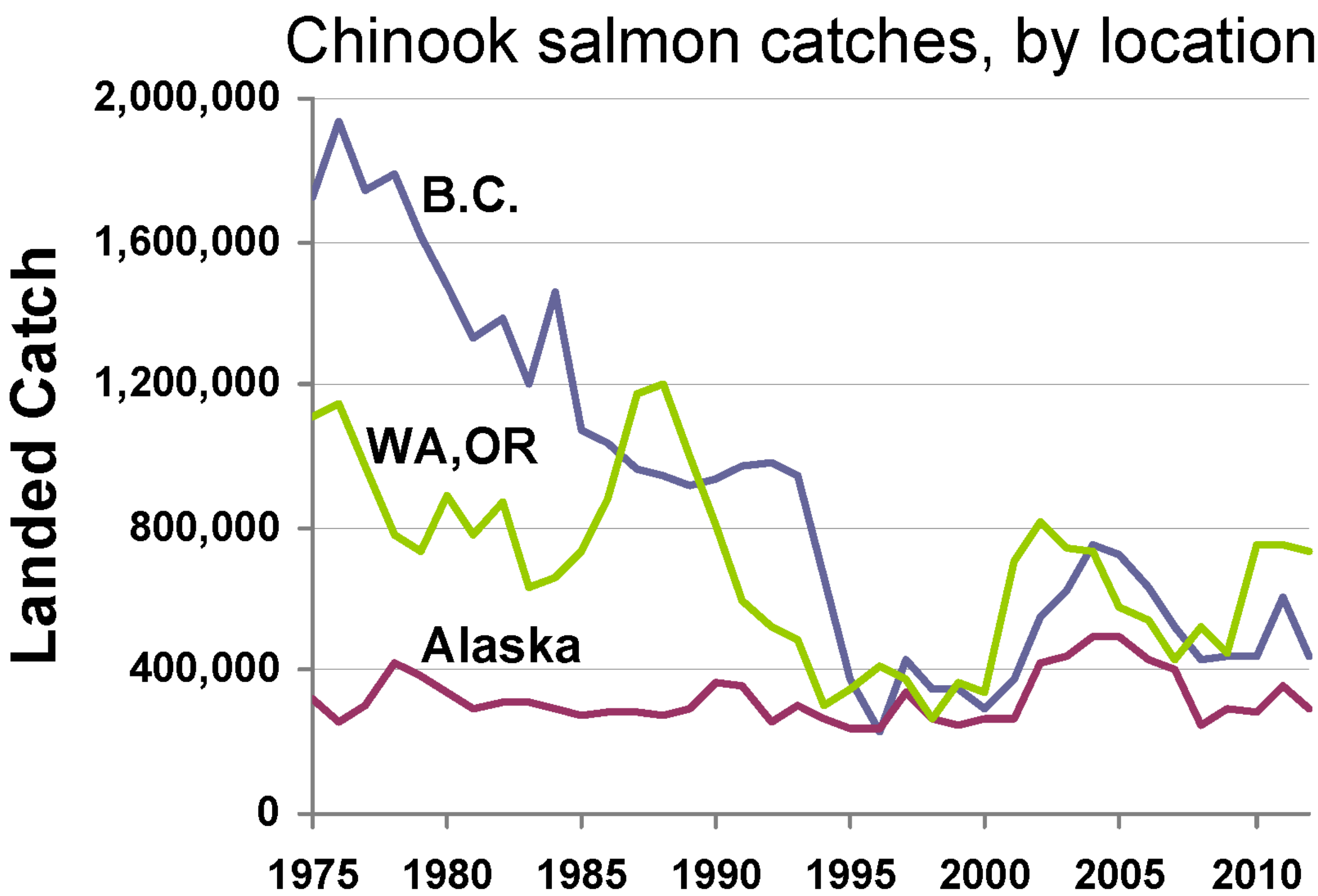


Figure ST-2. Total landed catch of Chinook salmon in three regions by catch year, regardless of the geographic origin of the fish. These catches include all catches from commercial, sport, and Tribal/First Nations fisheries. Source: CTC (2013).

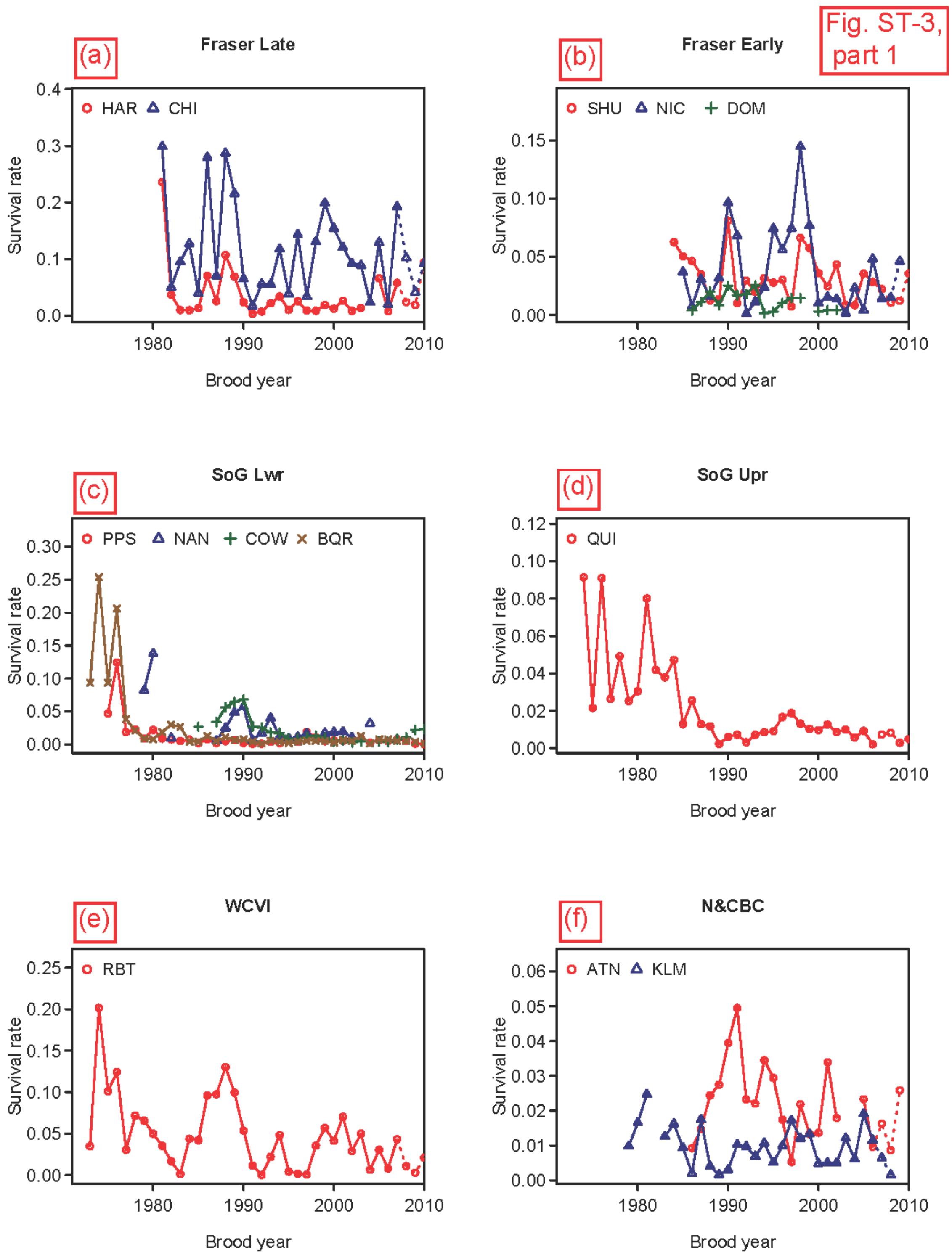


Figure ST-3. Part 1. Full caption at bottom of figure.

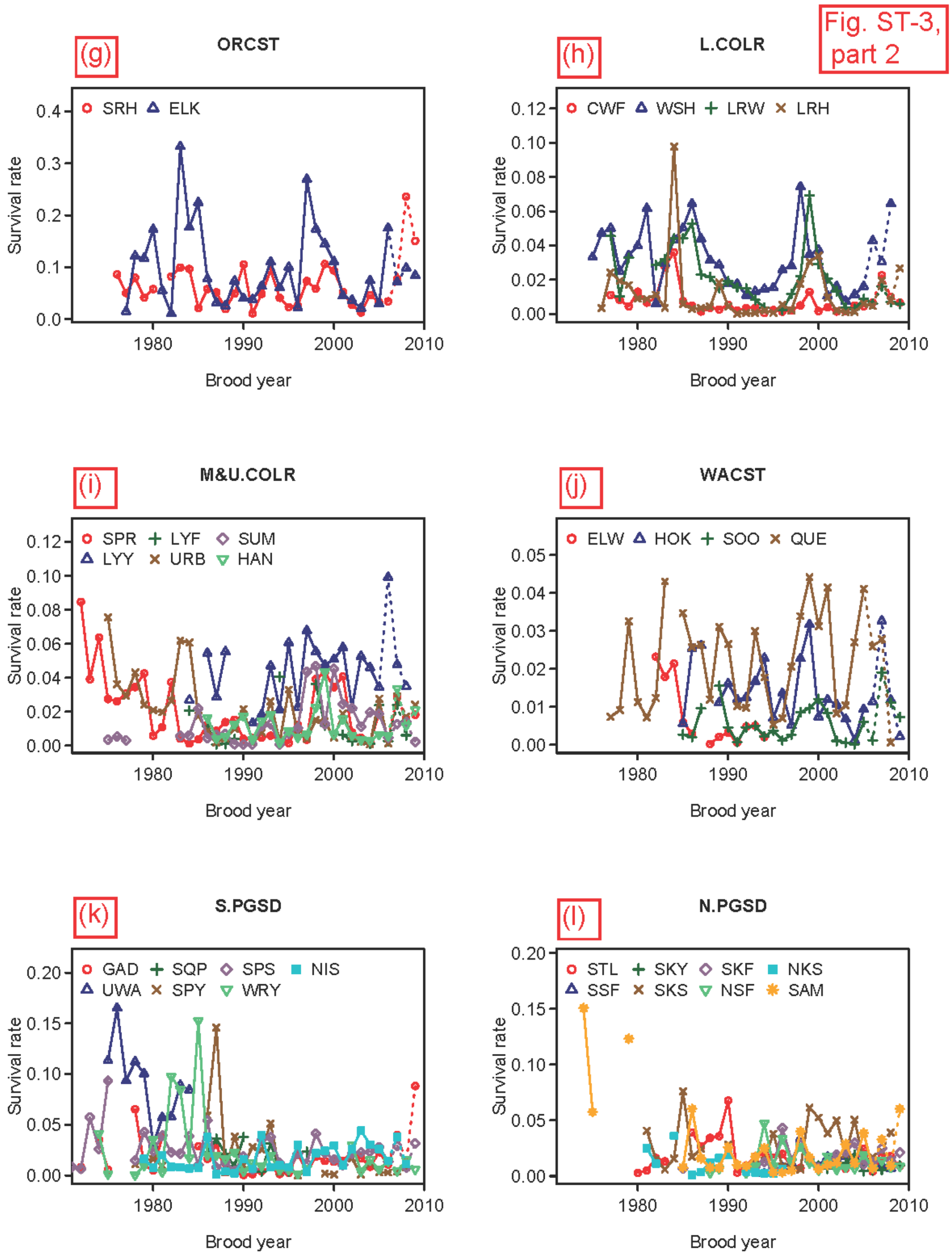


Figure ST-3. Part 2. Full caption at bottom of figure.

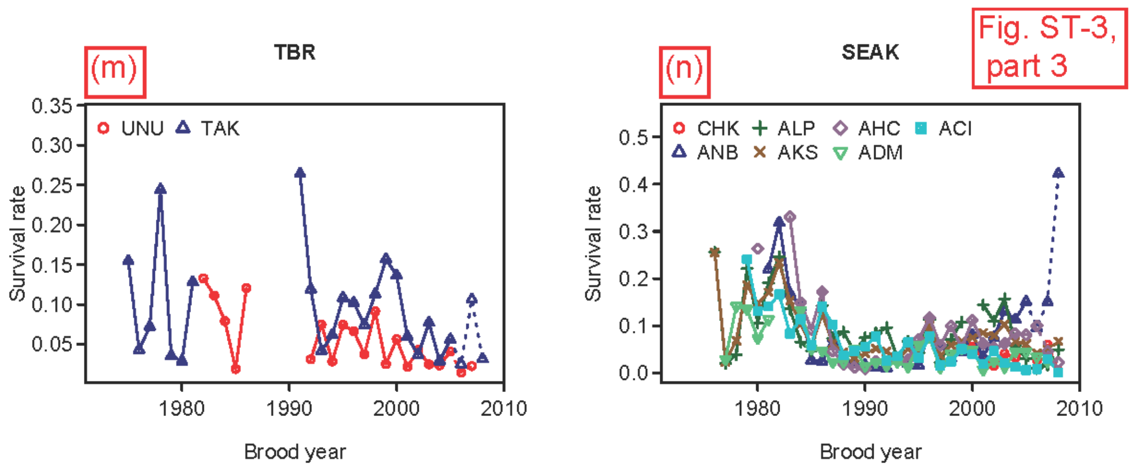


Figure ST-3. Time series plots of the Chinook Technical Committee's CWT-based age-2-cohort marine survival rates (proportion surviving), plotted by brood year. Data points between dotted lines were estimated from incomplete cohorts, where the final age class(es) had not yet returned. Note that the Y-axis scales differ among plots. Panels (a)-(e) include Southern B.C. Conservation Units. Acronyms for stocks and regions are defined in **Table ST-2**. Data source: Gayle Brown, DFO.

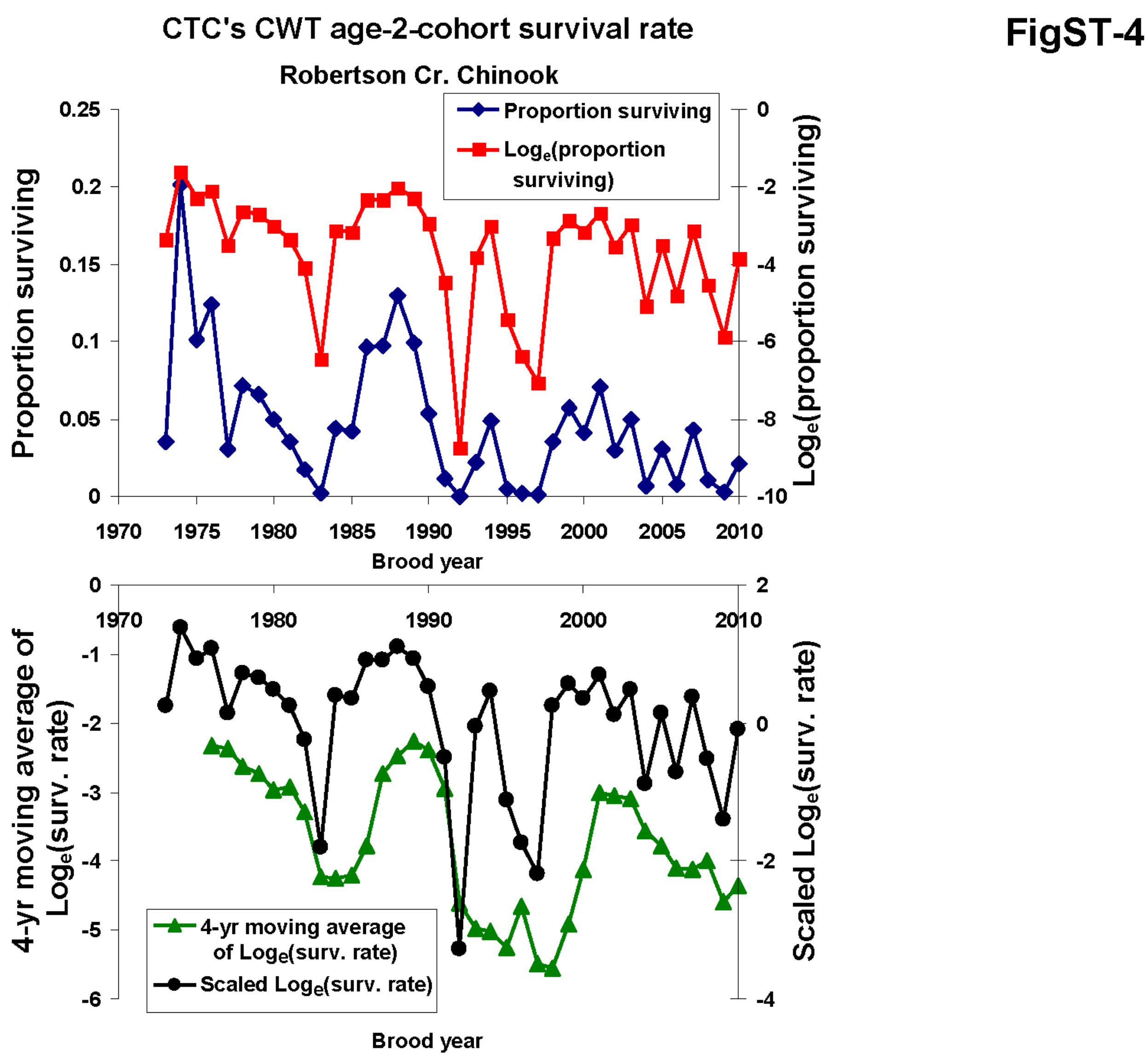


Figure ST-4. The Robertson Creek Chinook stock, West Coast Vancouver Island, illustrates the differences between the original CWT survival-rate indicator (proportion of fish surviving) and its three transformations that are used later (see **Box 2** for methods and explanations of legends).

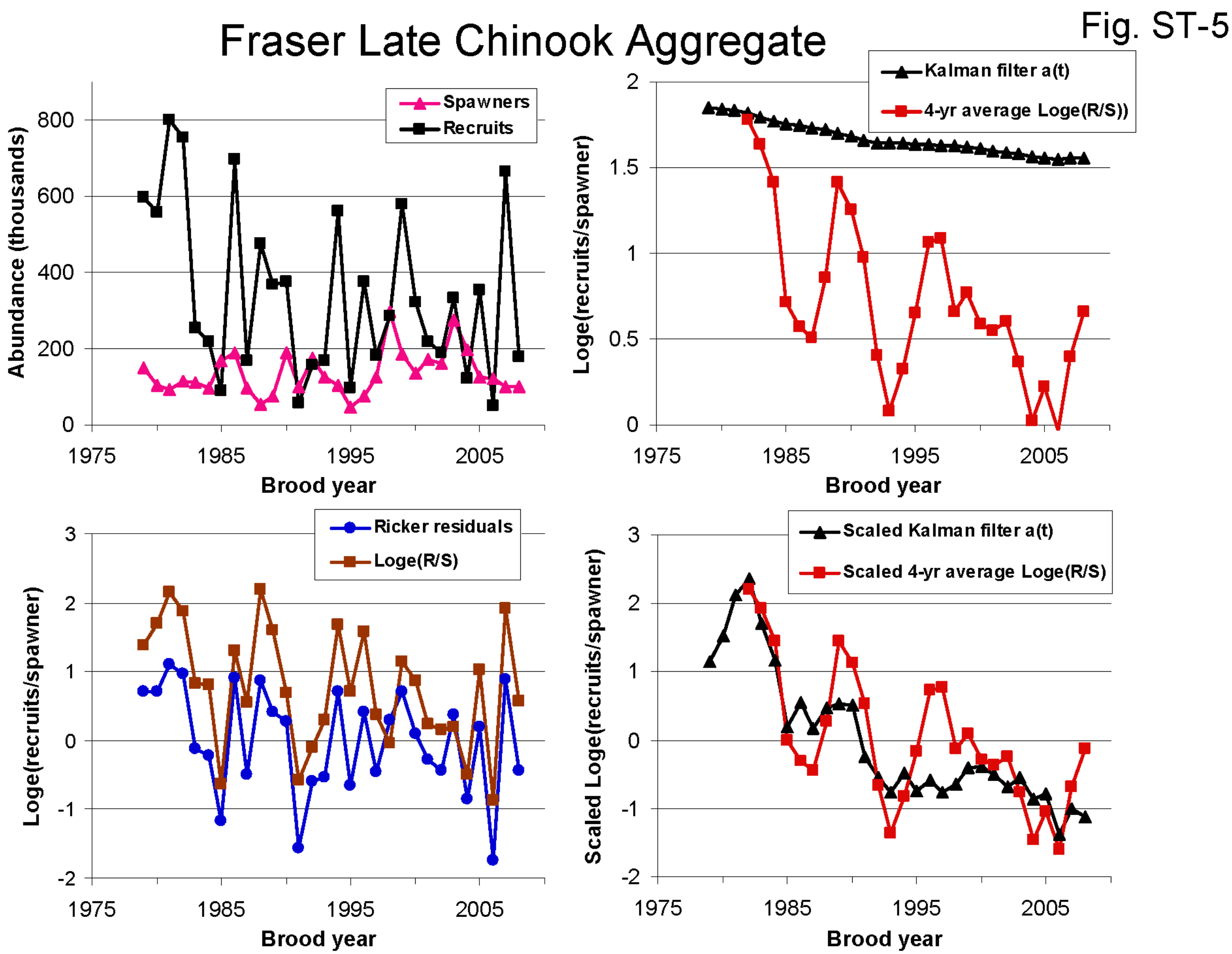


Figure ST-5. An example aggregate stock, the Fraser River Late run of Chinook salmon, illustrates six measures of life-cycle productivity that were derived from abundance of spawners (S) and their resulting adult recruits (R) (see **Box 3** for methods and explanations of legends). Estimates of the original abundances of spawners and recruits were reconstructed by the CTC using the Pacific Salmon Commission's coast-wide model. Source: Gayle Brown, DFO.

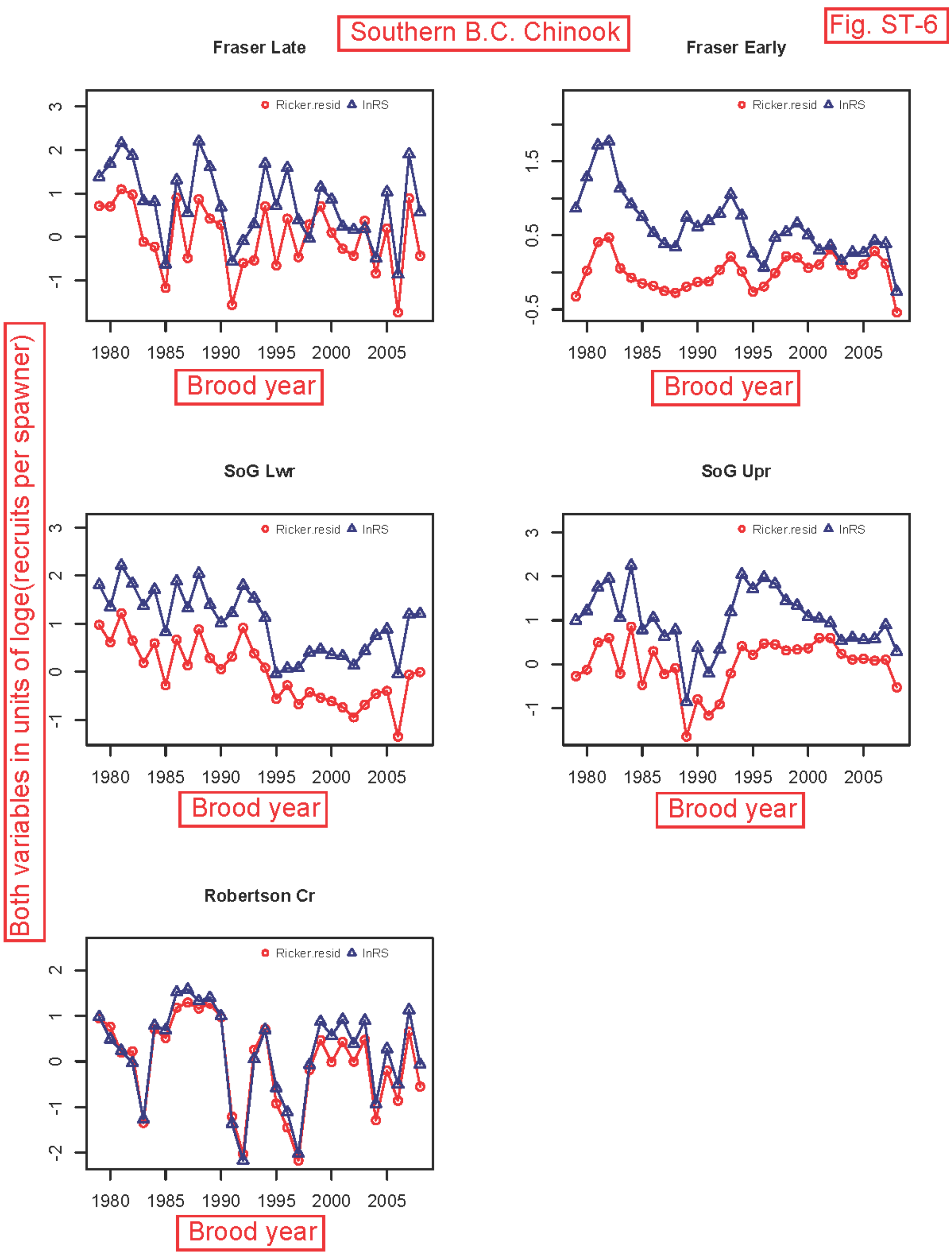


Figure ST-6. Two measures of life-cycle productivity derived from abundance of spawners (S) and their resulting adult recruits (R) for 5 Southern B.C. stock aggregates: annual $\log_e$(recruits per spawner) and residuals from the best-fit, stock-specific Ricker stock-recruitment model ("Ricker residuals"), plotted by brood year. Time series of spawners and recruits were reconstructed by the CTC using the Pacific Salmon Commission's coast-wide model. Source: Gayle Brown, DFO.

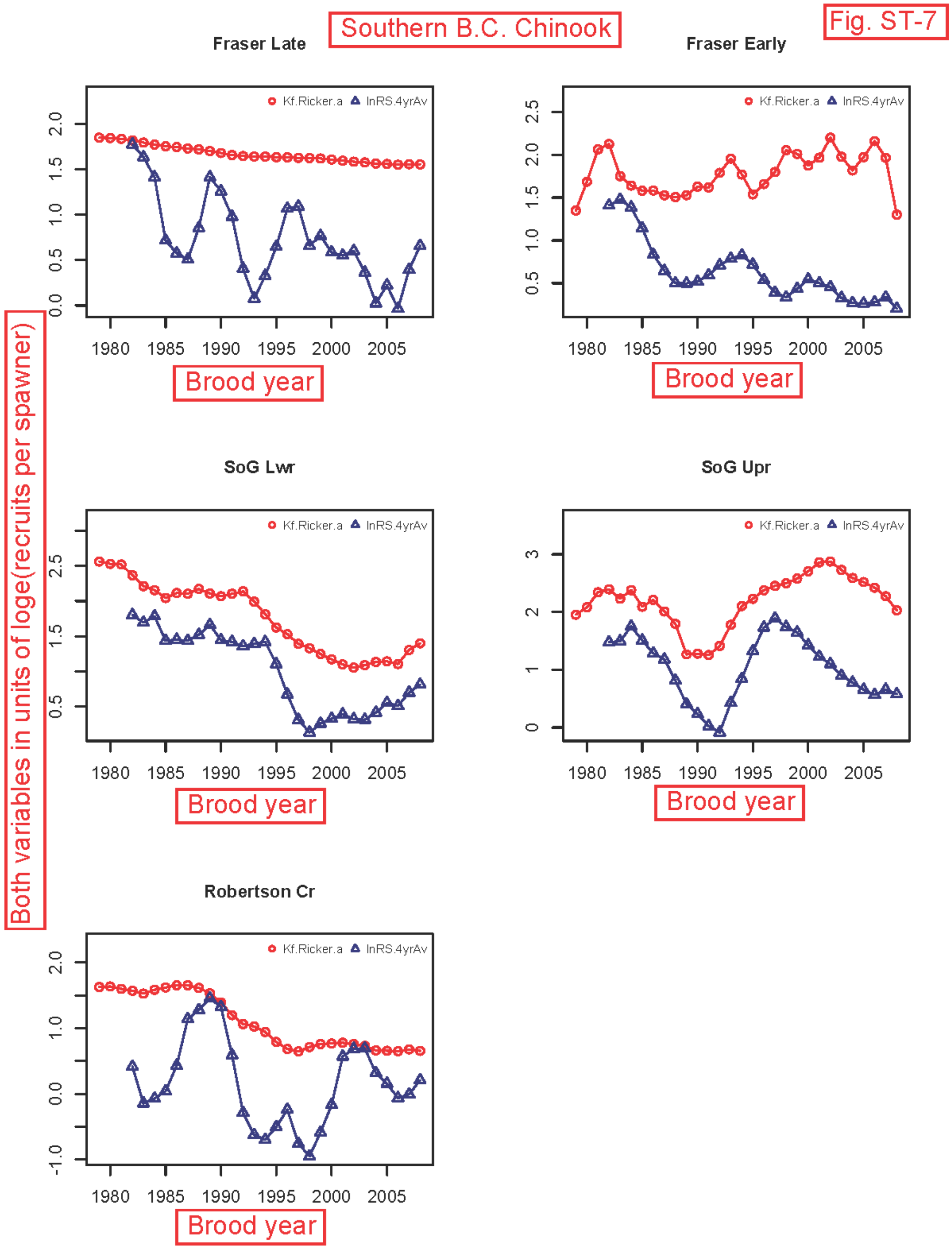


Figure ST-7. Time series of indicators of life-cycle productivity for 5 Southern B.C. stock aggregates: time-varying Ricker a_t parameter as estimated using a Kalman filter (open circles), and the 4-yr-moving average of $\log_e$(recruits per spawner) (open triangles), plotted by brood year. These smoothed indicators remove high-frequency between-year variation that may mask underlying long-term trends.

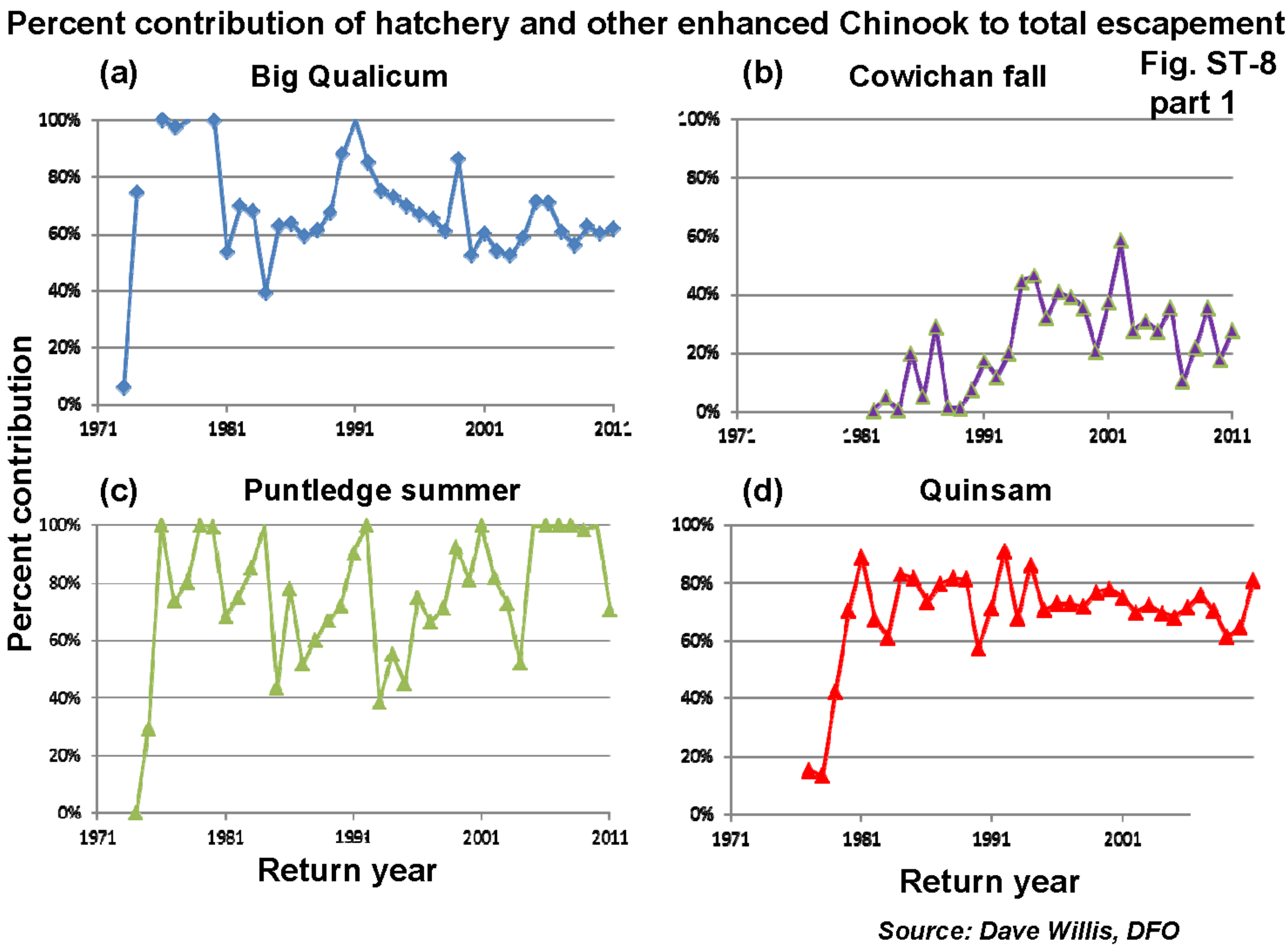


Figure ST-8. Part 1. Full caption at bottom of figure.

Fig. ST-8
part 2

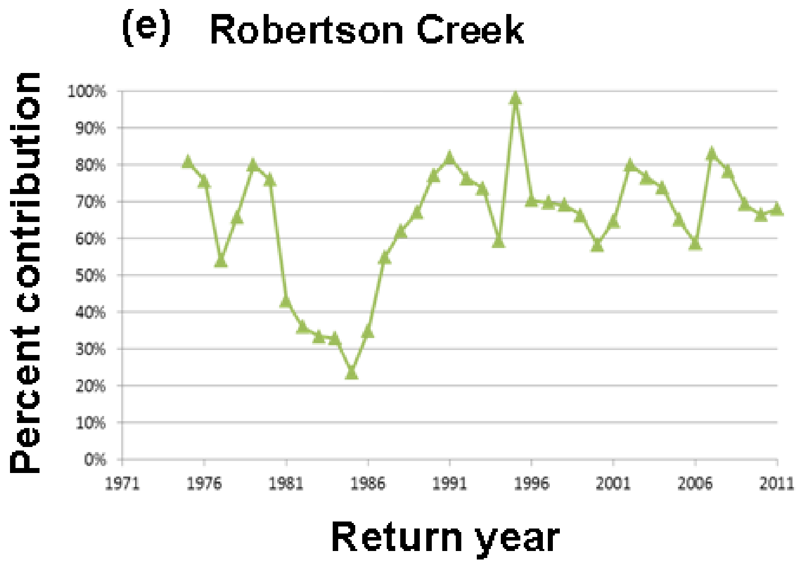


Figure ST-8. Contributions of hatcheries and other enhancement methods to total estimated adult spawning escapements, including natural spawners and hatchery removals, for five Southern B.C. Chinook stocks, plotted by year of spawning (return year). No information was provided on contributions of enhanced fish to catches. Source: Dave Willis, DFO, personal communication, 23 May and 3 June 2013.

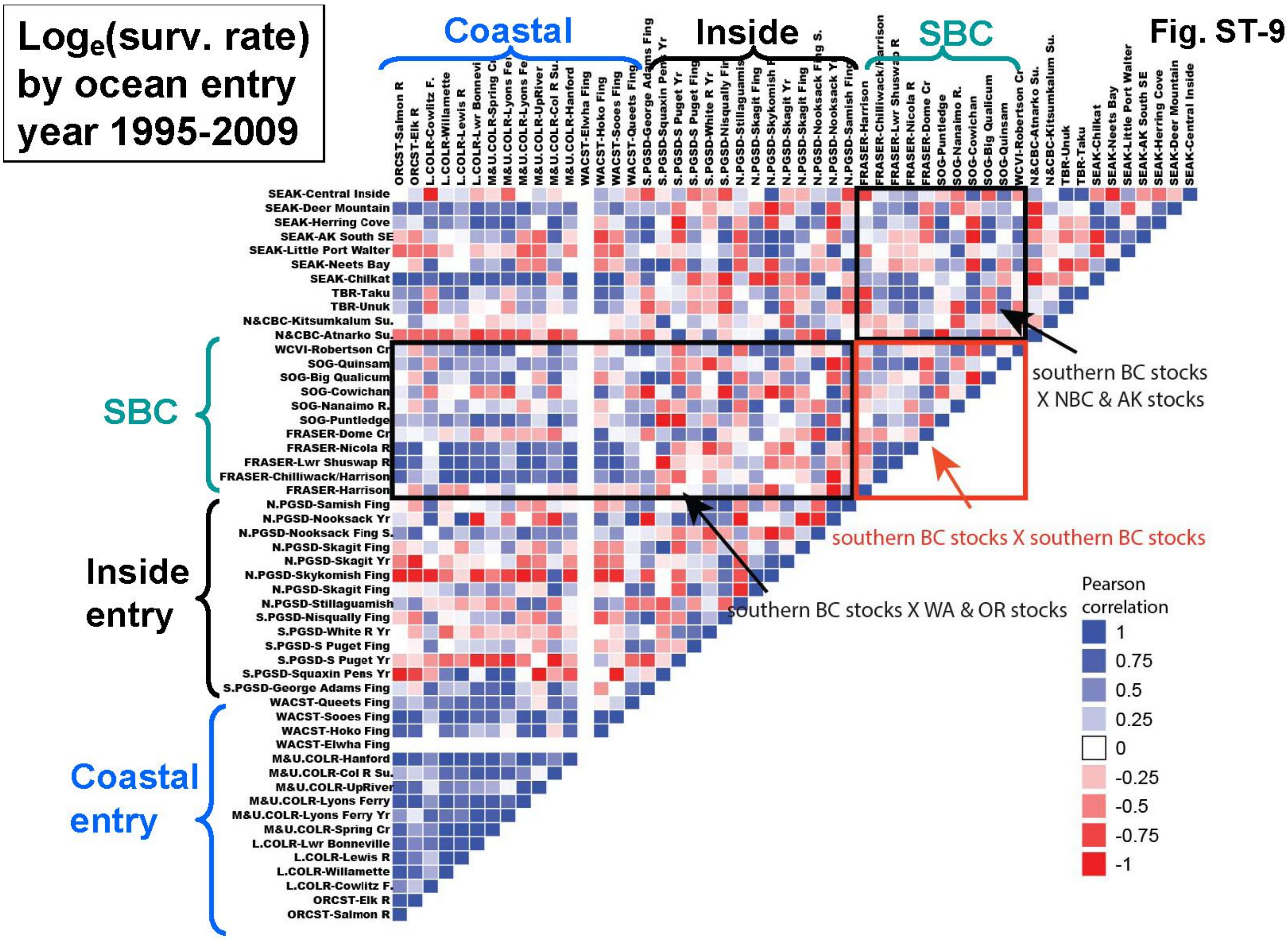


Figure ST-9. Pearson correlations between each pair of stocks that had time series for the CTC's CWT-based juvenile-to-age-2-cohort survival rate, for stocks from Washington up through Southeast Alaska. Results are for ocean-entry years 1995-2009 and with data series aligned to have the same ocean entry year for each stock, regardless of juvenile life-history type. Strength and magnitude of correlations are denoted by color. Note that by definition, diagonal elements have a correlation of 1.0 (the time series is correlated with itself).

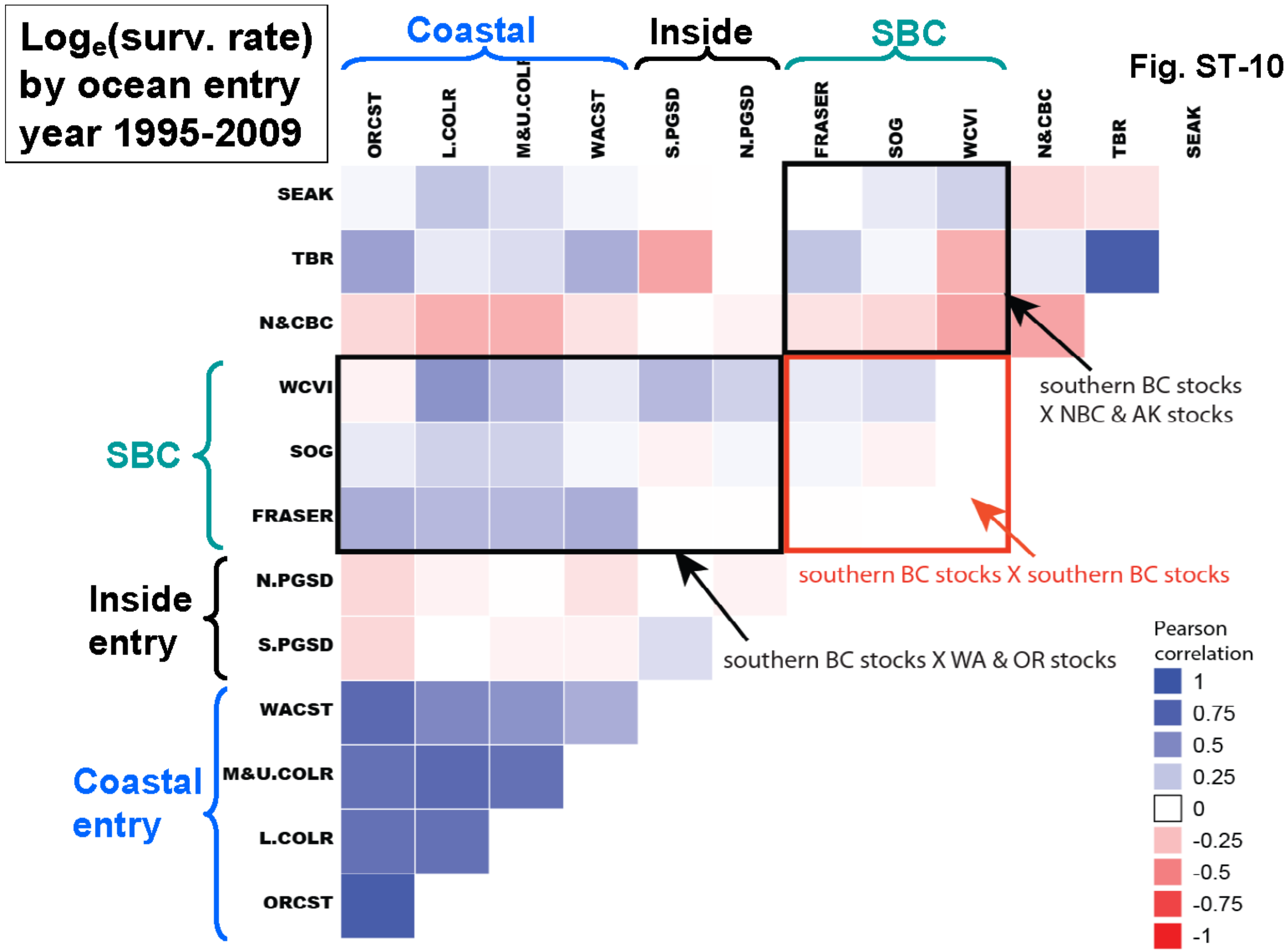


Figure ST-10. Summary of average correlations in juvenile-to-age-2-cohort survival rate within regions, based on the detailed pairwise correlation matrix in **Figure ST-9**, for ocean-entry years 1995-2009. Diagonal cells from that figure were omitted for calculating average pairwise correlations here within each region. No cell is shown here if there was only one stock in the region (which would result in a correlation of 1.0, thereby overestimating the average correlation among stocks within the three Southern B.C. areas, for example).

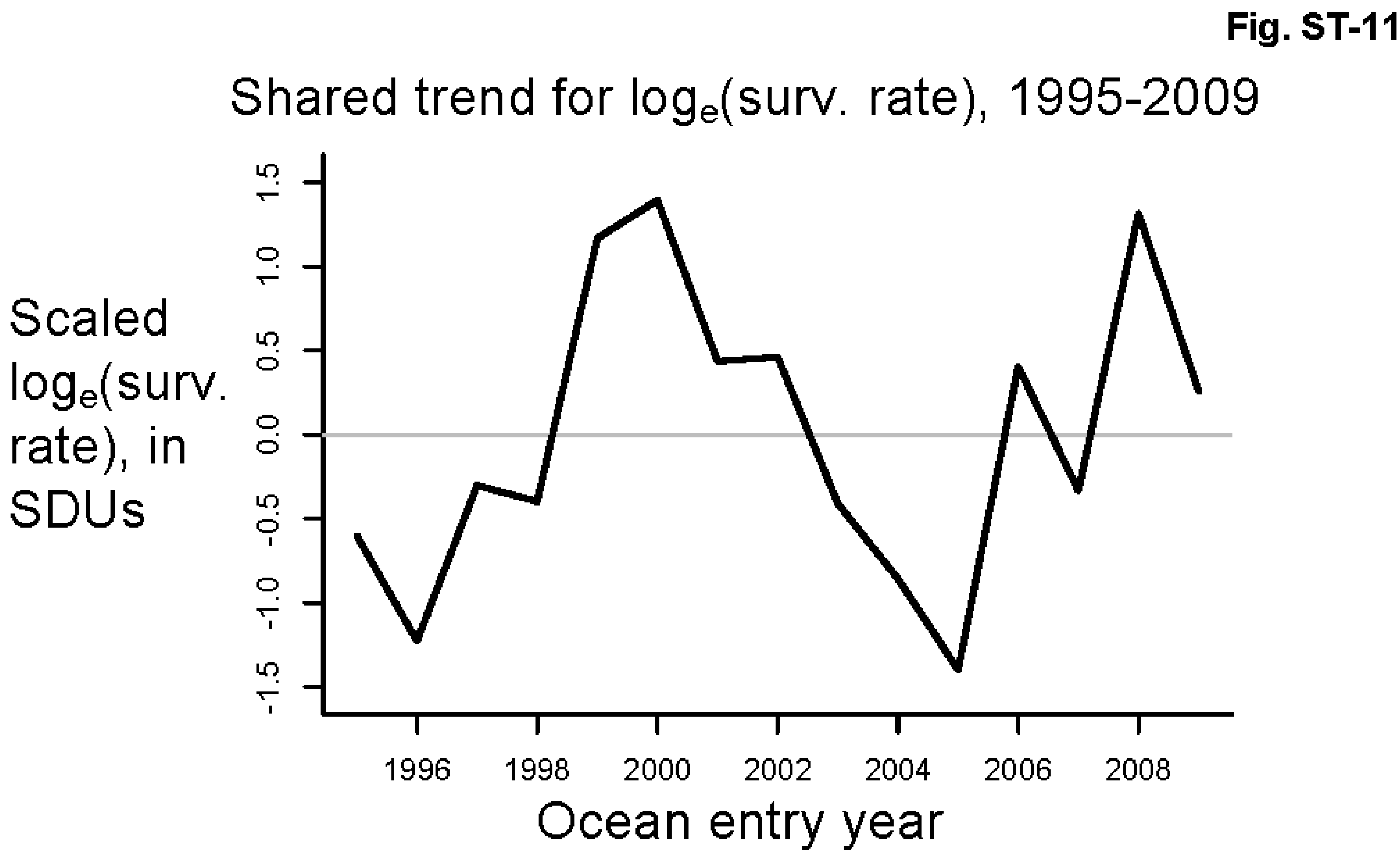


Figure ST-11. The shared, or common, time trend in the CWT-based age-2 cohort marine survival rate, for ocean-entry years 1995-2009, derived with Dynamic Factor Analysis (DFA), based on data from Oregon, the Columbia River, Washington, British Columbia, and Southeast Alaska.

Fig. ST-12

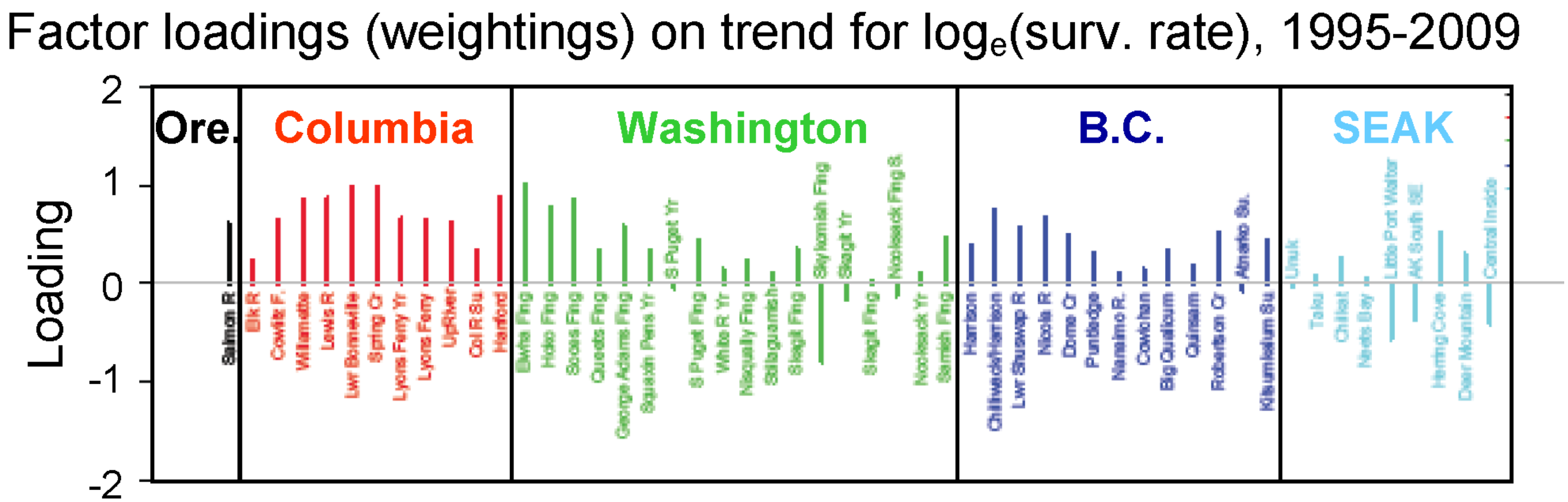


Figure ST-12. Stock-specific factor loadings (weightings) on the trend in the previous figure for $\log_e$(surv. rate), for ocean-entry years 1995-2009. Positive loadings mean that the stock has a time series that resembles the general trend; the higher the loading, the closer the resemblance. Maximum loading is 1.0.

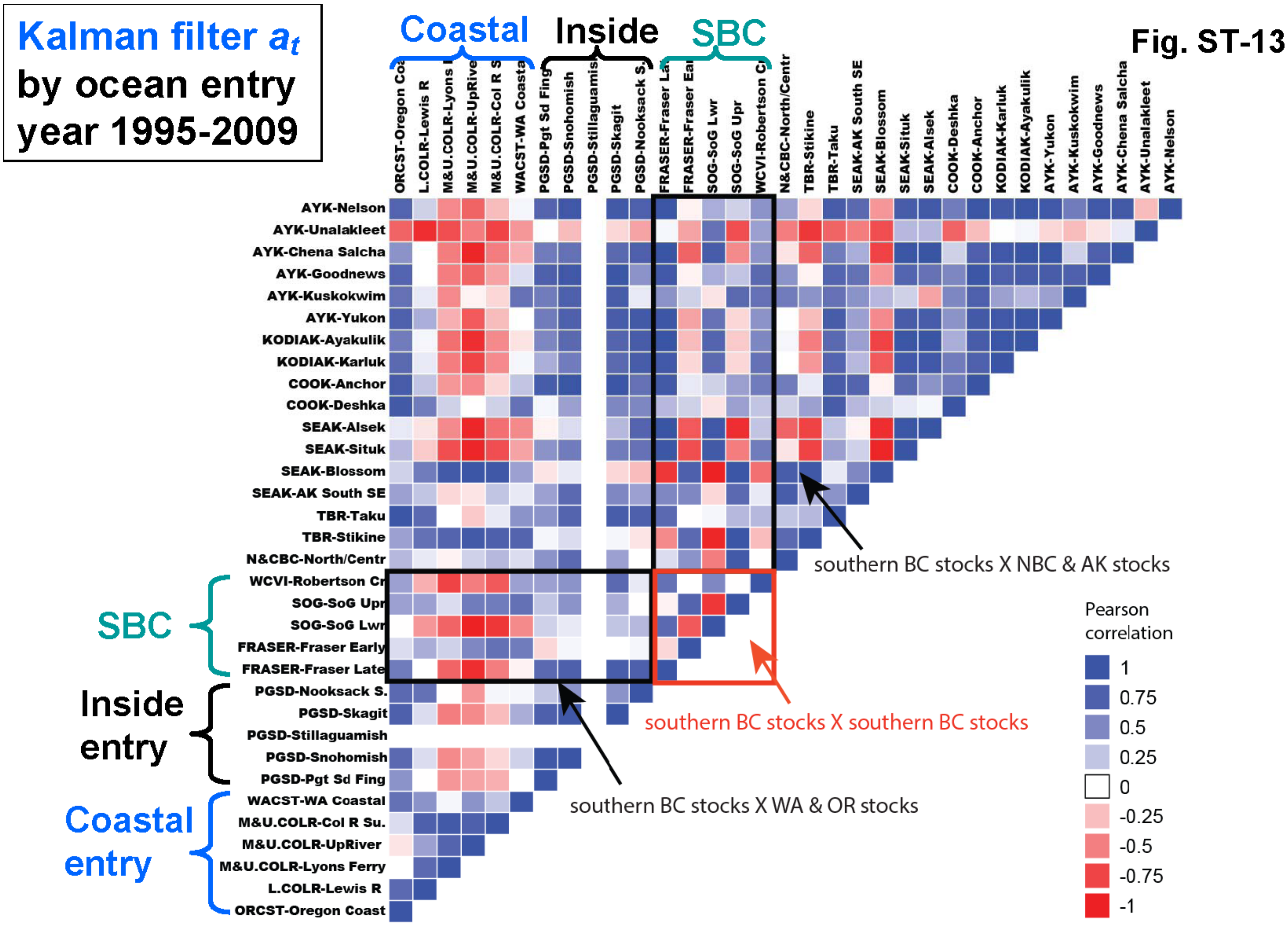


Figure ST-13. Pairwise correlations for the Kalman-filter-estimated time-varying Ricker a_t parameter between each pair of stocks that had time series for the CTC's CWT-based juvenile-to-age-2-cohort survival rate, for stocks from Washington up through Southeast Alaska. Results are for ocean-entry years 1995-2009 and with data series aligned to have the same ocean entry year for each stock, regardless of juvenile life-history type. Strength and magnitude of correlations are denoted by color. Note that by definition, diagonal elements have a correlation of 1.0 (the time series is correlated with itself).

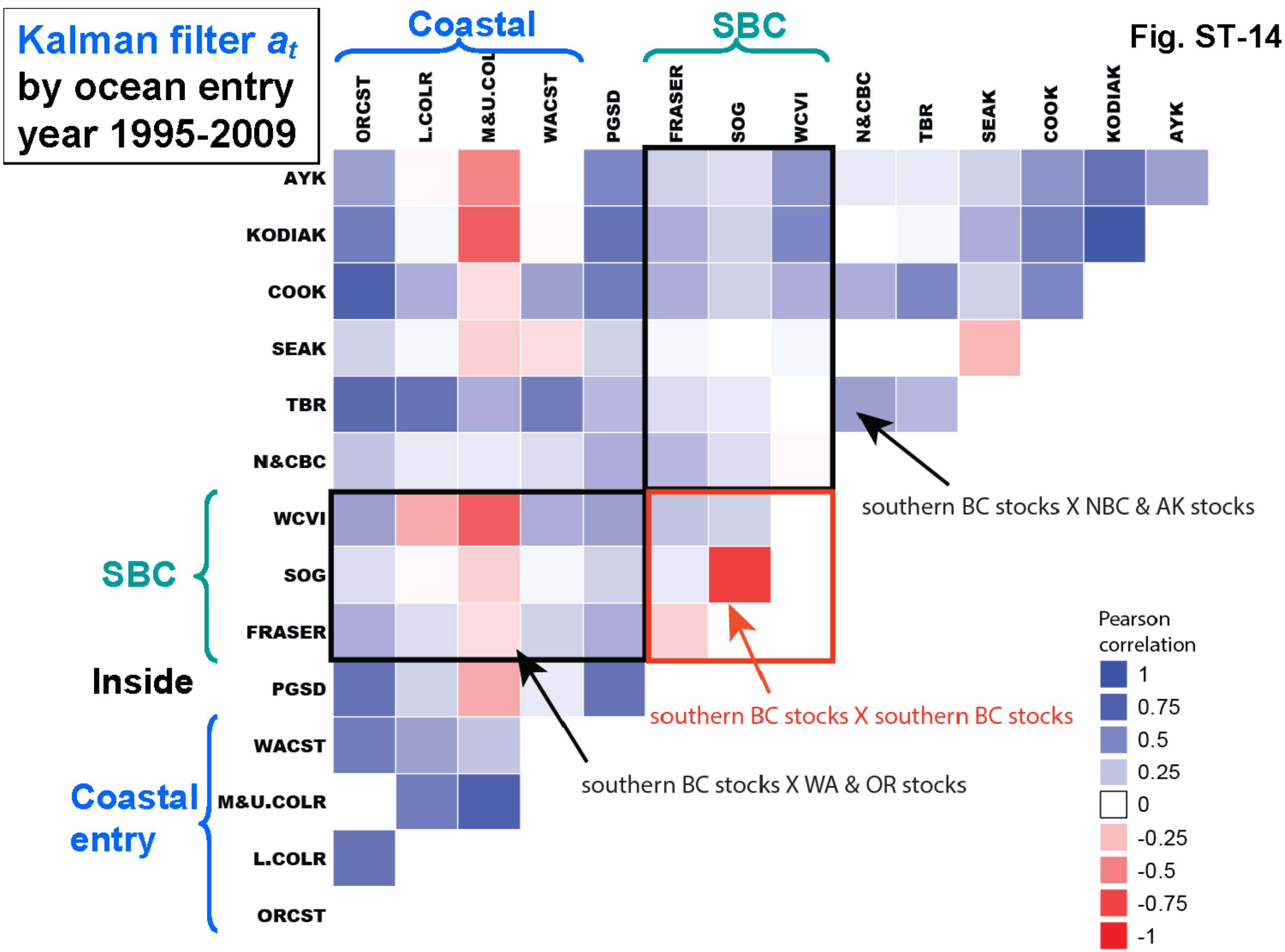


Figure ST-14. Summary of average correlations in juvenile-to-age-2-cohort survival rate within regions, based on the Kalman-filter-estimated time-varying Ricker a_t parameter correlation matrix in **Figure ST-13**, for ocean-entry years 1995-2009. Diagonal cells from that figure were omitted for calculating average pairwise correlations here within each region. No cell is shown here if there was only one stock in the region (which would result in a correlation of 1.0, thereby overestimating the average correlation among stocks within the three Southern B.C. areas, for example).

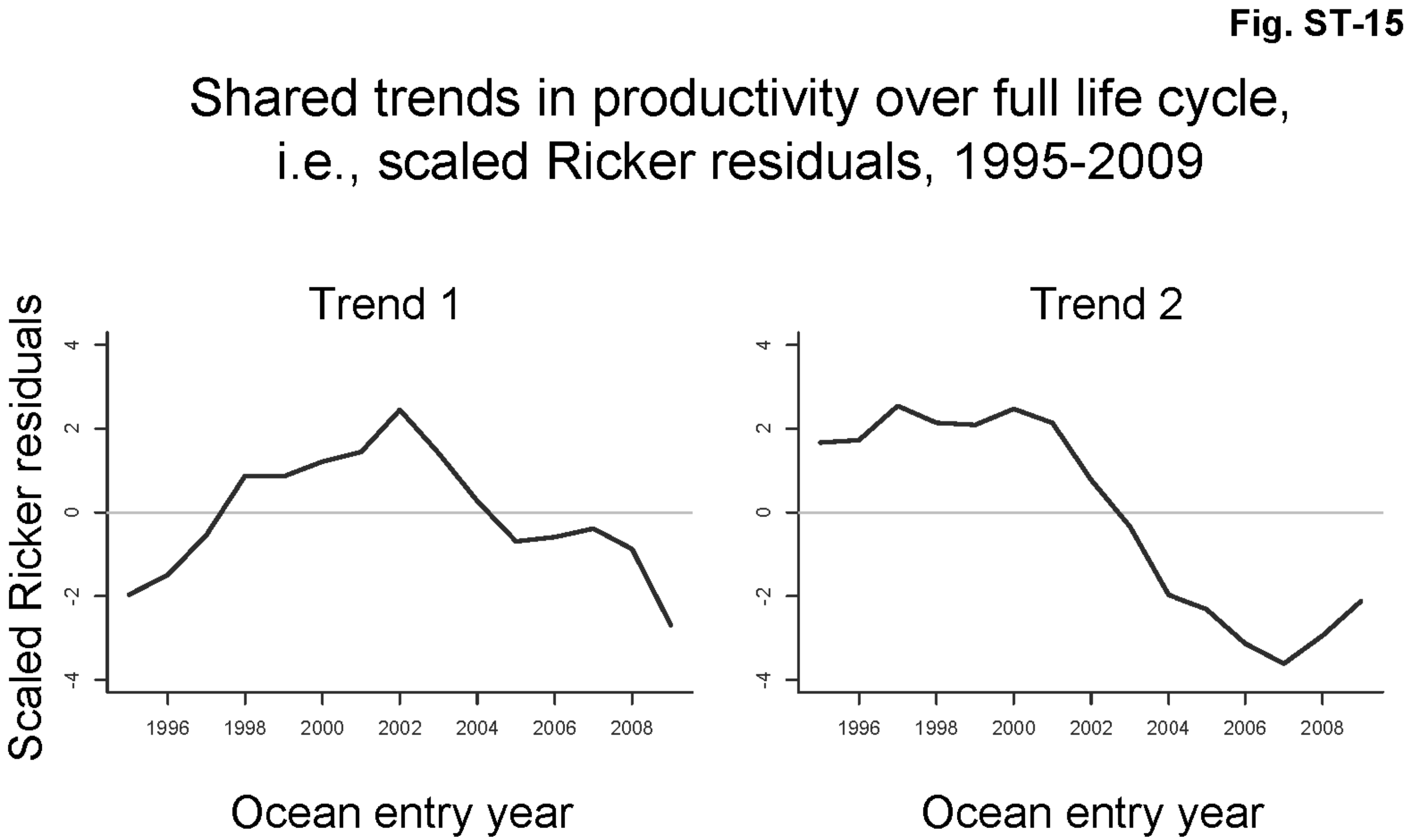


Figure ST-15. The two shared trends in residuals from the best-fit stock-specific Ricker stock-recruitment model that emerged from DFA of common time trend in the CWT-based age-2 cohort marine survival rate, for ocean-entry years 1995-2009.

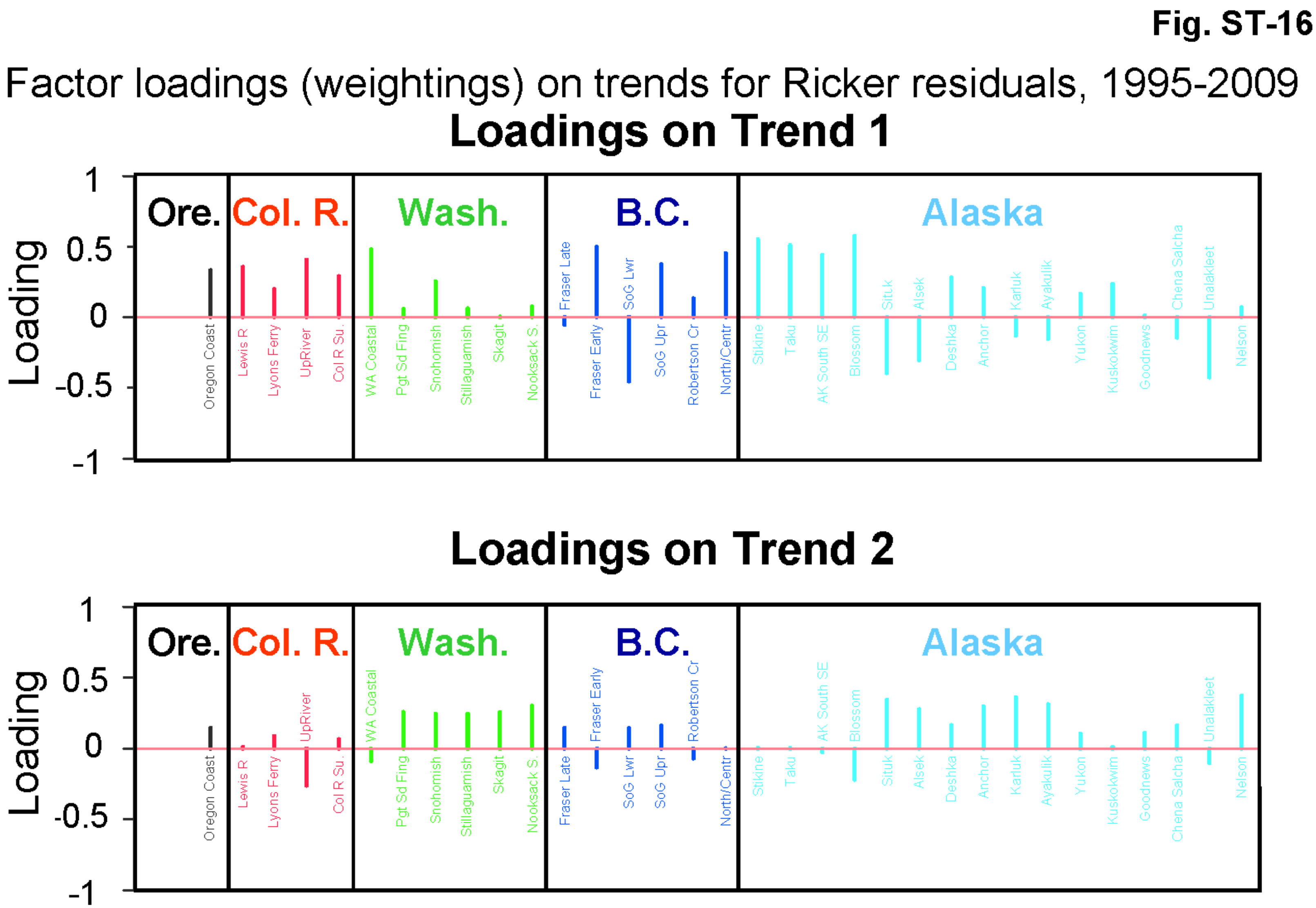


Figure ST-16. Same as **Figure ST-12**, except this shows the two shared trends in residuals from the best-fit stock-specific Ricker stock-recruitment model that emerged from DFA. Stock-specific factor loadings (weightings) on the trend in the previous figure for $\log_e$(surv. rate), for ocean-entry years 1995-2009. Positive loadings mean that the stock has a time series that resembles the general trend; the higher the loading, the closer the resemblance. Maximum loading is 1.0.

4 HARVEST

4.1 PLAUSIBILITY OF PROPOSED MECHANISMS

Virtually all theoretical approaches to management of fisheries have assumed or concluded that "too much fishing" can seriously reduce the abundance and long-term viability of harvested fish populations. For Pacific salmon populations, fishery dynamics theory has been heavily influenced by the landmark publication of Ricker (1954) titled "Stock and Recruitment". In Ricker's density-dependent model, the production of surviving adult salmon that would eventually return to spawn in the absence of fishing (the recruitment) is a non-linear (dome-shaped) function of the number of parental adult spawners (the stock). At low parental spawning abundance, the expected number of recruits is approximately linearly related to parental spawning abundance via an underlying "productivity" parameter, frequently referred to as the Ricker "alpha" parameter, which has a simple interpretation of "recruits per spawner" at low parental spawning abundance (and reflects the maximum rate of production per adult).

Ricker (1954), Hankin and Healey (1986), Hilborn (1985) and others have shown, for harvested populations governed by either deterministic or stationary (constant average productivity) Ricker-type stock-recruitment models, long-term equilibrium parental spawning abundances (escapements) and yield depend directly on exploitation rates. If exploitation rates are set higher than those appropriate to sustain the maximum sustained yield (MSY), then harvest can lead to greatly reduced abundance.

When viewed from the perspective of a stationary Ricker stock-recruitment model, fishery exploitation rates that are optimal in the sense of generating MSY or ensuring long-term population health at some reduced level of yield, depend directly on the underlying productivity of a population (**Figure H-1**). In stochastic "stationary" population models, realized productivity varies around a long-term average according to variation in environmental factors that may affect marine survival or to variation in freshwater factors (e.g., drought or flood events) that may influence the survival and growth of progeny. CTC (1999) and PFMC (2005) presented empirical examples of improving estimation of *average* population productivity by accounting for interannual variation in marine survival when estimates of marine survival are available from, say, run reconstruction analyses carried out using CWT recovery data. More recently, Peterman et al. (2003) and others have used Kalman filter estimation to allow assessment of possible temporal trends in productivity (time-varying Ricker alpha parameters) of "non-stationary" (changing average productivity) salmon populations. They have argued that fishery managers should adjust exploitation rates according to detected temporal trends in productivity. For example, under conditions of consistently poor marine survival, productivity would be expected to be reduced compared to the long-term average, and optimal exploitation rates should therefore be reduced as well.

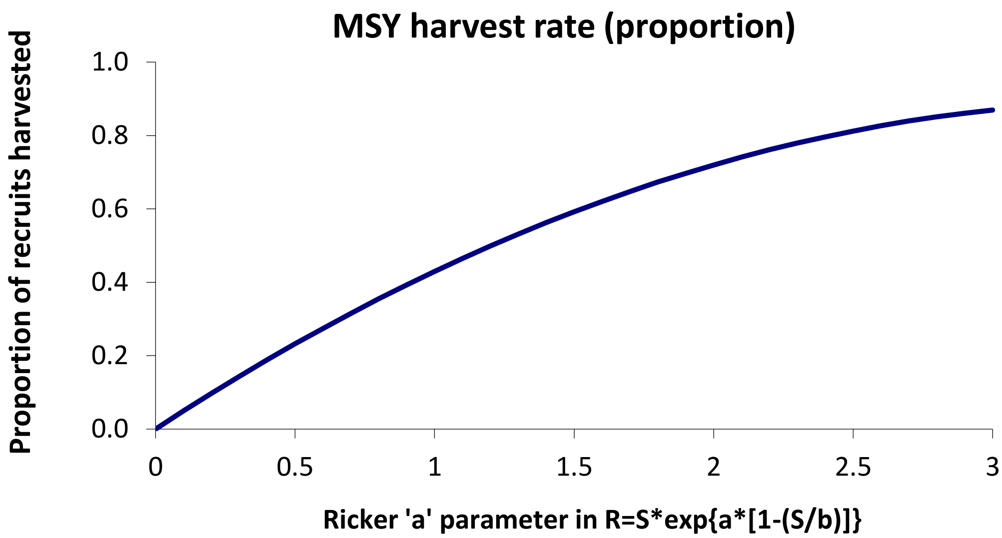


Figure H-1. Illustration of MSY harvest rate dependence on "a" parameter of a deterministic Ricker stock-recruitment model. The Ricker productivity parameter, "alpha" = exp(a),has the interpretation of recruits per spawner at low spawner abundance. The proportion of recruits harvested is defined as the maximum fraction of the mature adult recruits in an unexploited population that can be removed by fishing and maintain the maximum yield expected in future generations.

Based on the above brief review of the relation between the underlying productivity parameter of salmon populations and the corresponding optimal (e.g., MSY) exploitation rates, harvest would be a clear "stressor" on populations whenever there was evidence that exploitation rates exceeded those that would generate MSY given a population's underlying *average* productivity, or whenever exploitation rates consistently exceeded those that would generate MSY given a population's "current" productivity (e.g., during a period of consistently poor marine survival).

4.2 KEY EVIDENCE

In this section we review key evidence presented at the workshop or developed following the workshop that is critical for assessment of whether or not harvest is currently a significant stressor on Southern BC Chinook stocks. We review evidence in the following areas: (a) time-series of harvest of Chinook salmon in southern BC fisheries and in overall ocean harvest of Chinook salmon originating from southern BC rivers; (b) time-series of estimated exploitation rates for coded wire tagged "indicator stocks" that are assumed to directly reflect exploitation rates experienced by natural Chinook salmon populations; and (c) available estimates of population-specific productivities and associated MSY level exploitation rates, assuming stationary Ricker models. Because the ocean migration patterns of Chinook salmon stocks vary widely across populations (e.g., Weitkamp 2010) but are highly consistent between years (Tucker et al 2012), we often group information on harvests patterns and rates of Chinook salmon according to broad differences in migration patterns. For southern BC Chinook stocks, the panel was presented with three general patterns: locally-distributed, far north-migrating, and offshore. We also present summaries of estimated marine survival rates (based on recoveries of coded wire taggedfish from indicator stocks) for each of these stock groupings because they shed substantial light on likely temporal changes in productivities of southern BC Chinook stocks.Because much of the discussion below concerns differences in harvest patterns and total exploitation rates of stocks with different ocean distribution patterns, we first present a summary of the important differences in catch distributions of Chinook salmon originating from the 3 stock groupings.

4.2.1 Ocean Distribution Patterns of ChinookSalmon originating from Southern B.C. Streams

The patterns of age-specific ocean fishery exploitation rates (and ultimately the total exploitation rates) experienced by different Chinook stocks reflect the ocean distribution patterns of stocks as well as the intensity of fisheries encountered during ocean migrations.

- **Offshore Ocean Distribution Pattern**. Stream-type spring Chinook from southern BC streams (and usually also from Columbia River streams) do not spend much time in nearshore coastal waters as legally vulnerable immature adults but appear instead to move further offshore. Therefore, fish from this grouping are harvested almost entirely in nearshore or terminal locations in British Columbia, when maturing fish return to coastal waters and streams to spawn (**Figure H-2**). Southern BC indicator stocks exhibiting this kind of ocean distribution pattern are Dome Creek Spring Chinook and Nicola River Spring Chinook.

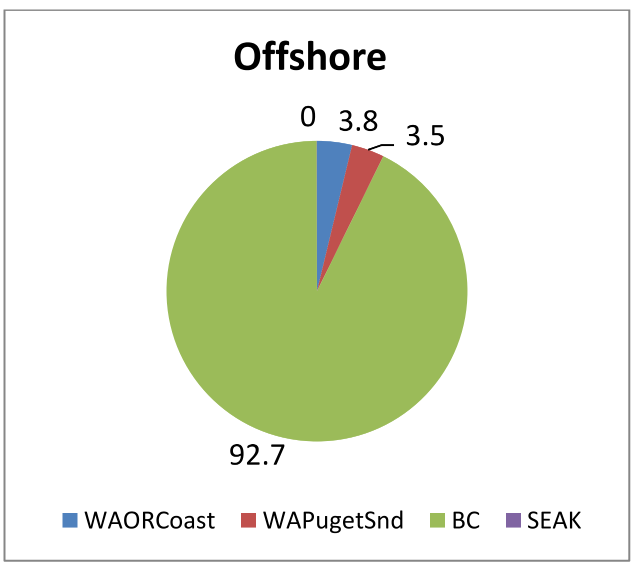


Figure H-2. Average percentage geographic catch distribution of southern BC Chinook salmon exhibiting an *offshore* ocean distribution pattern. Graph modified from one provided by C. Parken, DFO; reproduced with permission.

- **Locally-Distributed Ocean Distribution Pattern**. Stocks grouped within this ocean distribution pattern type are available in nearshore coastal waters as immature adults, but they do not engage in long-distance ocean migrations. These fish are primarily harvested in British Columbia and Washington coastal waters and in Puget Sound. Fish from these stocks are rarely captured in the Southeast Alaska troll fishery. Southern BC indicator stocks that exhibit this kind of ocean distribution pattern **(Figure H-3**) are: Chilliwack (Harrison Fall Chinook), Cowichan Fall Chinook, and Harrison Fall Chinook (Chehalis).

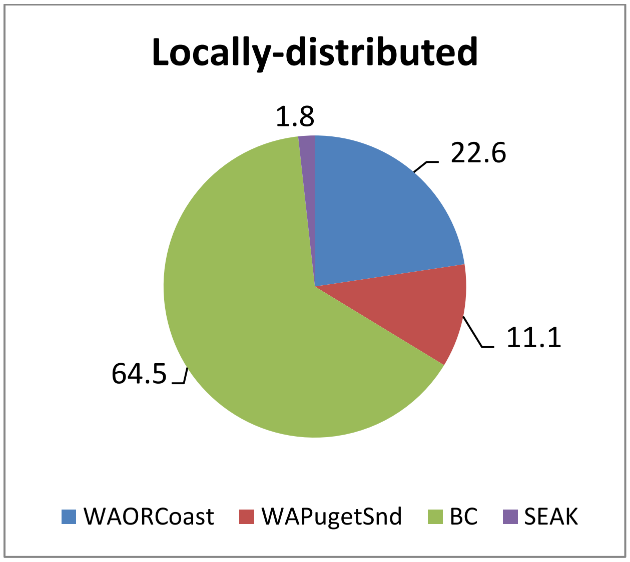


Figure H-3. Average percentage geographic catch distribution of southern BC Chinook salmon exhibiting a *locally distributed* ocean distribution pattern. Graph modified from one provided by C. Parken, DFO; reproduced with permission.

- **Far North-Migrating Ocean Distribution Pattern**. Chinook salmon with far north-migrating ocean distribution patterns are caught as immature adults in Alaskan ocean fisheries far to the north of British Columbia, as well as in British Columbia and Washington fisheries. Nearly half of the landings of fish from such stocks typically occurs in Southeast Alaska troll fisheries (**Figure H-4**) and they are very rarely landed in fisheries other than Alaska and BC. Southern BC indicator stocks that exhibit this kind of ocean distribution pattern are: Big Qualicum Fall Chinook, Lower Shuswap River Summer Chinook, Puntledge Summer Chinook, Quinsam Fall Chinook, and Robertson Creek Fall Chinook (west coast of Vancouver Island stocks are generally Far-north migrating Chinook).

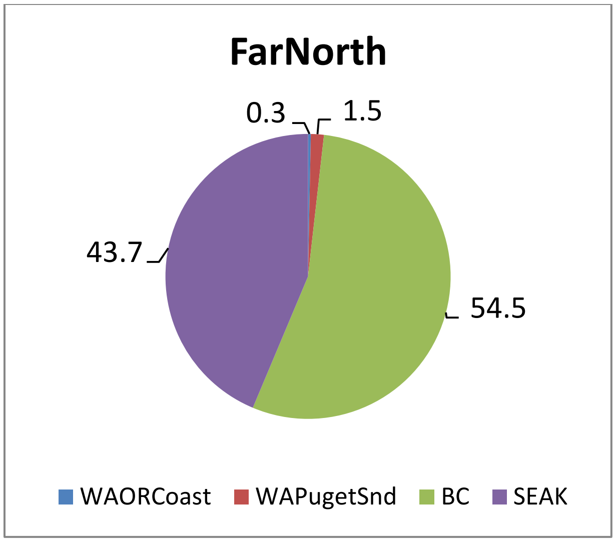


Figure H-4. Average percentage geographic catch distribution of southern BC Chinook salmon exhibiting a far north-migrating ocean distribution pattern. Graph modified from one provided by C. Parken, DFO; reproduced with permission.

4.2.2 *Ocean Harvests of Chinook Salmon From Southern BC*

Annual catches of Chinook salmon have decreased substantially along the entire west coast of North America. As displayed in **Figure ST-2** (reproduced below), total ocean harvest of Chinook salmon in British Columbia declined dramatically between 1975 and 1995 and has thereafter ranged from about 400,000 to 700,000 fish annually. Ocean harvest of Chinook salmon has also declined dramatically in southern BC fisheries, with declines most dramatic in commercial fisheries, less dramatic but substantial in sport fisheries, but with slow increases in First Nations landings of Chinook salmon (**Figure H-5**).

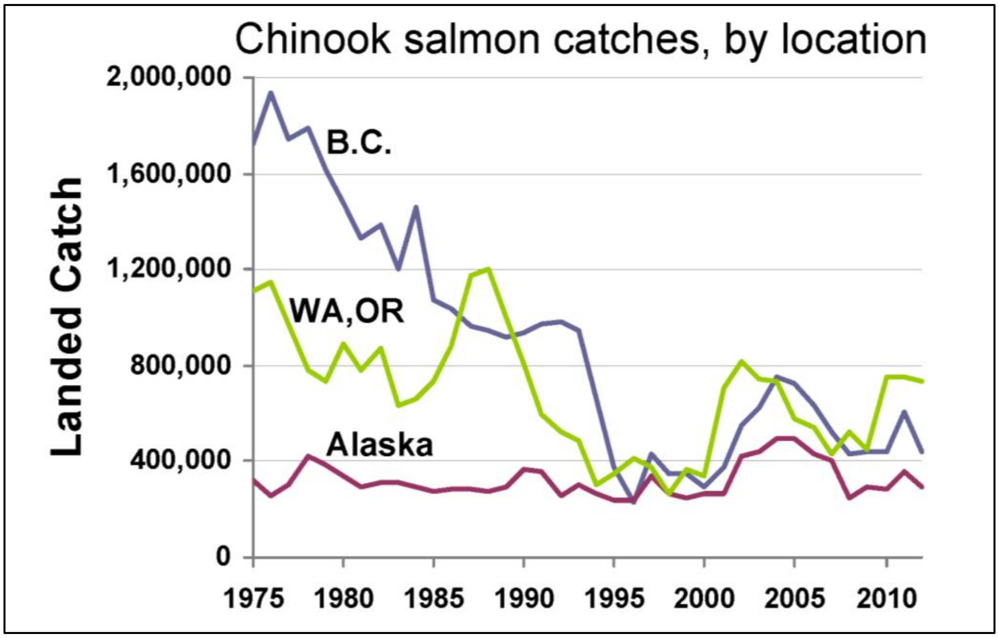


Figure ST-2. Duplicated from Section 3. Total landed catch of Chinook salmon in three regions by catch year, regardless of the geographic origin of the fish. These catches include all catches from commercial, sport, and Tribal/First Nations fisheries. Source: CTC (2013).

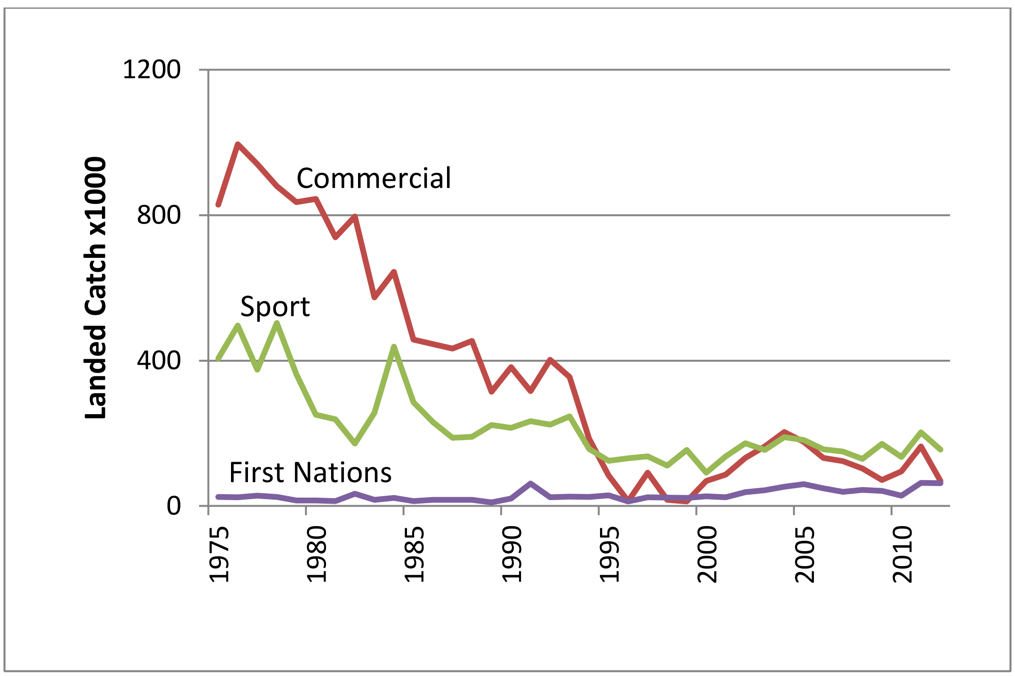


Figure H-5. Total landed catch of Chinook salmon in southern BC ocean fisheries. Based on data summaries available in CTC catch and escapement reports. Graph provided by C. Parken, DFO; reproduced with permission.

Many of the Chinook salmon caught in southern BC ocean fisheries originate from spawning streams outside of southern British Columbia, and Chinook salmon originating from southern British Columbia spawning streams are taken in ocean fisheries in Alaska, Washington, and Oregon.For example, based on CTC model stock composition estimates applied to observed annual ocean catches of Chinook salmon (as reported by agencies), Chinook salmon taken in the Georgia Strait Sport fishery (**Figure H-6**) originate primarily from southern British Columbia streams. In contrast, only a very small proportion of catches made in the WCVI ocean sport fishery originate from southern BC streams (**Figure H-7**).

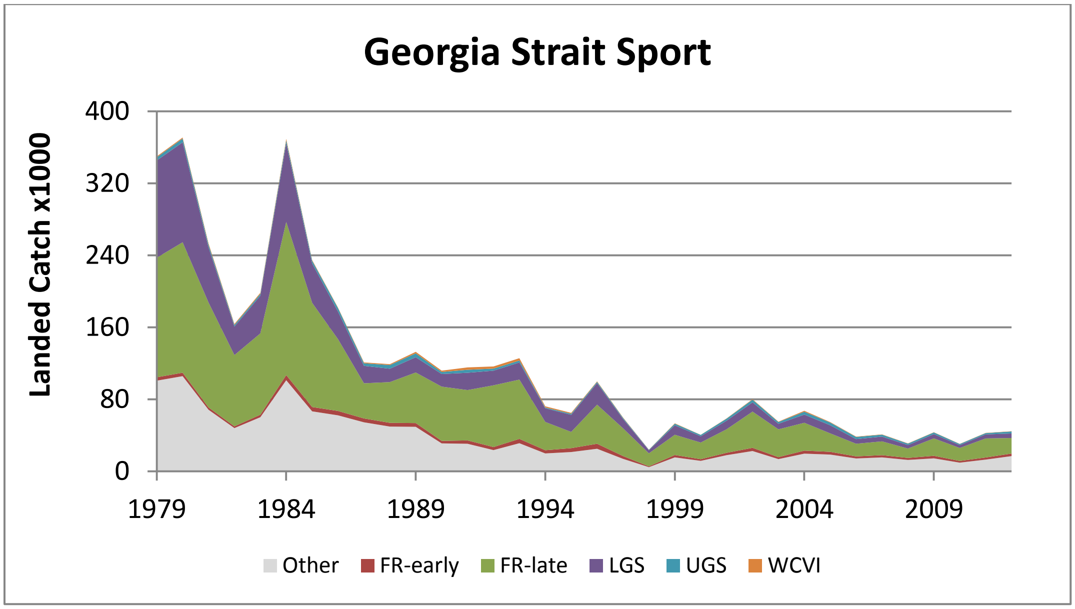


Figure H-6. Estimated stock composition of Chinook salmon landed in the Georgia Strait sport fishery, 1979-2012. FR-early = Fraser River early run, FR-late = Fraser River late run, LGS = Lower Georgia Strait, UGS = Upper Georgia Strait, WCVI = West Coast Vancouver Island. Graph provided by C. Parken, DFO; reproduced with permission.

The mixed-stock nature of ocean salmon fishery landings therefore makes it difficult to directly relate ocean fishery landings of Chinook salmon in southern BC to abundance or production of Chinook salmon from this region. If similar estimates of stock composition for groupings of Chinook originating from southern BC streams are applied to Chinook salmon catches taken in all ocean fisheries in the Pacific Northwest, then the nature of the trend in total ocean catches of Chinook originating from these SBC streams can be observed.

Figure H-8 shows that the estimated total ocean landings of Chinook salmon originating from southern BC streams declined rapidly from about 900,000 to about 280,000 over the period 1979-1987, then increased temporarily, but has ranged from only about 100,000 to 300,000 fish since 1995.

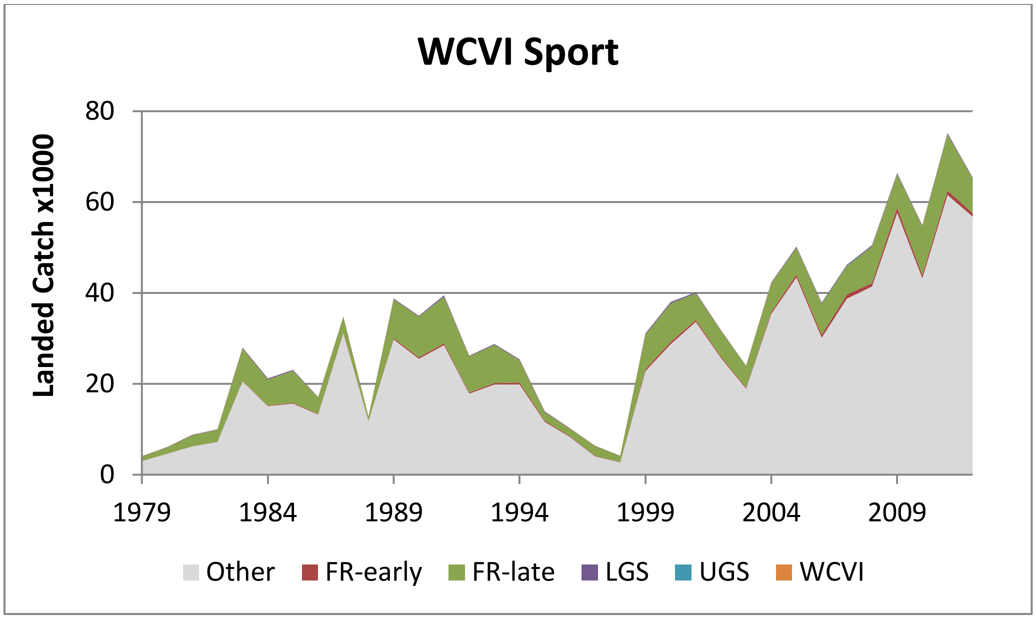


Figure H-7. Estimated stock composition of Chinook salmon landed in the offshore ocean sport fishery off west coast Vancouver Island, 1979-2012. FR-early = Fraser River early run, FR-late = Fraser River late run, LGS = Lower Georgia Strait, UGS = Upper Georgia Strait, WCVI = West Coast Vancouver Island. Graph provided by C. Parken, DFO; reproduced with permission.

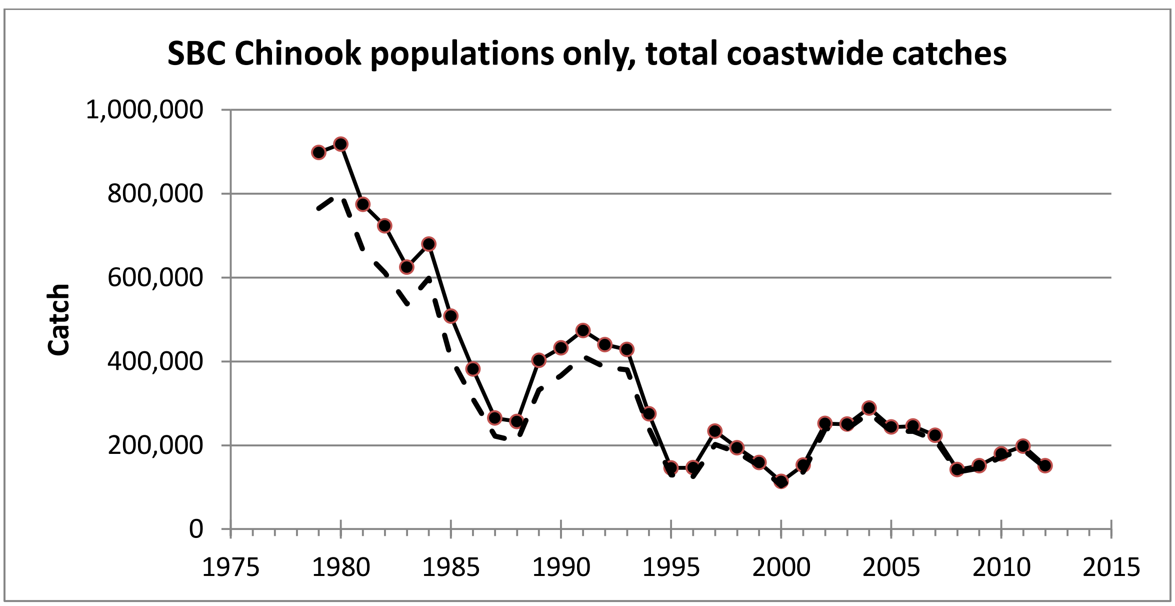


Figure H-8. Estimated coast-wide ocean fishery landings of Chinook salmon (excluding terminal net catches in the Fraser River and along the west coast of Vancouver Island) originating from streams in southern British Columbia only. Solid line includes ocean net (gill nets, purse seine) catches of Chinook; dashed line excludes ocean net catches. Based on CTC modeled stock composition and agency-reported landings (plot created by B Riddell with data provided from CTC catch files).

4.2.3 Freshwater Catches of Chinook Salmon in southern British Columbia

Although catches of Chinook salmon in southern B.C. freshwater (terminal) fisheries are relatively modest compared to catches in ocean fisheries, terminal catches and harvest rates vary considerably across stock types and can be substantial for certain stocks. Largest freshwater catches of Chinook salmon are made in the Fraser River system where terminal harvests in targeted Chinook commercial gillnet fisheries have been greatly reduced since 1980 for conservation of up-river spawners. Fraser River terminal Chinook runs by population were provided by C. Parken (DFO) based on a reconstruction model reported by English et al. (2007), and results were up-dated through 2012.

Fraser in-river harvests include spring and early-summer Chinook salmon with offshore ocean distributions that are harvested at rates (terminal catch/terminal run size) averaging about 25% since 1995 and appear to have slowly increased since the late 1980s (**Figure H-9**). Early run spring and summer Chinook are the most highly prized in terminal fisheries due to their high fat content and excellent flesh quality, which reflects their early state of maturity.

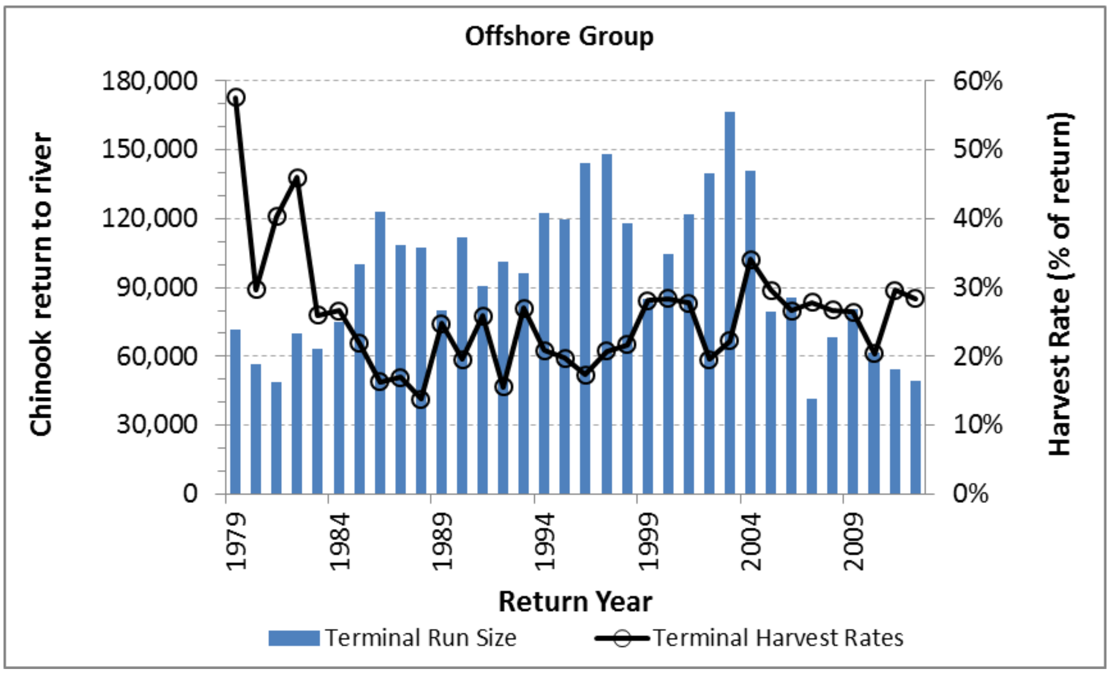


Figure H-9. Estimated terminal runs (excluding jacks) and terminal harvest rates (% of terminal run captured in terminal fisheries) for Fraser River spring and summer run stocks of Chinook salmon with "offshore" ocean distributions. Populations included in this group include Spring 5.2, Spring 4.2, and Summer 5.2 stock groups. Source: run reconstruction and harvest data provided by C. Parken, DFO, Sept. 2013.

Average terminal harvest rates for the far-north migrating group of Chinook salmon from the Fraser River have averaged 20% since 1995 (**Figure H-10**).Terminal harvest rates for this stock grouping were exceptionally high (40% to 65%) during the period 1979-1984, but thereafter rapidly declined to rates more consistent with the 1995-present period.

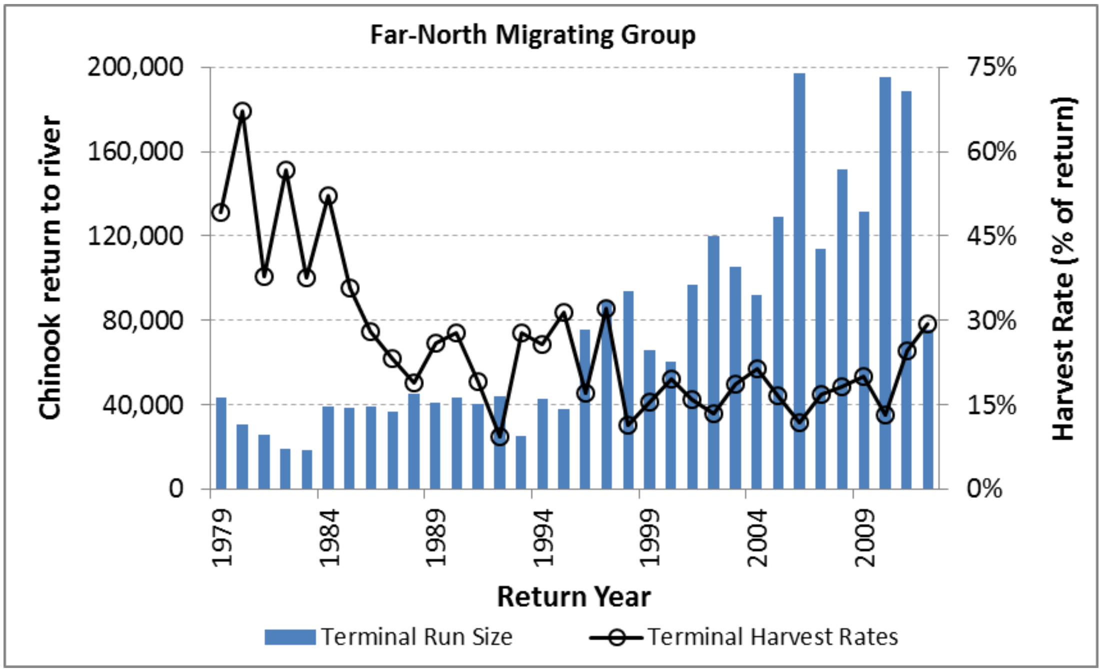


Figure H-10. Terminal run size and terminal harvest rates for far-north migrating Chinook salmon originating from the Fraser River system. Fraser River stocks within this grouping include Summer 4.1 Chinook and are largely the Thompson Summer Chinooks, the most abundant stock group in the Fraser River recently. Source: run reconstruction and harvest data provided by C. Parken, DFO, Sept. 2013.

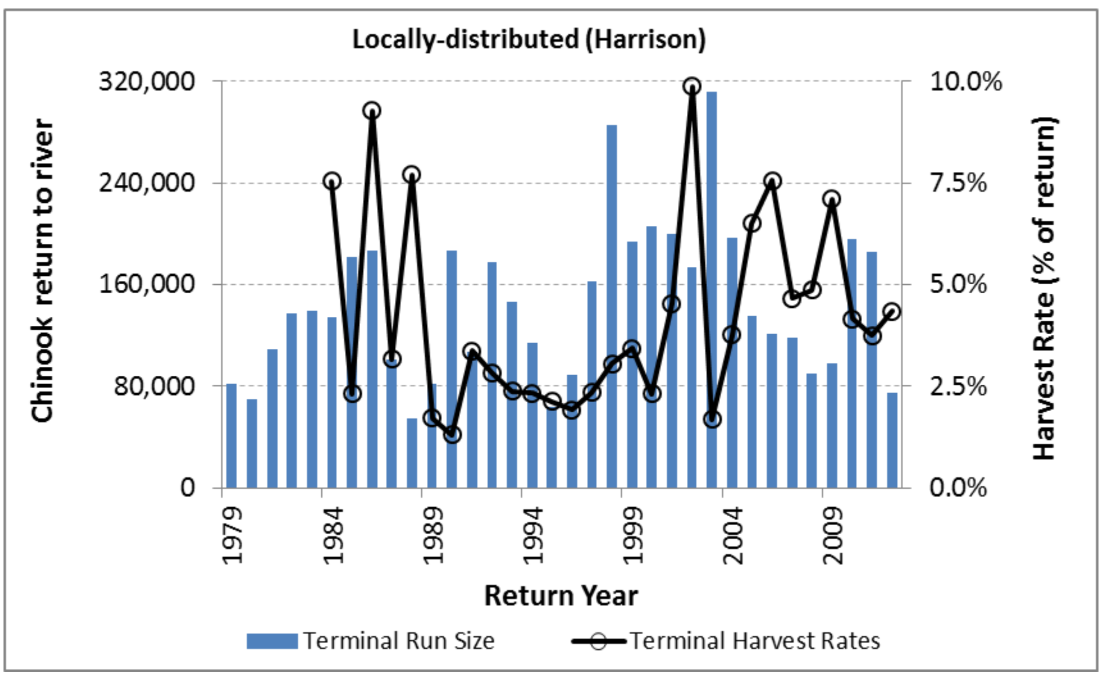


Figure H-11. Terminal catches of adult Chinook salmon and terminal harvest rates for locally-distributed fall Chinook salmon originating from the Harrison River in the lower Fraser River. Source: run reconstruction and harvest data provided by C. Parken, DFO, Sept. 2013.

Terminal run sizes for the locally-distributed Fraser River fall Chinook salmon stocks (represented by the Harrison stock) have been highly variable since 1979 but terminal harvest rates have been substantially less than for the offshore and far-north migrating groupings. Terminal harvest rates for Harrison River fall Chinook have averaged about 5% since 1995 (**Figure H-11**).

Terminal harvest may, however, be an issue for the locally-distributed Cowichan River fall Chinook. Terminal removals in the Cowichan River include a native fishery and the removal of adults for use as broodstock in the Cowichan Hatchery. The portion removed from the total return has been consistently higher since 2001; total returns and natural spawners have declined since 2001 (**Figure H-12**).

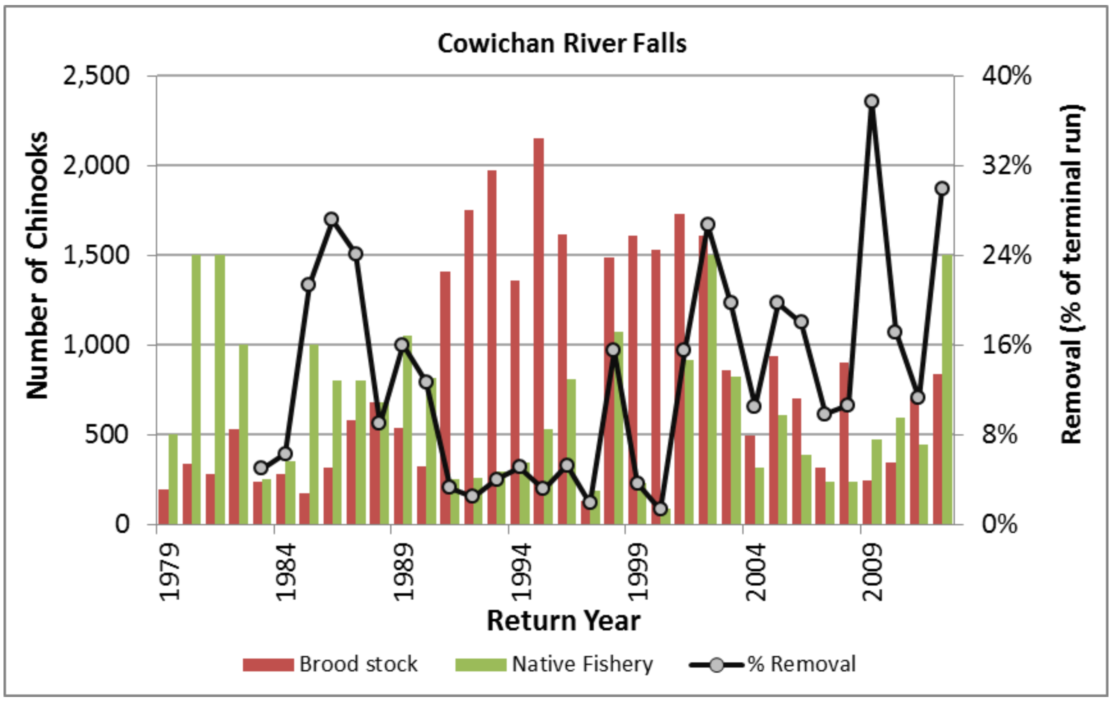


Figure H-12. Terminal removals (bar graphs) of adult Chinook salmon for brood stock and First Nation catch for locally-distributed fall Chinook salmon originating from the Cowichan River. The portion of the total return that these removals represent (i.e., the terminal harvest rate) is presented by the solid black line. Data provided by DFO.

These four plots of terminal runs and harvest rates are presented as examples of terminal fishing pressures but they are not the only populations or rivers with terminal fisheries. Significant fisheries also occur on the Somass/Stamp River return of Robertson Creek hatchery Chinook and much smaller fisheries may occur in other coastal streams, particularly those with a level of enhancement.

4.3 TOTAL EXPLOITATION RATES EXPERIENCED BY SOUTHERN BC CHINOOK

Throughout this section, we define brood year-specific "total exploitation rates" as the fraction of the adult "recruits" produced by spawning adults in year t that would have otherwise been expected to spawn (in the absence of fisheries) in years t+3, t+4, t+5, and t+6 (for a typical ocean-type fall Chinook stock) or in years t+4, t+5, t+6, and t+7 (for a typical stream-type spring Chinook stock) that are instead harvested (or suffer non-catch incidental mortalities) in all fisheries (both ocean and freshwater). Estimates of these total exploitation rates are available for a number of southern BC indicator stocks for which large groups of fish (usually of hatchery origin) have been released as smolts with adipose clips and release-specific identifying coded wire tags (AD+CWT). Recoveries of these AD+CWT fish in ocean and freshwater fisheries, in spawning escapements, and at hatcheries have been used to reconstruct the exploitation history of a cohort of Chinook salmon originating from a CWT release group and thereby allow calculation of total exploitation rates, as described above. (See Figure B-4 for a visual presentation of the exploitation and maturation history of a cohort of Chinook salmon.) In theory, the total exploitation rates and pattern of exploitation rates across ages that are experienced by an indicator stock should be essentially the same as those experienced by an untagged stock with similar life history (size at age, age at maturity, and ocean distribution pattern).

Assessment of trends in total exploitation rates to which southern BC Chinook salmon stocks have been subjected is important in at least two respects. First, trends in fishery landings reflect not just trends in abundance of salmon but also in the total exploitation rates that have been the consequence of regulations adopted for fishery management and catch allocation. Therefore, knowledge of trends in total exploitation rates aids interpretation of landings data. Second, estimated total exploitation rates can be compared to those which would be perceived as optimal based on estimated stock productivities.

Figure H-13 illustrates that ocean distribution pattern can have a substantial impact on the total exploitation rates experienced by salmon stocks originating from southern British Columbia. Because stream-type spring Chinook stocks like those originating from Dome Creek and Nicola River have an offshore ocean distribution pattern, they are essentially not vulnerable to coastal fisheries until they are enroute to their freshwater spawning streams as maturing adults. Exposure of offshore stocks to ocean fisheries is limited primarily to the (variable) age at which they mature, whereas fish originating from locally-distributed or far-north migration stock types are vulnerable to ocean fisheries as immature fish for as long as 4 seasons .As a consequence, total exploitation rates for these offshore stock types were less than for locally-distributed and far-north-migrating stock types over the period 1985 to 1995. **Figure H-13** also shows that there were dramatic reductions in ocean exploitation rates of locally-distributed and far north-migrating stocks over the period from about 1974-1995. Over this period, average total exploitation rates decreased from nearly 80% to about 40%. Since 1995, total exploitation rates for locally-distributed and far north-migrating stocks have ranged from about 35-50%, whereas those for offshore stocks have been a bit lower and more variable: these have ranged from less than 15% to more than 50%. Differences between total exploitation rates of offshore types compared to locally-distributed and far-north migrating types have become less as ocean fishery exploitation rates have been reduced because, as noted above, terminal harvest rates can be higher for offshore type spring and summer Chinook than for the other ocean distribution types.

With the exception of Chinook salmon stocks with unusually high productivities (Ricker model "a" parameter exceeding 2.5 on **Figure H-1**), total exploitation rates experienced by both locally-distributed and far north-migrating stock types were substantially in excess of those that would achieve MSY over the period 1973-1983. During that period, there is therefore little question that harvest was a very significant stressor on these stock types from southern BC.

A key question here is whether fishing may have been an important stressor since 1983, in particular since 1995 when total exploitation rates have been (for locally-distributed and far north-migrating stock types) fairly steady and substantially less than during earlier years. However, to determine the importance of exploitation rates, there are two complex considerations that are best addressed on a stock-by-stock basis. First is the degree to which current total exploitation rates are consistent with or lower than those considered optimal for a given stock, given available stock-recruitment analyses or other procedures for estimating the Ricker "a" productivity parameter over an entire data set. The second is the degree to which decreases in recent marine survival rates (from ocean entrance to ocean age 2) may have reduced the magnitude of these productivity parameters in recent years compared to long-term average productivities.

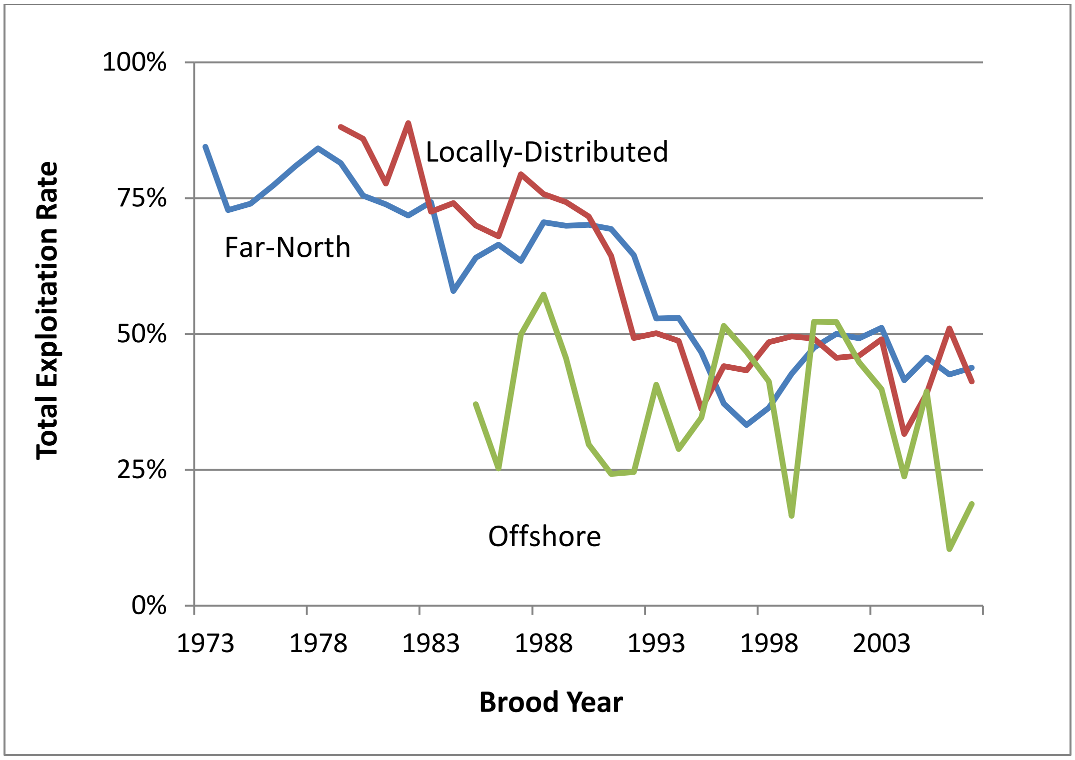


Figure H-13. Average estimated total exploitation rates by brood year for AD+CWT indicator stocks exhibiting one of three general ocean distribution patterns: far north-migrating, locally-distributed and offshore. Graph modified from one provided by C. Parken, DFO; reproduced with permission.

According to Parken et al. (Harvest Session Handout, May 2013 Workshop), total exploitation rates that would generate MSY for southern BC Chinook stocks have been estimated using a wide variety of methods: "…..directly from stock-recruit analysis for Cowichan (Tompkins et al. 2005) and Harrison (Brown et al. 2001) or indirectly by using habitat-based estimates of S_{MSY} and S_{REP} based on the watershed area model (Parken et al. 2006) to estimate the stock productivity parameter, or from a meta-analysis of ocean- or stream-type life history stocks (Parken et al. 2006) when a habitat-based estimate was not available." Based on graphs presented in Parken et al.'s harvest session workshop handout (Appendix Figures 2A, 2B, Harvest Session Handout, May 2013 Workshop) and provided to our panel at the workshop, we have developed **Table H-1** which compares realized total exploitation rates for southern BC indicator stocks (based on CWT recovery data) with approximate total exploitation rates for MSY (E_{MSY}) and corresponding Ricker 'a' productivity parameters.[12] We write the Ricker model as: R=S*exp{a*[1-(S/b)]}, and we use Hilborn's (1985) approximate solution to solve for E_{MSY}: $E_{MSY} = 0.5a - 0.07a^2$.

Note that only one stock (Dome Creek in **Table H-1**) had a mean total exploitation rate for the period 1995-2008 that would be regarded as "stressful" when compared with E_{MSY} values based on the existing estimates of productivities of individual southern BC Chinook salmon stocks (compare columns 3 and 5 in **Table H-1**). However, as noted elsewhere in this report, there is substantial evidence that recent marine survivals (since early 1990s) of southern BC Chinook, for at least far north-migrating and locally distributed ocean distribution types, have been substantially below long-term average survivals since the early 1990s (**Figure H-14**).Such declines in marine survival should translate directly into declines in stock-specific productivities (i.e., recruits per spawner). Based on examination of trends in marine survival rates over time, we conjecture that recent productivities, measured by the Ricker 'a' parameters, have only been about ½ of their long-term average and we calculated adjusted estimates of E_{MSY} that would correspond to these lowered productivities (last column of **Table H-1**). If mean total exploitation rates are compared to these *adjusted* E_{MSY} values, then 6 of the 12 indicator stocks show recent total exploitation rates that exceeded *adjusted* E_{MSY} values. Robertson Creek (recent mean total exploitation rate = 0.578 (but see footnote to **Table H-1**) compared to *adjusted* E_{MSY} = 0.44), Cowichan (recent mean total exploitation rate = 0.644 compared to *adjusted* E_{MSY} = 0.43), and Dome Creek (recent mean total exploitation rate = 0.698 compared to *adjusted* E_{MSY} = 0.36) would seem of special concern. (Note, however, that the Dome Creek estimates of total exploitation rate may be unreliable – see further discussion below.)

[12] Note that in a presentation given at the workshop, the notation $F_{MSY,}$ rather than E_{MSY}, was used to denote the total exploitation rate at MSY. The symbol F has since about 1950 consistently been used in fisheries science to denote the instantaneous fishing mortality rate (or force or fishing). F does not have an upper bound of 1.0, whereas the total exploitation rate is restricted to the interval bounded by 0% and 100%. We encourage future use of the more appropriate E_{MSY} notation that we have used in this report.

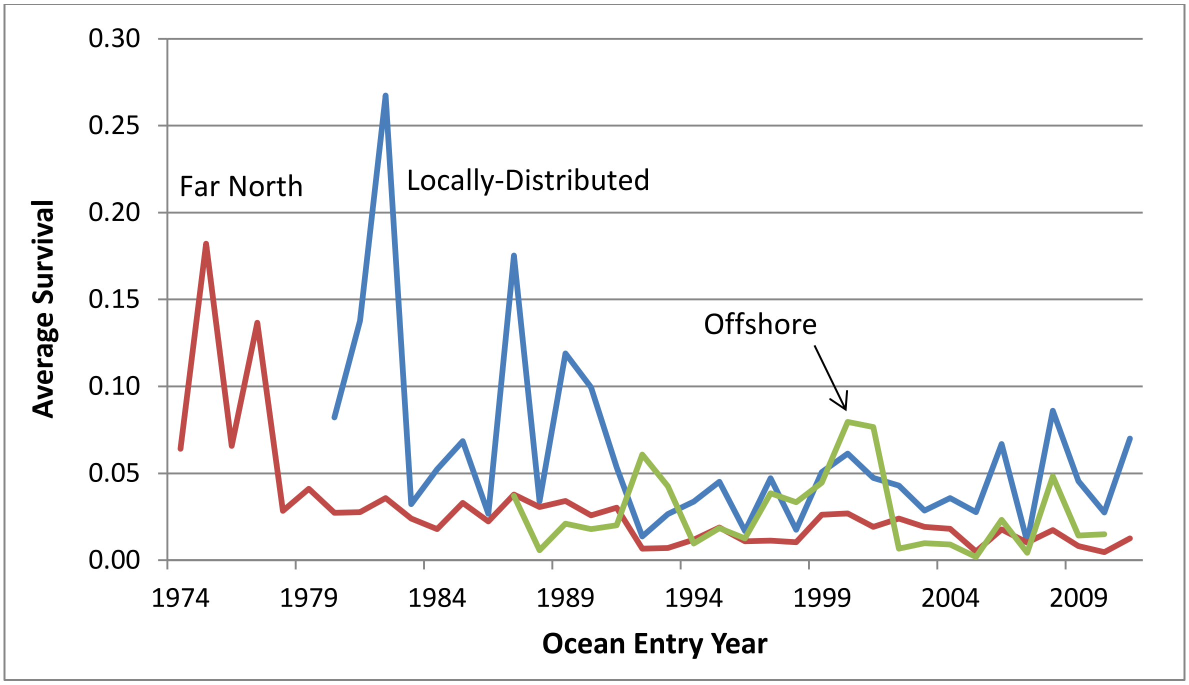


Figure H-14. Estimated marine survival rates (survival rates from release to ocean age 2) for AD+CWT Chinook salmon indicator stocks exhibiting one of three general ocean distribution patterns. Graph modified from one provided by C. Parken, DFO; reproduced with permission.

Table H-1. Mean stock- (CU-) specific brood year total exploitation rate 1995-2008, assumed Ricker 'a' productivity parameter, E_{MSY} (total exploitation rate at MSY), adjusted Ricker 'a parameters, and adjusted EMSY. Boldface identifies stocks for which 1995-2008 brood year total exploitation rates (similar to those displayed in **Figure H-10**, but stock-specific) exceed adjusted E_{MSY} based on a conjecture that current productivities (Ricker 'a' parameter) are ½ of those that have been assumed to be "average" in stock assessments. Adjusted Ricker 'a' parameters are ½ of assumed values, i.e., those estimated to represent "average" productivity in stock assessments.

CU	Indicator Stock	Mean 1995-2008 brood exploit. Rate	Assumed Ricker 'a'	E_{MSY}	Adjusted Ricker 'a'	Adjusted E_{MSY}
FAR NORTH MIGRANTS						
SWVI	Robertson	**0.578***	2.03	0.73	1.015	**0.44**
NEVI	Quinsam	0.405	2.03	0.73	1.015	0.44
Qual-Punt Falls	Big Qualicum	0.415	2.03	0.73	1.015	0.44
Mid ECVI Summer	Puntledge	0.302	2.03	0.73	1.015	0.44
Shuswap Summer 0.3	Lower Shuswap	**0.486**	2.07	0.74	1.035	**0.44**
Thompson Summer 0.3	Lower Shuswap	**0.486**	1.59	0.62	0.80	**0.35**
LOCALLY-DISTRIBUTED						
Nanaimo-Chemainus	Nanaimo	**0.507**	2.34	0.79	1.17	**0.49**
Cowichan	Cowichan	**0.644**	1.87	0.69	0.99	**0.43**
Lower Fraser Fall	Harrison (Chehalis)	0.355	1.67	0.64	1.34	0.54
Lower Fraser Fall	Chilliwack	0.301	1.67	0.64	1.34	0.54
OFFSHORE						
Lower Thomspon Spring (1.2)	Nicola	0.238	1.51	0.60	0.75	0.34
Upper Fraser Spring	Dome	**0.698**	1.65	0.63	0.82	**0.36**

*The total exploitation rate for the Robertson Creek stock is probably unusually high due to the intensive terminal fisheries targeting these hatchery-origin fish.

Missing Brood Years: Cowichan –2004, Dome Ck –1999, 2002-2008, Chehalis –2004, Nanaimo –1998, 2003, 2005-2008, Puntledge –1995

4.4 Has Harvest Likely Been a Factor Responsible for Recent Trends in Abundance of Southern BC Chinook?

Time trends in escapements of southern BC Chinook vary among stocks and range from substantial decreases to substantial increases (see "Status and Trends" section). As explained in the Introduction, this workshop was motivated by widespread declines in ocean harvest of Chinook and by perceived declines in spawning escapements in many populations. Given the very substantial declines in total exploitation rates during the mid-1970s to mid-1990s, it is surprising that there has not been a corresponding increase in freshwater returns and abundance of spawners of many stocks of southern BC Chinook.

Absence of a positive response of escapements to substantial reductions in estimated total exploitation rates could be due to a number of factors which are identified below in bold print. Following each of these possible factors is a brief summary of our assessment of the degree to which these factors may be related to the absence of continuing positive response to reduced exploitation rates. (Recall that there was an immediate positive response to reduction in exploitation rates in the mid-1980s, when marine survivals were high compared to the present period.)

Underestimated Mortalities

Some possibly important mortality factors may be underestimated, thereby leading to negative bias in estimates of total exploitation rates or positive bias in assumed ocean survival rates for age 2 and older Chinook salmon. These may include at least (a) unknown levels of by-catch of Chinook salmon in Eastern Bering Sea or other ocean fisheries targeting pelagic-schooling species, (b) uncertain levels of catch and release mortality in mark-selective or other non-retention fisheries, or (c) increased rates of mortality due to marine mammal predation on Chinook salmon.

Parken presented available information on the first two of these factors at the workshop. Catch and release mortalities seem currently unlikely to be accounting for large unknown mortalities and, in any event, attempts have been made to estimate these mortalities and include them in assessments. Catch and release mortality in Chinook salmon fisheries under PSC jurisdiction have actually declined substantially in recent years (1999-2008) relative to 1985-1995, due to management measures implemented to reduce this type of mortality (CTC 2011). Levels of by-catch merit further evaluation and cannot be excluded as a source of mortality without further study. The uncertain impacts of marine mammal predation seem worthy of additional attention (see e.g., Hilborn et al. (2012) workshop and the Ecopath/ecosim simulation results described therein).

Reduction in and Uncertain Values of Stock-Specific Productivities

Although total exploitation rates have been substantially reduced when compared to their levels in the late 1970s and early 1980s, and although recent exploitation rates of indicator stocks seem well below those that would achieve MSY under conditions of *average* productivities, they may in some cases remain excessively high.

Consistently poor marine survival rates since the mid-1990s suggests that recent full life-cycle productivities of southern BC Chinook stocks have been lower than their long-term averages. Recent total exploitation rates, although greatly reduced from historic rates, may remain excessive when compared with *current* rather than *average* productivities of some southern BC Chinook stocks.

Stock-specific productivity estimates used to establish MSY brood exploitation rates for most BC Chinook have been based on watershed/habitat information, rather than on empirical estimates of adult spawners and subsequent recruits. These productivity estimates may be positively biased or unreliable, thereby leading to estimates of E_{MSY} that are greater than appropriate or unreliably estimated. It seems unlikely that habitat-based methods would lead to consistent bias in estimation of stock-specific productivities, but there is no doubt that the technical basis for setting optimal exploitation rates is weak for many stocks.

Recent Total Exploitation Rates may Exceed Those for MSY Given Current Stock-Specific Productivities

Table H-1 illustrates that recent total exploitation rates would in some cases be regarded as excessive relative to E_{MSY} if reduced marine survivals have reduced average stock-specific productivities by one half.

The relative stability of recent low CWT-based marine survival rates for southern BC Chinook indicator stocks compared to previous relatively high values (see Status and Trends section) indicates that there has been a substantial and persistent reduction in survival from smolt to age 2 for some Chinook stocks and that an appropriate management response would be to lower exploitation rates. Although those rates have indeed decreased (**Figure H-13**), the question is, were they reduced by enough and early enough on particular stocks to avoid contributing substantially to the observed decrease in spawner abundances?

The answer to the above question involves answering two other questions at a stock-specific level. First, what was the actual decrease in productivity, reflected by the Ricker 'a' parameter, as distinct from the decrease in marine survival rate? Second, what timing and amount of reduction in exploitation rate would have been necessary to achieve MSY escapement or other management objectives? The first question can be answered with advanced methods of analysis such as applying a Kalman filter to estimate temporal changes in productivity for non-stationary Ricker stock-recruitment models (e.g., Peterman et al. 2003). That method was applied to stock-recruitment data for the few southern BC Chinook populations with appropriate data, and several stocks showed decreases in productivity (see "Status and Trends" section).(The maximum detected decrease was about 46% (from 2.6 to 1.4), for the WCVI stock grouping.) To answer the second question, though, the graph in **Figure H-1** is not sufficient to set harvest rates. Instead, the answer requires more complex simulations known as "Management Strategy Evaluations (MSEs)" (Sainsbury et al. 2000) or "closed loop simulations" (Walters 1986).Such simulations produce state-dependent decision guidelines that take into account not only time dynamics of fish populations, but also dynamics of the fishery, as well as observation error, implementation uncertainty (reflecting when regulations are followed imperfectly), and other sources of variation. Those methods are widely used in stock assessments of non-salmonid marine fishes (Walters and Martell 2004), and two recent examples of their application to salmonids are Collie et al. (2012) for Alaskan chum salmon and Pestal et al. (2012) for Fraser River, B.C. sockeye salmon. Pestal et al. (2012) explored alternative harvest guidelines to respond to decreases in productivity of those sockeye salmon populations that have occurred in the last two decades. Given the apparent reduction in productivity of some Southern B.C. Chinook stocks, we strongly recommend that Chinook scientists and managers learn from these other salmonid analyses and apply similar methods to Chinook to increase the chance of meeting management objectives.

Recent total exploitation rates for Nicola River spring Chinook, which exhibit an offshore ocean distribution, have been below levels that would be a cause for concern, even if current productivity of this stock were just ½ of the long-term average. Harvest might therefore not be judged a significant stressor for this stock or, presumably, other BC spring Chinook stocks with offshore ocean distribution patterns. We note, however, that existing estimates of total exploitation rates for the Dome Creek indicator stock, which also exhibits an offshore ocean distribution pattern, were consistently much higher than for Nicola River spring Chinook (**Table H-1**) *and have exceeded* E_{MSY} *even for average stock productivity*. The rather dramatic inconsistency in estimated total exploitation patterns of Dome Creek and Nicola River indicator stocks, coupled with the relatively high terminal harvest rates to which offshore spring and summer Early Fraser runs are subjected, is a substantial cause of concern given the recent declines in spawning escapement of these stocks. Reasons for the inconsistency in estimated total exploitation rates of these two indicator stocks may include low sampling rates in intensive terminal First Nation fisheries directed at these stocks, relatively poor estimates of spawning escapements, differences in years used to calculate 1995-2008 means, and/or small CWT release group sizes (C. Parken, pers. comm.). Together, these factors can all contribute to highly unreliable estimates of exploitation rates. It is also possible, however, that the differences between estimated total exploitation rates for these two stocks are real, presumably due to dramatic differences in terminal fishery harvest rates for these two indicator stocks.

4.5 Uncertainties, Critical Information Gaps, and Recommendations

- The small number of indicator stocks, especially for the offshore ocean distribution type (mostly stream-type spring Chinook), limits the level of assurance with which estimates of total exploitation rates for indicator stocks can be used to infer likely total exploitation rates for untagged stocks of interest. Inconsistency in estimated total exploitation rates for Dome Creek (no longer tagged) and Nicola River spring Chinook is also of substantial concern. It is particularly important to add additional indicator stock(s) for the offshore ocean distribution type.

- Estimates (rather than indexes) of spawning escapements and freshwater harvests seem lacking (or not presented) for many southern BC Chinook stocks, thereby ruling out formal stock-recruitment analyses for estimation of stock-specific productivities and possible temporal changes in productivities. Watershed-and habitat-based methods for estimating productivities have merit, but they are less desirable than stock-recruitment analyses, in particular because they do not allow incorporation of marine survival rates as a factor that may influence recruitment. We recommend additional compilation and analysis of stock-recruitment data in all cases where this is possible.

Additionally, habitat-based estimates of productivities could be used as a starting point for stocks for which generation of useful stock-recruitment data is impossible.

- For the few stocks for which useful stock and recruitment data exist, we recommend fitting Ricker models which include marine survival as a covariate (methods previously mentioned and originally developed by the PSC's Chinook Technical Committee). If time series are suitably long, then this kind of analysis should generate an estimate of long-term "average productivity" (the interpretation of the Ricker alpha parameter when survival varies according to marine environment). These values might be better to use for long-term stock productivity values than existing alphas which may be in some cases be positively biased (when compared to long-term average productivities) due to chance inclusion of many early years with unusually favorable ocean environment and exclusion of more recent data. For these stocks, estimates of marine survival could be used to determine the degree to which current (i.e., brood year-specific) realized productivities likely differ from the long-term average. These kinds of analyses have been previously carried out for at least Harrison and Cowichan stocks (Brown et al. 2001, Tompkins et al. 2005). If updated to the most recent completed brood years, then explicit estimates of recent productivities could be made by adjusting the long-term average productivities by brood-year-specific estimates of marine survival.

- We note the critical role that CWT releases and recoveries of indicator stocks have played in assessment of the possibility that harvest may be a continuing serious stressor on southern BC Chinook. Without CWT-based estimates of marine survival and total exploitation rates, it is difficult to imagine how one might rigorously explore the potential effects of fishing on abundance trends. Therefore, we believe that it is extremely important to continue CWT tag recovery programs for indicator stocks, at least until the time that some alternative approach can be shown to generate similarly accurate estimates of marine survival rates and total exploitation rates.

5 FRESHWATER HABITAT

5.1 PLAUSIBILITY OF PROPOSED MECHANISMS

For most salmon populations the freshwater stage accounts for about half of the total egg-to-adult mortality (Bradford 1995). In the case of Chinook salmon, data collated to 1994 suggests the freshwater period may only account for 35-40% of the total, although this estimate does not include mortality of smolts during their seaward migration, nor the mortality of adults as they migrate upstream to spawning areas. This is a large enough fraction of the total mortality that the hypothesis is *plausible* that changes in freshwater conditions could contribute to changes in overall recruitment or subsequent spawner abundance.

Chinook salmon utilize a variety of habitats in freshwater, and habitat use depends on the life history and configuration of habitats available to them (Healy 1991). Spawning occurs in rivers downstream of large lakes, other large rivers and smaller streams, often in association with groundwater that serves to maintain a stable incubation environment. Emergent fry disperse downstream, and that redistribution can range from the colonization of habitat in the natal steam, to longer migrations to downstream locations. For many ocean-type populations, juveniles migrate to estuaries where they spend approximately 1-2 months before moving to the marine environment (Levings et al. 1986). Juveniles have been observed rearing in the margins of large lakes (Russell et al. 1981). Further redistributions of juveniles may occur in early summer and prior to winter for stream-type populations. Variation in the juvenile life history can occur among individuals within populations, among populations, and among CUs (Bradford and Taylor 1997). An examination of causal factors affecting freshwater survival must account for this diversity in freshwater habitat use.

Mortality in freshwater can occur as a result of environmental factors (e.g., spawning gravel composition, streamflow, ice and freezing) during the incubation stage, and environmental (streamflow, temperature, water quality), and biological (food production, predation, competition, disease) factors during the rearing phase. All of these factors can be affected by human activities, such as land use, water removals, waste discharges and others. Little is known of mortality during the seaward migration, however, disease and predation can cause losses (Fujiwara et al. 2011). Mortality during migration is a potential driver for population trends, especially for populations that have long riverine migratory routes. Similarly, environmentally induced mortality of adult fish during their spawning migration will also affect escapement trends. Variation in mortality during migration has the potential to synchronize trends in abundance for the populations that use these common habitats. Prespawning mortality rates as high as 70% have been observed in some populations (e.g., ODFW 2000).

Conditions experienced in one habitat may not immediately cause mortality but can affect survival in a later stage in the life cycle. For example, freshwater rearing environments can affect the size, condition or phenology of seaward migrating smolts, and this would be expected to cause variation in ocean survival. Similarly, the ocean conditions that adult salmon experience prior to entry to freshwater may affect their body condition, health and timing of river entry, and all of these may be expected to influence the likelihood of successful migration and reproduction.

Southern BC Chinook CUs vary in size and they often contain many spawning groups and a large number of watersheds. For freshwater mortality to be a driver of trends in abundance or productivity within or among CUs, either it must operate at a large spatial scale such as that observed for covarying populations or CUs, or it must operate on a habitat that is used by all populations at some point in their life cycle (i.e., for mainstream rearing habitats or during downstream migration). Stream-specific escapement data were not analyzed here, so the spatial scale of variation within CUs cannot be assessed. Rather, we seek stressors that cause variation at the CU level, and could potentially extend to multiple CUs for cases where adjacent CUs show similar temporal patterns in spawner abundance or other response variables of concern.

5.1.1 ENVIRONMENTAL FORCING

Large-scale environmental forcing is a mechanism that could cause all populations within a CU to have similar trends in abundance. Examples include trends or interannual variation in weather, snowpack or streamflow patterns. These factors often vary at a scale of 100s to 1000s of kilometres. Unfortunately, evidence to support the hypothesis that large-scale environmental forcing can cause coherence in abundance or survival of salmonids during the freshwater (juvenile) stage is lacking, although the number of studies that have been conducted are few. Bradford (1999) found that coherence in the production of coho smolts was limited to streams less than 30 km from each other, and even for adjacent streams the correlation in annual smolt estimates was low ($r < 0.3$). A similar conclusion was reached by Rogers and Schindler (2008) for sockeye salmon. Bradford (1999) suggested that impacts of environmental factors would be "translated" to effects on stream biota as a function of the nature of the catchment, and with the possible exception of very extreme events, the effects of an environmental forcing agent could be watershed-specific. For example, a high flow could be detrimental in a steep stream with a simplified channel, but could be beneficial in another situation where off-channel areas become flooded and available for rearing fish. Furthermore, limited evidence suggests that the freshwater life history of SBC Chinook salmon is plastic, with juveniles undergoing a variety of migration and rearing strategies in their first year (Healy, 1991; Bradford and Taylor 1997). This diversity will reduce the likelihood that a single environmental or biological forcing agent will be able to generate coherent trends in survival across a broad spatial scale. Indeed, the diversity of life histories strategies within populations of Chinook salmon has been proposed to be a bet-hedging strategy against fluctuation in environmental conditions (Healey 1991).

Therefore the environmental factors most likely to cause broad-scale variation in abundance are those that affect survival in habitats that are used by individuals from many CUs. In freshwater this mainly concerns mainstem river environments. The life stages affected include rearing juveniles for stream-type populations and migrating smolts, both of which may be affected by flows and temperatures at key points in time. Examination of available trends in environmental conditions is warranted for these stages. As the greatest degree of covariation in the recent decline is for the interior Fraser River stream-type CUs, an analysis of environmental factors affecting rearing and migration conditions in the Fraser river may have utility.

The mortality of adult salmon (particularly sockeye) migrating upstream in the Fraser River has become much more common in the past 2 decades, and is coincident with a rise in river temperature to critical levels (Martens et al. 2011). Mortality at the spawning areas is also observed. Many summer-run Chinook salmon populations (primarily stream-type populations) migrate during the peak river temperatures (English et al. 2007), and they are likely to be exposed to increasingly stressful temperatures. Because this mortality occurs directly on returning fish, it could also be a contributor to trends in adult abundance.

5.1.2 ANTHROPOGENIC EFFECTS

Human-caused degradation of freshwater habitat is often a factor in the decline of salmon populations. Key activities include forestry, road and other linear developments, agriculture and urban development, water regulation and surface and groundwater withdrawal, dams and other barriers, estuary development, waste discharges and pollution.

The major developments to Chinook salmon-producing watersheds in the southern BC region were largely completed 50 or more years ago. Most areas suitable for agriculture were developed by the early 1900s. Lowland areas were drained for development, and a number of rivers were dyked for flood control. Estuaries were extensively modified for human use, including marina and port construction, log booming and dumping, and other uses. The effect of excessive water withdrawals on salmon production in the Thompson drainage was identified in the 1950s (DoF and IPSFC 1954) and has been ongoing. Most hydroelectric facilities were completed by the 1960s, and some have had significant effects on Chinook salmon populations (e.g., Alouette, Bridge, Shuswap Rivers, Hirst 1991). Changes in the operations of many facilities resulting from BC Hydro's Water Use Planning process early 2000s have likely led to improved conditions for salmonid populations at most facilities.

Some human activities have increased over time and that increase continues into the modern period. Urbanization of southern British Columbia has accelerated in the past 30 years. Forestry has reached nearly all areas of the SBC region. The effects of forestry (and forest road construction) often take decades to manifest themselves in aquatic habitats, so long-term trends could be expected to result from earlier activities. Many areas in the Fraser River basin have been affected by mountain pine beetle. Changes to stream hydrology and river temperatures may occur as a result of large-scale changes in land cover, although those changes are complex and are not necessarily detrimental to Chinook salmon (Zhang and Wei 2012). Paulsen and Fisher (2001) found correlations between various land use activities and the survival of juvenile Chinook salmon in headwater streams of the Snake River basin, illustrating the plausibility of linkages between human-induced stressors in freshwater and Chinook salmon productivity.

From a population perspective, habitat degradation can cause a decline in salmon abundance through two mechanisms:

1. *Continuous deterioration of habitat*. Human activities that cause time trends in habitat quantity or conditions may cause a corresponding time trend in salmon productivity and abundance. Corroboration for this mechanism requires a demonstrable time trend in habitat conditions (or human or land-use activities) that coincides in time and space with a trend in salmon abundance or productivity. An example might be an incremental increase in the volume of water extracted from a river that supports Chinook salmon spawning, or a trend in water temperature.

2. *Interactions between human-induced declines in habitat quality and other stressors*. This mechanism does not require a time trend in habitat conditions, and will occur if another factor (ocean conditions, fishing mortality) reduces the rate of return of spawners. Bradford and Irvine (2000) provide an example of this mechanism in their analysis of Thompson River coho salmon. They found that spawning populations from the watersheds most impacted by road development had greater rates of decline during a period of low ocean survival and high fishing rates compared to those populations from more pristine habitats. In these cases, populations from watersheds that were more impacted by freshwater habitat impacts were less resilient to other stressors. The prediction of this hypothesis is that the rate of change in abundance of a salmon population should be correlated with measures of the recent status of the habitat (the analysis does not require habitat trend data). Comparisons across populations (e.g., Bradford and Irvine 2000) require that stressors other than freshwater habitat are similar among populations so that variation between populations can be ascribed to freshwater habitat conditions.

5.2 Key Evidence

5.2.1 Spatial Analysis of Habitat Stressors

Strategy 2 of Canada's Wild Salmon Policy (WSP) requires that the status and trends of habitat conditions be evaluated at the CU scale. Stalberg et al. (2009) created a list of potential indicators for evaluating habitat status for the WSP. "Pressure" indicators were defined as those factors that declines in habitat quality (largely through human activities). Pressure indicators were evaluated from remote sensing data, GIS layers or databases (e.g., water licenses). Recently, Porter et al. (2013) developed a set of "habitat report cards" for southern BC Chinook CUs using the WSP pressure indicators. Some of the indicators for land cover alterations in these report cards are based on a single snapshot of land use based on remote sensing data compiled 20-30 years ago.

Metrics from this analysis were used by DFO scientists in a correlation analysis with SBC Chinook escapement data as a test of mechanism (2) listed above. The analysis used the land-use pressure indicators and the 3-generation trends in spawner abundance that were provided by DFO before the workshop. The analysis was redone after the meeting with revised trend data (these are the data of **Figure ST-1**). Parallel analyses were conducted with all CUs and with only the CUs categorized as subject to low or no hatchery influences. Because the data were a single snapshot of habitat impacts, an analysis of trends in habitat conditions was not possible.

No correlations were found between recent trends in escapement and the habitat indicators, regardless of which set of trend data was used, or whether CUs with extensive hatchery releases were included.

Explanations for this result range from issues with the type and quality of the data available, to more fundamental issues of whether Chinook salmon populations are vulnerable to habitat features that the indicators are attempting to measure. With respect to data issues, the following caveats were mentioned in the workshop presentation or are evident from the analysis:

1. Some of the land cover indicators were collected 20-30 years ago therefore may not portray habitat conditions experienced during the decline of the last three generations.
2. Analyses of potential effects of changes in freshwater habitat on adult salmon (abundance or productivity) require that the different groups of fish being compared have similar patterns in survival for non-freshwater life stages so that variation among these groups is largely due to freshwater conditions that the groups experience. This requirement is clearly violated in this analysis because the CUs have a diversity of life history types, marine distributions and exposure to fisheries. All of these factors can create trends in abundance unrelated to freshwater habitat conditions.
3. Some CUs are quite large and encompass a variety of watersheds, habitats and a range of human-induced impacts. These tend to be averaged out for CU-level analyses, which may mask important habitat-production linkages in specific watersheds.
4. The habitat indicators were selected for pragmatic reasons, related to the availability of Province-wide remote sensing data or databases and for their potential linkages to stream habitat conditions, mainly for smaller streams. They may not be the most ideal indicators for evaluating habitat effects on Chinook salmon productivity because most Chinook salmon populations spawn and rear in relatively large rivers and our understanding of the linkages between conditions in large rivers and land-use activities is poor compared to small headwater streams.

5.2.2 Trends in Environmental Conditions

In addition to the habitat-based analyses summarized above, an analysis of trends in key available environmental variables was summarized at the workshop. These variables were air and water temperatures, and river discharge data. Date coverage is not complete for all CUs (nor all rivers within a CU), so a CU-level comparison of trends was not possible.

It was noted that flow and water temperatures are impacted by flow regulation installations at many sites, particularly on Vancouver Island. Those rivers also have major hatcheries, which create difficulties for any analyses of how environmental conditions may affect the productivity of wild fish abundance and productivity.

Data analyses were organized seasonally and spatially, but few consistent trends occurred in environmental variables over the past 15 years (3 generations). An exception was an increase in mid-summer air temperatures in some regions, and an increase in the incidence of stressful high (>18° C) river water temperatures. These could have an effect on survival during upstream migration, survival after exposure to in-river fishing gear, and reproductive success. High temperature may also have adverse effects on rearing juveniles of stream-type populations (Brett et al. 1982).

It was concluded there was no obvious freshwater environmental driver that could explain recent trends in Chinook salmon abundance.

5.3 Has Freshwater Habitat Likely Been a Factor Responsible for Recent Trends in Abundance of Southern BC Chinook?

Chinook salmon use freshwater and estuary habitats for spawning, rearing and migration and there is little doubt that changes in those habitats will affect the productivity of the populations that use them. In the SBC region, hydroelectric development has probably had the largest impact on freshwater habitats, followed by water withdrawals in arid regions. However, many of the changes associated with these activities occurred more than 50 years ago and do not necessarily explain the recent trend in Chinook abundance over the last 15 years.

Land use, forestry, urban development, and linear (roads, pipelines) developments have increased over time, but there is no readily available evidence to suggest that the variation in patterns of decline or increase observed in recent years among CUs is related to these land use activities. Freshwater habitat effects may be overwhelmed by other drivers, or obscured by a lack of appropriate data for analysis. It is possible that for many land-use activities, the effects (at the CU scale) are not large because most Chinook salmon production is from larger rivers that are probably less affected by upslope changes than small creeks. Further, standards of practice for many industries and activities that have been developed over the past 30 years may be effective in reducing some of these effects.

For the CUs in which adults migrate during the summer, threats imposed by climate change are imminent, and have the potential to parallel patterns currently observed in Fraser River sockeye salmon.

5.4 Future Needs

Tracking the role of freshwater habitat changes in the production of juvenile Chinook salmon is SBC is extremely difficult given the diversity of Chinook salmon life histories and habitat use within the SBC region. Establishing a long-term monitoring program for juvenile stages is challenging given the size of the rivers, and the diversity of habitats that a single population can use. Appropriate management of land and water use, and activities in and around water, can ensure habitats remain functional over time.

There is a direct link between river temperatures and flow conditions and the survival and reproductive success of adults migrating upstream to their natal areas (e.g., Strange 2012). In light of projections of warming temperatures in many rivers during the migration of spring and summer run Chinook salmon (Hague and Patterson 2009, Hasler et al. 2012), the monitoring of river temperature and migration and reproductive success is warranted because this can allow for in-season adjustment of fisheries in response to adverse environmental effects (e.g., Hague and Patterson 2007 for Fraser River sockeye salmon).

6 Marine Habitat

6.1 Plausibility of Proposed Mechanisms

Among Pacific salmon, Chinook salmon are characterized by their highly variable juvenile life history, large average size, high fecundity, and older ages at maturity (Healey 1991). Much of their life history occurs in the marine environment, where they are exposed to wide array of factors affecting growth and survival. While mortality occurs throughout the marine life history of salmon populations (Ricker 1976), a paradigm of salmon biology is that mortality during the first marine year is high, variable, and a substantial contributor to year-class strength (e.g., Peterman 1987; Beamish and Mahnken 2001; Pearcy and McKinnel 2007; Farley et al. 2007). Growth of juvenile salmon during initial marine residency is rapid, and important for avoiding size-selective predation and building lipid reserves to provide energy during the first winter at sea. Recent declines in survival of Puget Sound Chinook salmon have been attributed to reduced quality of feeding and growing conditions during early marine residency (Duffy and Beauchamp 2009). The importance of the early marine period on survival of Pacific salmon is also supported by studies of spatial scales of covariation in recruits per spawner and the greater correlation of coastal ocean conditions during early sea life with marine survival than survival at other life history stages (Wertheimer et al. 2004; Mueter et al. 2005; Pyper et al. 2005; Magnusson 2001).

The expert panel that reviewed the decline of Fraser River sockeye salmon and the disastrous sockeye return in 2009 concluded that ocean conditions inside the Strait of Georgia were likely a major causal factor in the long-term declines in Fraser sockeye productivity and very likely to be a major factor in the extremely low productivity associated with the 2009 return (Peterman et al. 2010). Thomson et al. (2012) similarly attributed both the poor return of Fraser River sockeye salmon in 2009 and the very large return in 2010 to marine conditions during early marine residency of the fish in the Strait of Georgia and Queen Charlotte Sound-Hecate Strait region. The poor return of sockeye salmon in 2009 were survivors of juvenile sockeye salmon entering the Strait of Georgia in 2007. Poor survival was also observed for most Chinook salmon indicator stocks for juveniles entering the Strait of Georgia in 2007 (Beamish and Sweeting 2012), consistent with the concept that anomalous marine conditions during early marine residency affected survival of many southern BC Chinook salmon stocks. McKinnell et al. (2011) attributed low survival of juvenile Fraser sockeye in 2007 to poor conditions in Queen Charlotte Sound, and high survival in 2008 to much lower temperatures in the Gulf of Alaska, the coldest observed since the 1970s.

6.2 Key Evidence

6.2.1 Evidence for Marine Effects

As noted in the "Status and Trends" section, workshop presentations documented declines in abundance of spawners between 1995 and 2012 for many stocks of SBC Chinook salmon across CU aggregates (**Figure ST-1**). These declines have occurred regardless of substantial reductions in harvest rates and large differences between CUs in the scale of anthropogenic habitat alterations and enhancement activities. The general declines in spawner abundances across CUs suggest that mortality causing the decline occurred in habitat shared by SBC stocks.

Releases of hatchery-reared indicator stocks with CWT allow estimation of survival from release to ocean age 2. Because most southern BC indicator stocks are released at or near the ocean, these estimated survival rates provide excellent indicators of marine survival conditions. (Note, however, that some stocks, such as those originating in the middle- and upper- Fraser River, may experience substantial freshwater mortality associated with downstream migration of juveniles.) Marine survival rate anomalies based on these hatchery CWT releases show reduced survival rates in recent years for most SBC Chinook indicator stocks (**Figure MH-1**). There is some evidence that during periods of low ocean productivity, hatchery fish survive at a lower rate than wild fish (Nickelson 1986; Beamish et al. 2012). Delayed mortality factors, including stress from high density rearing environments or presence of diseases such as bacterial kidney disease, could also result in lower survival of hatchery salmon. However, limited comparisons of the relative performance of marked wild and hatchery smolts support the assumption that the hatchery marine survivals are generally representative of trends and processes affecting wild stocks (**Figure MH-3**; Magnusson 2001).

In some cases, the decline in marine survivals extends prior to 1995 (**Figure MH-1**). Where data are available, marine survival were observed to be much higher prior to 1985 (e.g., Big Qualicum, **Figure MH-2**). But, not all SBC Chinook salmon stocks have shown a pattern of general decline in marine survival (**Figures MH-1, ST-3**). Chinook salmon and other salmon stocks with early or late entry timing into the Strait of Georgia have fared better than those with the more common May/June timing, suggesting temporal differences in early marine conditions can have strong effects on early marine survival. For example, pink and chum salmon in southern British Columbia, with early entry timing, and Harrison River sockeye salmon and North Thompson (Fraser) River Chinook salmon, with late entry timing, have been at high abundance during the recent period of generally poor Chinook salmon returns (Beamish et al. 2010). Harrison River Chinook salmon, which migrate directly to the estuary as fry, have shown no clear trend in survival but have exhibited high variability throughout the time series (**Figures MH-1, ST-3**). These differences relative to entry timing again support the local effects hypothesis, and also emphasize the importance of life-history diversity in the success of salmon meta-populations.

Both local and broad-scale effects were shown to influence marine survival in marine habitats. Local effects were indicated by higher correlation of marine survivals for Chinook salmon stocks with closer ocean entry points (**Figure MH-4**). Geographic concordance of survival has been shown for Chinook salmon stocks from California to southeast Alaska (Sharma et al. 2013), and for other species along the eastern Pacific Rim (Mueter et al. 2005; Pyper et al. 2005), supporting the hypothesis of local marine conditions as a primary driver of marine survival.

In addition to evidence for the effects of local marine conditions, analyses supporting broad-scale effects influencing Chinook salmon marine survival and productivity were presented. The "Status and Trends" section of this report analyzes the correlation of CWT marine survival data and time-varying Ricker a values for Chinook salmon from Oregon to Alaska, showing that southern British Columbia stocks exhibit patterns that are shared to some extent across a large geographic range (**Figures ST-10, ST-14**). Dynamic factor analysis of productivity indexes and residuals from the spawner-to-recruit relationships for Chinook salmon stocks from Oregon to Alaska indicated shared trends across this broad spatial scale (**Figures ST-11, ST-15**). Consistent with these analyses are the recent declines in Chinook salmon productivity and marine survival indexes observed northward beyond BC to Alaska stocks from SEAK to the Yukon (ADFG 2013), indicative of a broad scale effect. Sharma et al. (2013) also found marine survivals of Chinook salmon from Oregon to Alaska to be linked to regional and ocean-basin scale environmental indexes, as well as more local conditions.

Annual deviations in marine survival of SBC stocks from the broadly shared trend described above indicates that there are other key factors affecting productivity that are not shared across a wider group of stocks, again suggesting that local processes causing variation in productivity are also prominent. The differential response of SBC stocks with anomalous marine entry timing discussed above may contribute to the differences in time trends in productivity among individual stocks.

6.2.2 Mechanisms for Marine Survival Effects

Chinook salmon from SBC encounter a wide variety of marine conditions in the nearshore environment near their ocean entry point, along their coastal migration pathways, and during their protracted ocean residency. These varying conditions can affect both bottom-up and top-down processes, influencing predation rates, growth, and survival for salmon. Sea-surface temperatures during the first summer at sea have been shown to be significantly related to marine survival for a number of Chinook salmon stocks (Magnusson 2001; Sharma et al. 2013). Climate indices show cyclic variation over time and influence conditions in salmon marine habitats (**Figure MH-5**). The North Pacific Gyre Oscillation (NPGO) shown in **Figure MH-5** has exhibited a pattern since 1995 similar to the widely shared trend in marine survival derived from dynamic factor analysis (**Figure ST-11**); the correlation coefficient (r) between the two time series is 0.78. Large spatial-scale concordance of survival and productivity of Chinook salmon could be caused by atmospheric and oceanographic conditions influencing local marine environments similarly during early marine residency, or could be indicative of mortality occurring later in the marine residency of the co-varying stocks.

Physical and biological oceanographic conditions can vary greatly at regional and local scales (**Figure MH-6**). As articulated by Dave Mackas during Workshop discussions, the physical conditions driving primary and secondary productivity are very different between the Strait of Georgia and the outer coast of Vancouver Island. Such differences result in differences in primary and secondary production in terms of quantity of the production, prey types, and timing. Synchrony of entry timing, distribution, and migration of juvenile Chinook salmon with phytoplankton blooms and secondary production peaks may be critical for growth and survival (**Figure MH-7**). Prey type and quantity are also important factors affecting growth and thus survival during initial marine residency of Chinook salmon (**Figure MH-8**; Duffy and Beauchamp 2011).

Top-down predation processes may be major factor in salmon survival under certain conditions. Distribution of predators of juvenile salmon such as hake and mackerel in the 1980s and Humboldt squid in 2005 have been associated with poor returns of certain stocks of SBC Chinook salmon. Spiny dogfish and river lamprey have been identified as significant predators on juvenile salmon during their early residency in the Strait of Georgia (Beamish and Neville 2001). Marine mammal predation has also been identified as a potential contributor to the recent decline of Chinook salmon. Populations of sea lions, harbor seals, white-sided dolphins, and humpback whales have dramatically increased since the 1970s. Northern resident killer whales have also increased substantially over the last two decades, though southern resident killer whales have remained mostly stable (Hilborn et al. 2012). In their review of the decline of Fraser sockeye salmon, Peterman et al. (2010) concluded that marine mammal predation was very unlikely a cause for the poor 2009 returns, but was a possible contributor to the long-term decline. They identified resident killer whales as having the potential to affect trends in abundance of Chinook salmon, because of their dietary preference for Chinook salmon. Information presented at the workshop identified South Thompson Chinook to be the dominant stock in the southern resident killer whale diet, yet this stock has been on an increasing trajectory through most of the recent decade in spite of this predation. However, Hanson et al. (2010) found that other middle- and upper-Fraser River stocks of Chinook salmon are the dominant killer whale prey at certain times of the years; some of these stocks have been declining. Some conservation units of Chinook salmon may be more vulnerable to opportunistic predation by marine mammals because of marine mammal distribution. For example, harbor seals are more abundant in the Strait of Georgia (**Figure MH-9**), where they predate both on outmigrant smolts and returning adult salmon in river systems such as the Puntledge and Courtney Rivers (Yurk and Trites 2000; Brown et al. 2003).

Simulation modeling indicates that commensurate with the increased abundance of marine mammals, mortality rates of Chinook salmon from marine mammal predation increased in 1990 to a relatively stable but higher level than occurred from 1960 through the 1980s (**Figure MH-10**). Exploitation rates of Chinook salmon have declined substantially from the 1970s to the present (**Figure H-13**). As a result, marine mammal predation may now be a more significant mortality factor than fishery removals for SBC Chinook salmon, while total mortality due to both marine mammal predation and fishing is considerably less in recent years than pre-1990 (**Figure MH-10**). Because total mortality from both these sources have declined substantially from approximately 1980 through 2003, it is unlikely that these factors were driving the general decline in SBC Chinook abundance since 1995. However, the higher rate of marine mammal predation in recent years may indeed affect the ocean abundance of Chinook salmon during periods of low stock productivity (Hilborn et al. 2012), and inhibit recovery of depressed stocks.

Harmful algal blooms were also considered as a possible mechanism for decreased survival of SBC Chinook salmon in the nearshore marine environment. Peterman et al. (2010) concluded that such blooms were an unlikely contributor to the decline of Fraser sockeye salmon. Similarly, no consistent association has been found between Chinook salmon marine survival and major blooms of harmful algae (**Figure MH-11**), However, some stocks (Cowichan River and Dome Creek) did have lower survival during major bloom years (**Figure MH-1**), suggesting that the location of blooms could have stock-specific effects.

Another potential factor affecting Chinook salmon survival in the marine environment considered in the Workshop was competition with juvenile pink salmon. Pink salmon in southern British Columbia and Puget Sound are abundant for the odd-year line, and are very scarce for the even-year line. Ruggerone and Goetz (2004) concluded that since 1983, competition between odd-year line juvenile pink salmon and Puget Sound Chinook salmon resulted in substantial reduction in Chinook salmon marine survival. Peterman et al. (2010) examined the pink salmon hypothesis in relation to Fraser River sockeye salmon population dynamics, and concluded that interaction between the species was a possible-to-likely contributing cause to recent declines. However, data presented at the Chinook Workshop indicated no effect of pink salmon juveniles on marine survival of SBC Chinook salmon (**Figure MH-12**). In fact, the pattern of odd-even year differences in survival in Puget Sound Chinook salmon reported by Ruggerone and Goetz (2004) has not persisted in recent years (Duffy et al. 2011), in spite of high abundance of odd-year pink salmon. Greene et al. (2005) also found no effect of pink salmon runs on return rates of wild Chinook salmon to the Skagit River, which has the largest runs of any river in Puget Sound of both Chinook and pink salmon.

Intraspecific density dependent competition between wild and hatchery Chinook salmon is another potential mechanism that may affect marine survival of SBC Chinook stocks. There was little association with the scale of hatchery releases and marine survival except for east coast of Vancouver Island stocks (**Figure MH-13**). The relationships are confounded by the general decline in survival from the 1970s as hatchery programs increased their production through the 1980s. Since 1990, hatchery releases overall have been reduced by 33% (**Figure MH-14**). This reduction in releases, and evidence that hatchery Chinook salmon survive at a substantially lower rate than wild Chinook salmon during periods of low productivity (Beamish et al. 2012), make it unlikely that intraspecific competition is responsible for the recent general decline in SBC Chinook salmon.

6.3 Has Marine Habitat Likely Been a Factor Responsible for Recent Trends in Abundance of Southern BC Chinook?

The Panel concluded that conditions in the marine environment during the first year of marine residency of SBC Chinook salmon was very likely a key driver in recent trends in survival and productivity. Both local and basin-scale oceanographic conditions are affecting marine survival. There is strong evidence of direct effects of local marine conditions on the survival of Chinook salmon, especially in the Strait of Georgia. Differences in marine survival in relation to migration timing demonstrate the adaptive value of the wide diversity in life-history strategies of SBC Chinook salmon. It is not clear whether the large-scale effects reflect atmospheric and oceanographic conditions that similarly influence local marine conditions encountered by juvenile Chinook salmon across a wide geographic range, or whether they are the result of later mortality in shared ocean habitats. The Panel noted that small changes in overall mortality in marine environments result in large changes in realized marine survival. For example, a change from 96% to 98% total ocean mortality, a 2% increase, results in a 50% reduction in survival, from 4% to 2%. Such small changes in mortality can be difficult to detect and ascribe to specific mechanisms, although the resultant changes in overall marine survival can be readily detectable with the current CWT program.

6.4 Uncertainties, Critical Information Gaps, and Recommendations

6.4.1 Need for Long-term, Integrated Monitoring in the Strait of Georgia and the West Coast of Vancouver Island

The Panel has identified the first year of ocean residency of SBC Chinook salmon as the life history phase most likely to explain the decline in productivity and recruitment of these fish. Better understanding of the ecological processes affecting this life history phase could contribute to 1) identification of limiting factors; 2) development of strategies to mitigate or compensate for such factors; and 3) improvement of forecasting models for adaptive management of salmon fisheries and escapements. To achieve these objectives, the Panel recommends continued support and improvement of long-term, integrated oceanographic and ecological research in the Strait of Georgia and coastal WCVI. Such research includes monitoring of physical processes, comprehensive sampling for zooplankton and nekton associated with juvenile salmon, juvenile salmon size, diet, and energetic measurements, and estimates of predation on juvenile and adult salmon by various potential predators such as hake and marine mammals.

Monitoring programs also need to continue the research efforts to define residency and migration paths of different stocks of SBC Chinook salmon during their near-coastal periods. Analytical or technological innovations should be pursued to estimate relative stock-specific survival of SBC Chinook salmon during their early marine residency.

These recommendations are consistent with those of Peterman et al. (2010) for Fraser River sockeye salmon. They are also consistent with the efforts of the Pacific Salmon Foundation, Long Live the Kings, and other private and public organizations to initiate the Salish Sea Marine Survival Project, a collaborative US-Canada research program directed at identifying the primary factors affecting salmon survival in the Salish Sea (Strait of Georgia, Puget Sound, and Strait of Juan de Fuca).

Presentations at the Workshop on the marine ecology of Chinook salmon in British Columbia waters highlighted the substantial efforts that DFO has directed to this issue. Given today's budget environment, maintaining and expanding these projects is extremely challenging. The Panel emphasizes the need for such research, and the importance of coordination and cooperation across scientific disciplines and organizations to get the most useful and cost-effective results. Consistent monitoring provides a baseline for the evaluation of unusual fluctuations in salmon survival, such as the response of some SOG Chinook salmon and Fraser River Chinook salmon to marine conditions in 2007 and 2008 (Peterman et al. 2010; Thomson et al. 2012; Beamish and Sweeting 2012).

The Panel identified both local and broad-scale signals in the marine survival and productivity trends of SBC Chinook salmon. Efforts to relate near-shore environmental conditions to salmon survival and productivity necessarily entail evaluation of the linkage between the near-shore and larger-scale oceanographic and atmospheric conditions. Research in more off-shore areas is progressively more difficult and expensive due to the greater geographic scale and the increasingly complex stock composition of fish sampled. However, as seen at the Workshop, juvenile salmon surveys by DFO provide valuable information on annual variation in stock distribution, fish size and condition, and relative abundance, and should be continued.

6.4.2 Capability to Separate Freshwater and Marine Effects on Stock Recruitment and Productivity

Essential to the Panel's conclusion on the importance of marine conditions to the status of SBC Chinook salmon was the capability to track marine survival for a number of indicator stocks of Chinook salmon. This capability depends on a robust system of coded-wire tagging of hatchery smolts, and intensive sampling for tags in salmon fisheries and returns to hatcheries and spawning areas. Maintenance of the coded-wire system is crucial to monitor marine survival and annual variation that can be associated with marine environmental factors. This is in addition to the necessity of the CWT system for estimating harvest and exploitation rates of salmon stocks to effectively manage Chinook salmon fisheries under the Pacific Salmon Treaty and for local objectives.

There is a need to separate and monitor freshwater and marine effects on wild populations of SBC Chinook salmon. Pearcy and McKinnel (2007) noted that after 100 years of study, we are rarely able to even distinguish freshwater and marine mortality for populations of salmon. The information provided to the Panel on marine survival was almost all based on hatchery Chinook stocks. As noted previously, direct comparisons of wild and hatchery stocks support the assumption that the marine survival hatchery indicator stocks are representative of associated wild stocks. However, there is evidence that wild stocks can respond differently to marine conditions than hatchery fish (Nickelson 1986; Beamish et al. 2012). Model-generated survival indices for Chinook salmon populations in the PSC Coastwide Chinook Model do not consistently correlate with CWT-survival indices (CTC 2012a; **Table ST-4**). There are a number of reasons for this lack of correlation. The wild stock purportedly represented by the hatchery indicator stock could have a different marine entry timing and/or ocean distribution, resulting in a differing marine survival trends. As noted in the "Status and Trends" section of this report, there is also large uncertainty in the survival indices for PSC model stocks caused by temporally variable hatchery contributions to spawners and recruits, and the juvenile-to-age-2 cohort marine survival rate by definition only covers a part of the life history, whereas the spawner-to-recruit data series reflects reproduction and survival processes across the entire life history. The research plan developed in response to the decline of Chinook salmon populations in Alaska focuses largely on establishing wild indicator stocks representing diverse life-history types across a wide geographic range (ADFG 2013). Stock assessments would include escapement enumeration, estimates of smolt production, and estimates of fishery harvests, so that both freshwater and marine survival can be estimated and monitored. Such an approach provides data that can be used to evaluate the effect of environmental and anthropogenic factors in both marine and freshwater habitats, and also provide improved information to assist managers in controlling fisheries to define and achieve escapement objectives. This approach is consistent with Strategy 1 of Canada's Wild Salmon Policy, Standardized Monitoring of Wild Salmon Status. Candidate stocks for intensive monitoring could be selected from the suite of wild escapement indicator stocks tracked by the CTC, and build on the work done under the PSC Sentinel Stock program (CTC 2012b). Highest priority for wild-stock marking is for stocks from CUs in the Fraser River that are not now represented by a hatchery indicator stock.

6.4.3 Identification of Parameters for Improvement of Forecasting Models

Forecasting of Chinook salmon is an important component of coast-wide management. Pre-season forecasts provide managers and users insights into the potential scope of harvests and management constraints to meet escapement goals. In the context of management of Chinook salmon under the Pacific Salmon Treaty, pre-season forecasts of salmon abundance are used to establish annual catch limits for abundance-based managed (AABM) fisheries from southeast Alaska to the west coast of Vancouver Island (CTC 2012b). While pre-season forecasts are used to set harvest levels in a given year, the agreed-upon allowable catch is actually calculated from post-season data. In recent years, there have been substantial under-harvests and over-harvests of Chinook salmon in AABM fisheries, due primarily to forecast error resulting in differences between preseason and postseason estimates of abundance (CTC 2012a). Many of the stock-specific forecasts underlying the aggregate fishery abundance estimates are based on either simple running averages of prior year returns or sibling regression, where estimates of earlier-maturing siblings in a cohort are used to predict older age-classes. Such forecasting models for salmon typically explain only a small percentage of the annual variation in actual returns (Haeseker et al. 2008). Improved understanding of factors in the marine environment affecting salmon survival may provide opportunities to improve standard forecast models (Greene et al. 2005; Sharma et al. 2013; R. Carmichael, Oregon Department Fish and Wildlife, unpublished data). Monitoring may also identify direct indicators of year class strength that can be used to directly forecast survival or year-class strength of salmon (Peterson et al. 2010; Wertheimer et al. 2012).

6.4.4 Life Table for Chinook Salmon during Ocean Residency

Salmon are vulnerable to natural mortality processes throughout their lives. Both the magnitude and variability of mortality at various ages or life-stages contribute to the survival of a cohort. Instantaneous and annual mortality rates in the marine environment are generally assumed to be much higher for smaller, younger fish, and much lower for older age classes (e.g., Parker 1968; Ricker 1976; Wertheimer and Thrower 2007). Although mortality rates may be highest during initial marine residency, variation in survival later in the first year of marine life may also substantially affect age-class strength (Beamish and Mahnken 2001; Moss 2005). The lower mortality rates associated with older age classes (Ricker 1976) are often assumed to have low variability; for example, the PSC Chinook model assumes stable annual natural mortality rates for older age Chinook salmon. There are examples, however, of extreme events causing high mortality variation for older age classes of Pacific salmon (Pearcy and McKinnell 2007). Increased depredation by marine mammals, one of the hypotheses considered for the decline in SBC

Chinook salmon, could result in relatively high and variable mortality at older age classes. The shared trends in survival and productivity for Chinook salmon across broad geographic range could also be indicative of mortality factors operating later in the life-history of Chinook salmon, after they have migrated beyond local near-shore areas that define survival during early residency.

Definition of mortality rates and their annual variability would give insight into the mechanisms affecting survival. Multiple-stage tagging studies have been used to estimate mortality at different life-history stages (e.g., Parker 1968; Ricker 1976). Tagging studies could be incorporated into salmon survey operations, utilizing live-box cod-end systems and tagging fish of different ages with traditional external tags at a variety of times throughout the calendar year. Stock identification of fish tagged at sea using modern genetic methods would enhance such studies. Deployment of acoustic tags has been used on a limited scale to examine residence time, migration, and potentially mortality in the Strait of Georgia. Experiments with new, smaller tags that could be used on Chinook salmon of various sizes and ages could provide information on survival bottlenecks in coastal and inshore waters. Sibling regression models may be used to examine the assumption of low variation in natural mortality for older age classes. The residuals around sibling regression models represent deviation from an average natural mortality between a given year class and the subsequent predicted older age class. Retrospective analysis of patterns of residuals for sibling regression models could provide information to determine if there is evidence of increased non-fishing mortality of older age classes of SBC Chinook salmon in recent years.

6.5 Chapter Tables and Figures

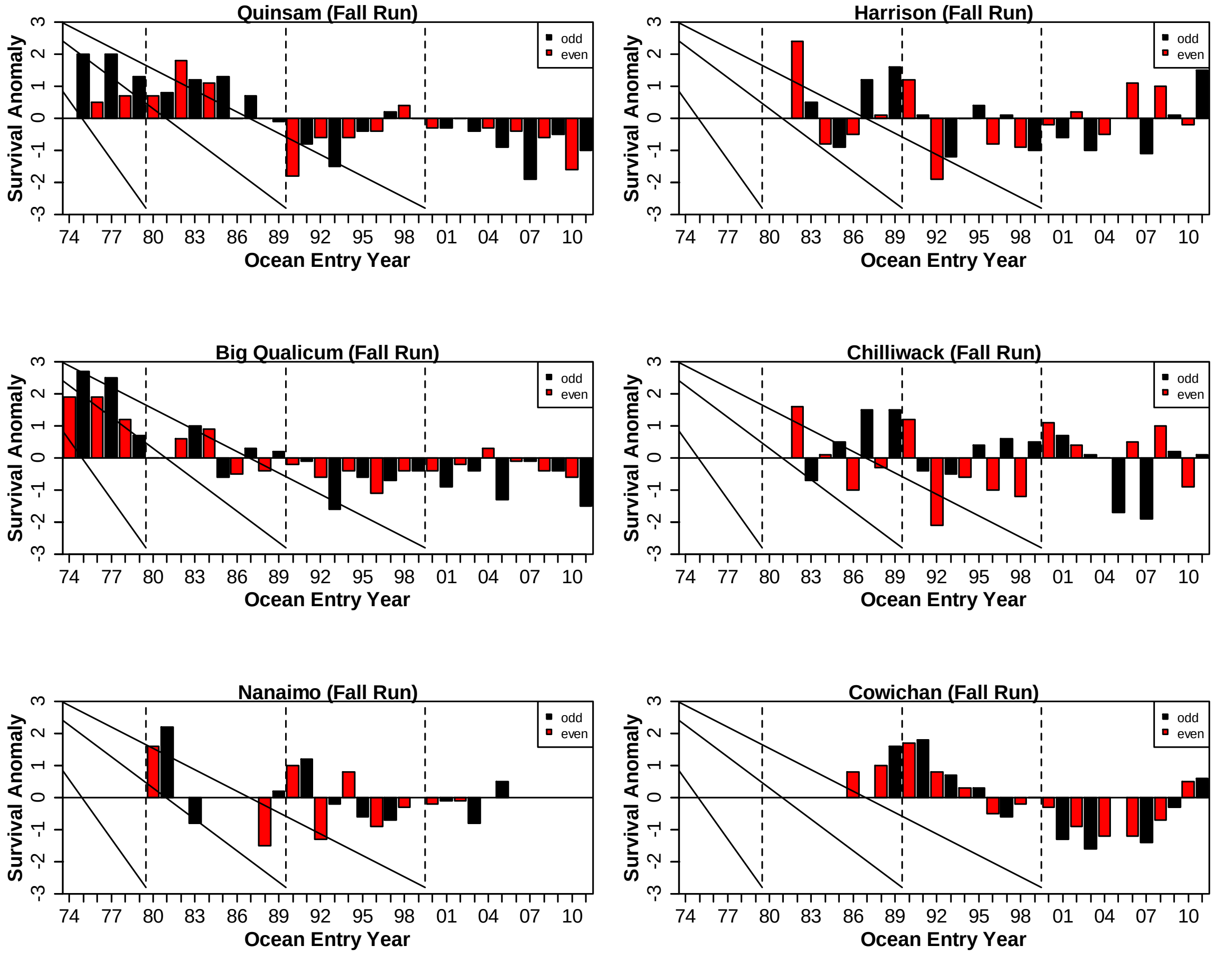


Figure MH-1a. Marine survival anomalies for hatchery indicator stocks for Strait of Georgia fall Chinook salmon populations. From Marc Trudel, DFO, presentation 1, slide 19.

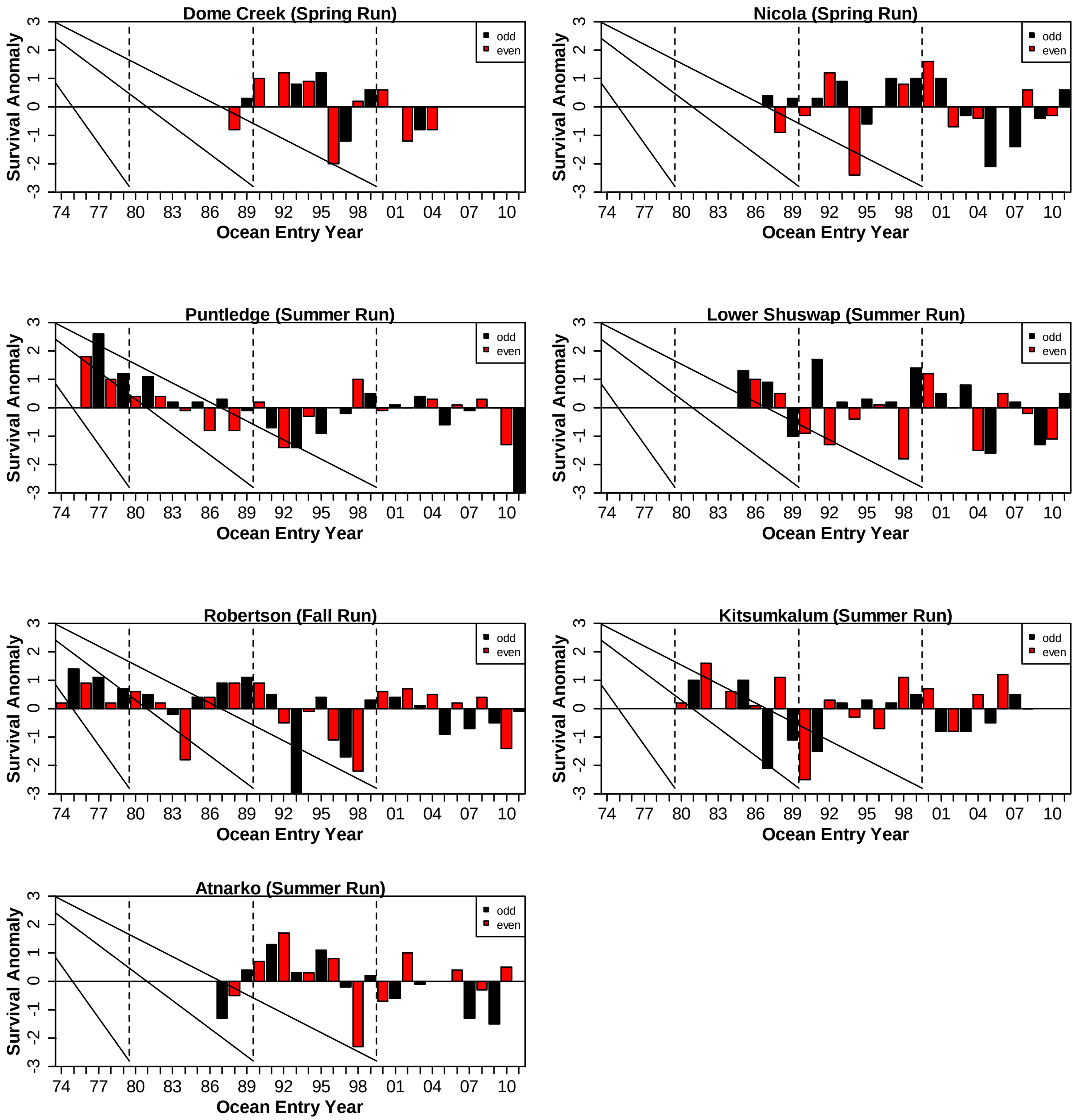


Figure MH-1b. Marine survival anomalies for hatchery indicator stocks for Strait of Georgia spring and summer Chinook salmon (upper four graphs) and outer coast Vancouver Island fall and summer Chinook salmon (lower three graphs). From Marc Trudel, DFO, presentation 1, slides 20-21.

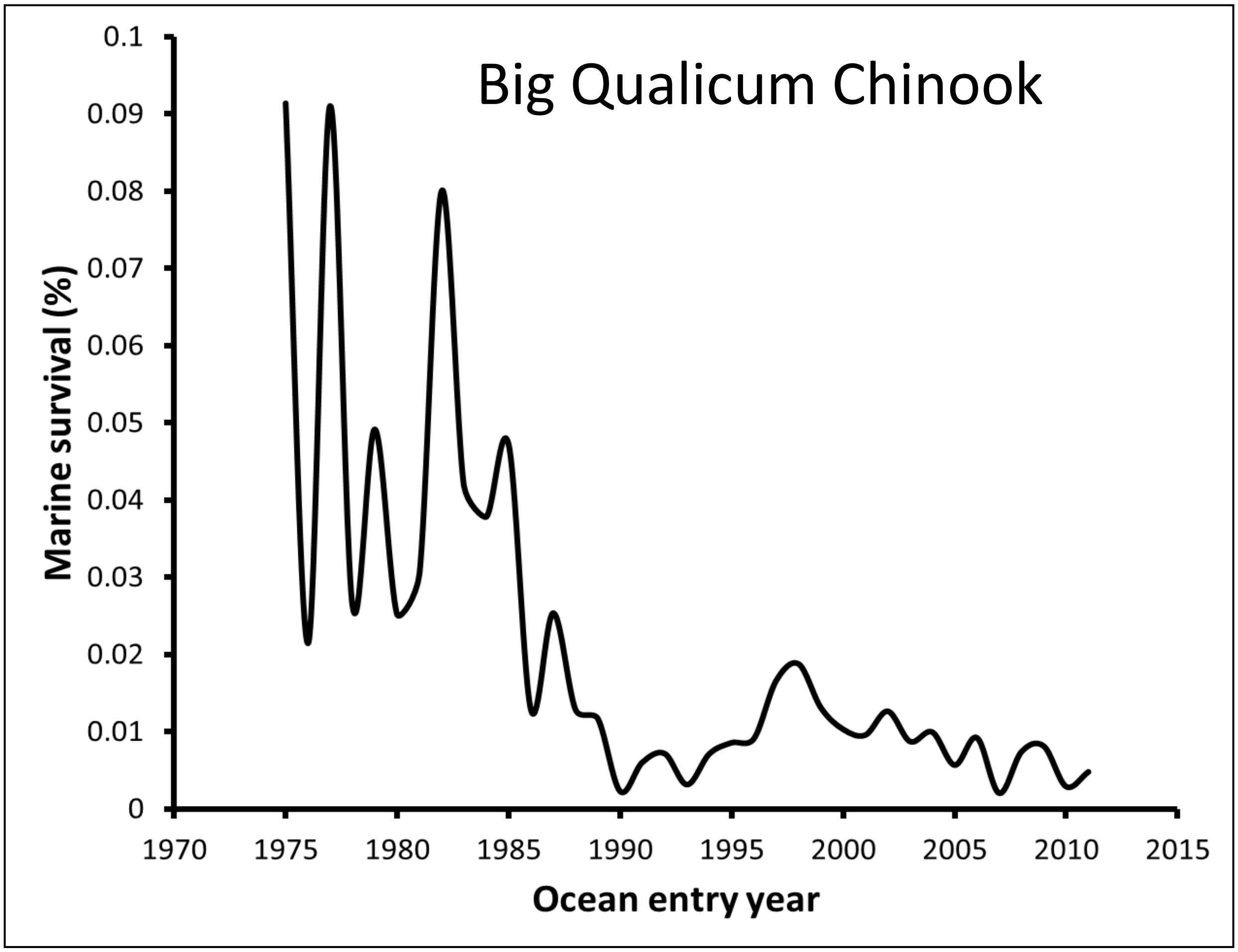


Figure MH-2. Marine survival of Big Qualicum Chinook salmon. From Marc Trudel, DFO, presentation 2, slide 10.

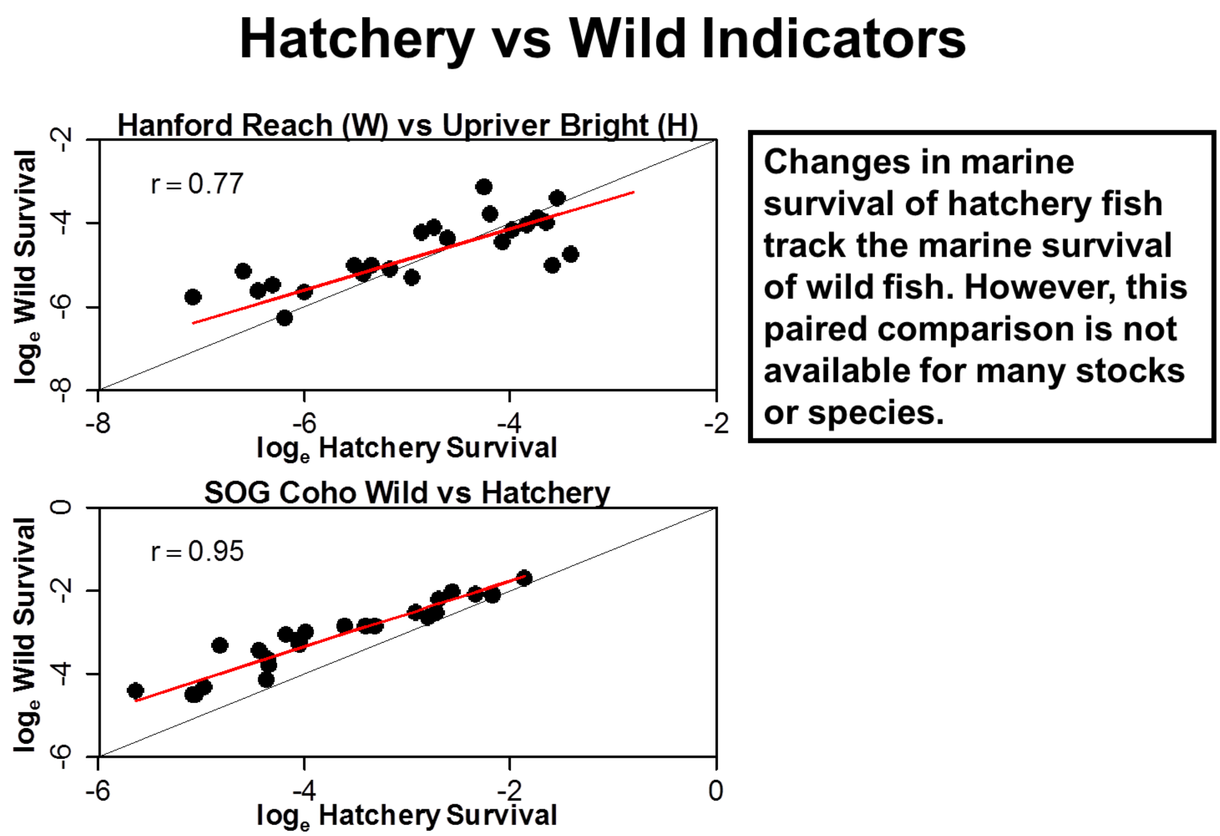


Figure MH-3. Comparisons of marine survival of hatchery and wild Chinook and coho salmon. From Marc Trudel, DFO, presentation 1, slide 14.

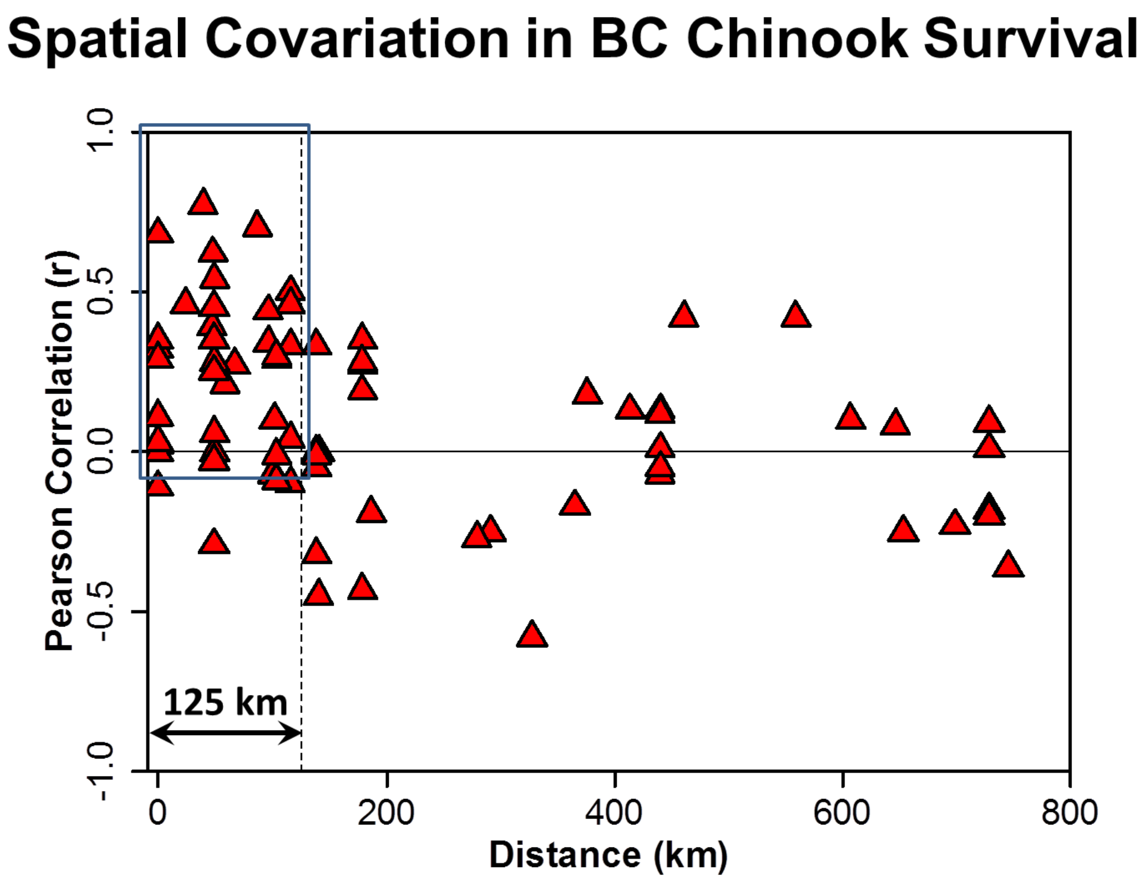


Figure MH-4. Bivariate Pearson correlation coefficients of marine survival rates and distance between marine entry points for British Columbia Chinook salmon stocks. From Marc Trudel, DFO, presentation 1, Slide 23.

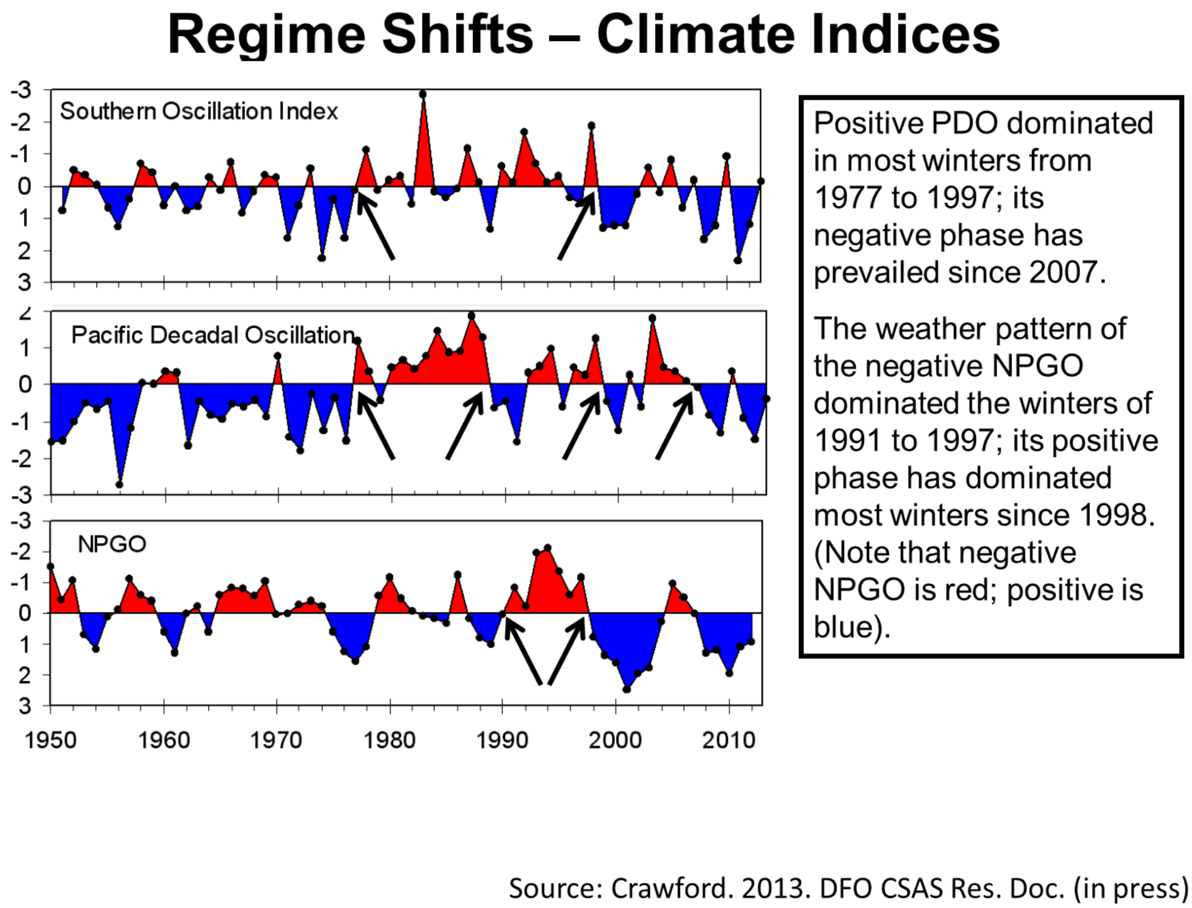
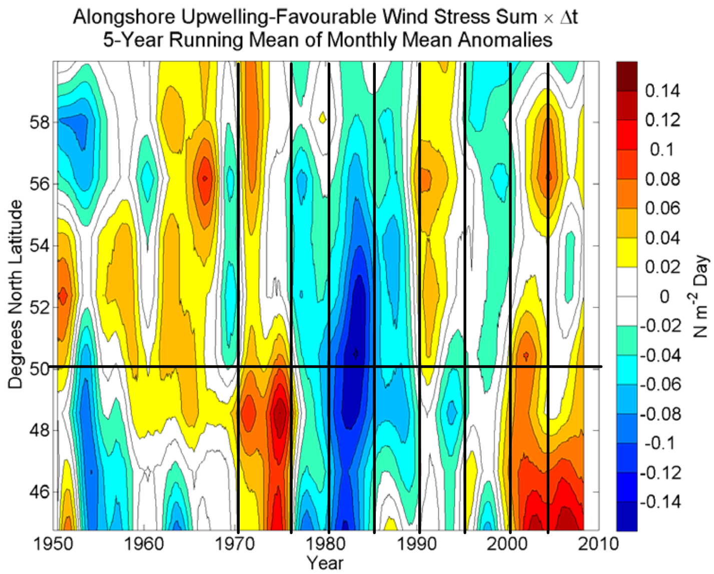


Figure MH-5. Climate indices reflecting temperature and oceanographic conditions in the North Pacific Ocean. From Marc Trudel, DFO, presentation 1, slide 55.

Regime Shifts - Upwelling

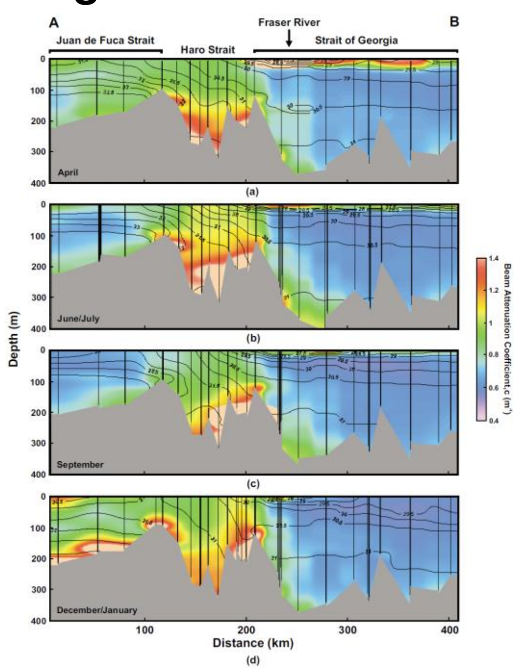


During 1970-75 and 2000-09, upwelling better in southern regions; 90-95 better in north. The opposite pattern is observed for downwelling winds.

NB only upwelling winds contributed to this anomaly time series so it is biased to April-Sept.

Source: Hourston and Thomson. 2011. DFO CSAS Doc. 2011/054.

Regional Differences in the Strait of Georgia



Haro Strait

- Strong tidal mixing
- Highly turbid waters
- Low chlorophyll-High nutrients
- Predator distribution linked to tidal cycle

Southern Strait of Georgia

- Higher particle sinking rate
- Stronger stratification

Northern Strait of Georgia

- Organic rich particle
- Weaker stratification

Sources: Johannessen et al. 2006. Atmoshere-Ocean 44: 17-27; Masson and Peña. 2009. Estuar. Coast Shelf Sci. 82: 19-28; Zamon. 2001. Fish. Ocenogr. 10: 353-366; Zamon. 2003. Mar. Ecol. Prog. Ser. 261: 243–255

Figure MH-6. Variation in the nearshore marine environment. From Marc Trudel, DFO, presentation 1, slides 56 and 59.

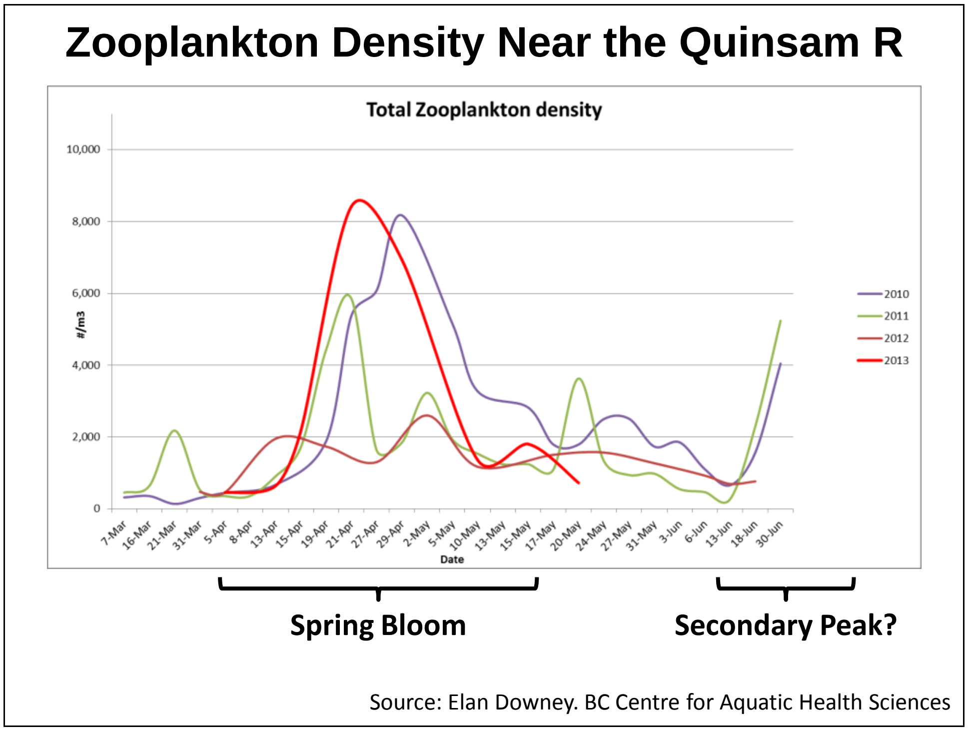


Figure MH-7. Interannual variation in timing of zooplankton densities at a Strait of Georgia sampling location. From Marc Trudel, DFO, presentation 1, slide 45.

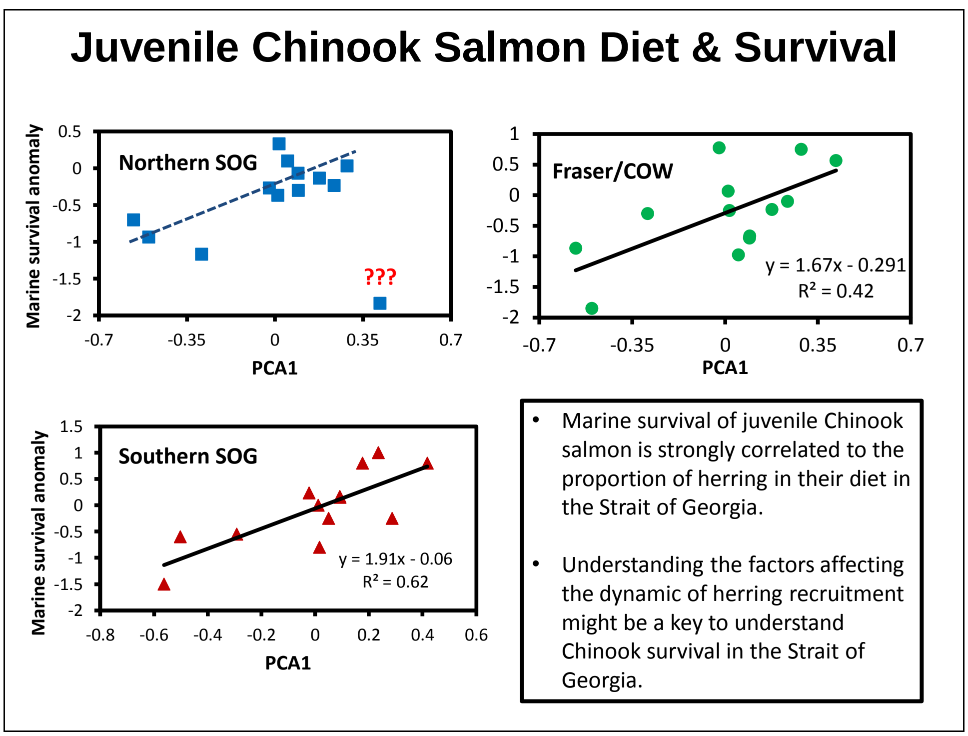


Figure MH-8. Correlations of Chinook salmon marine survival anomalies and the proportion of herring in their young-of-the year herring in their diet. From Marc Trudel, DFO, presentation 1, slide 63.

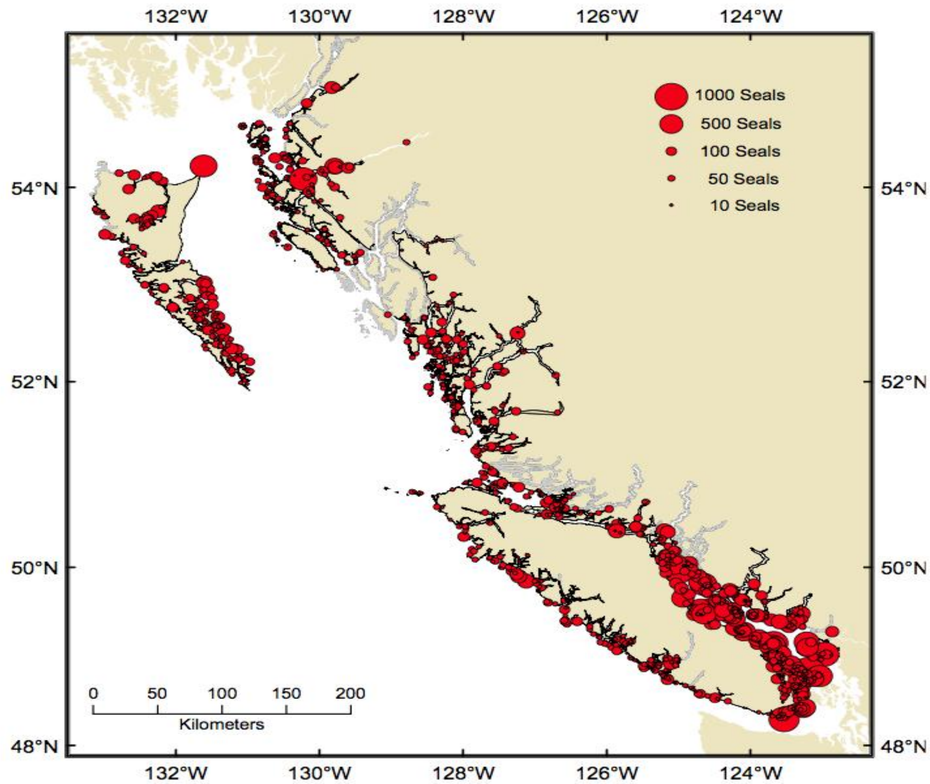
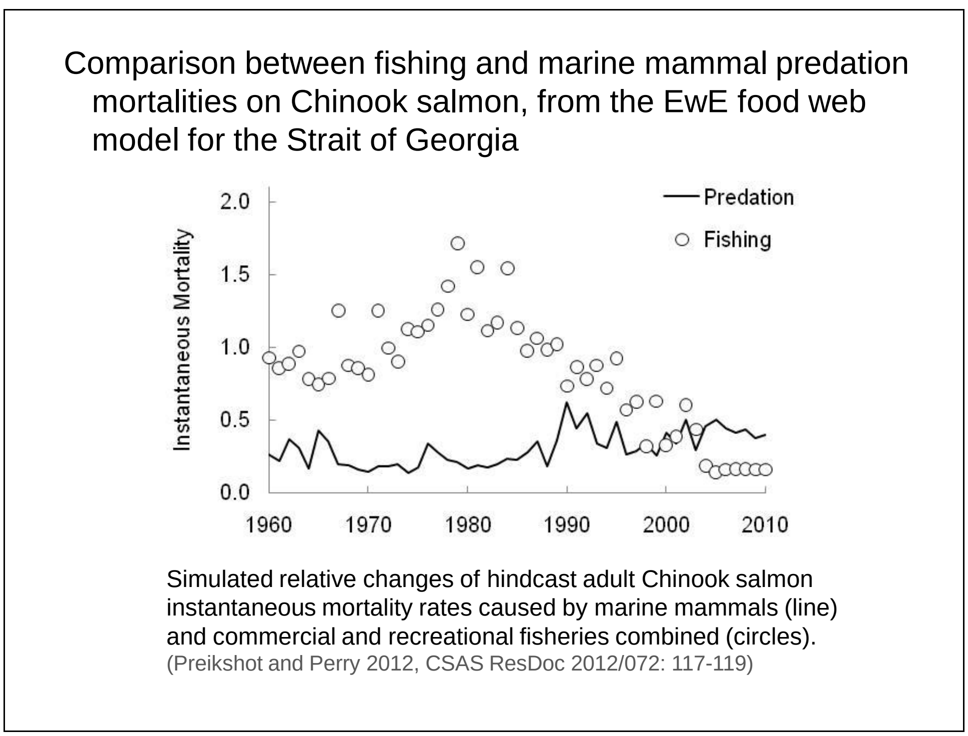


Figure MH-9. Distribution of harbor seals in British Columbia. From Marc Trudel, DFO, presentation 1, slide 77.



FigureMH-10. Eco-path model simulation of mortality of adult Chinook salmon due to marine mammal predation and fishing. From Marc Trudel, DFO, Presentation 1, slide 82.

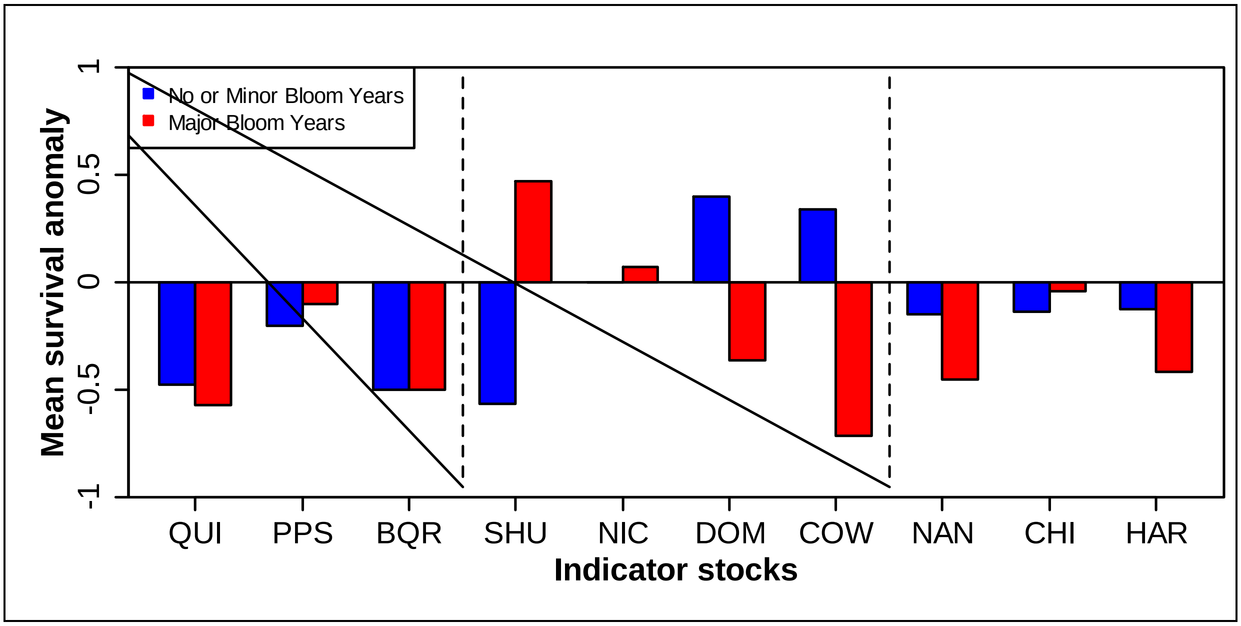


Figure MH-11. British Columbia Chinook salmon marine survival in relation to harmful algal blooms. From Marc Trudel, DFO, Presentation 1, slide 75.

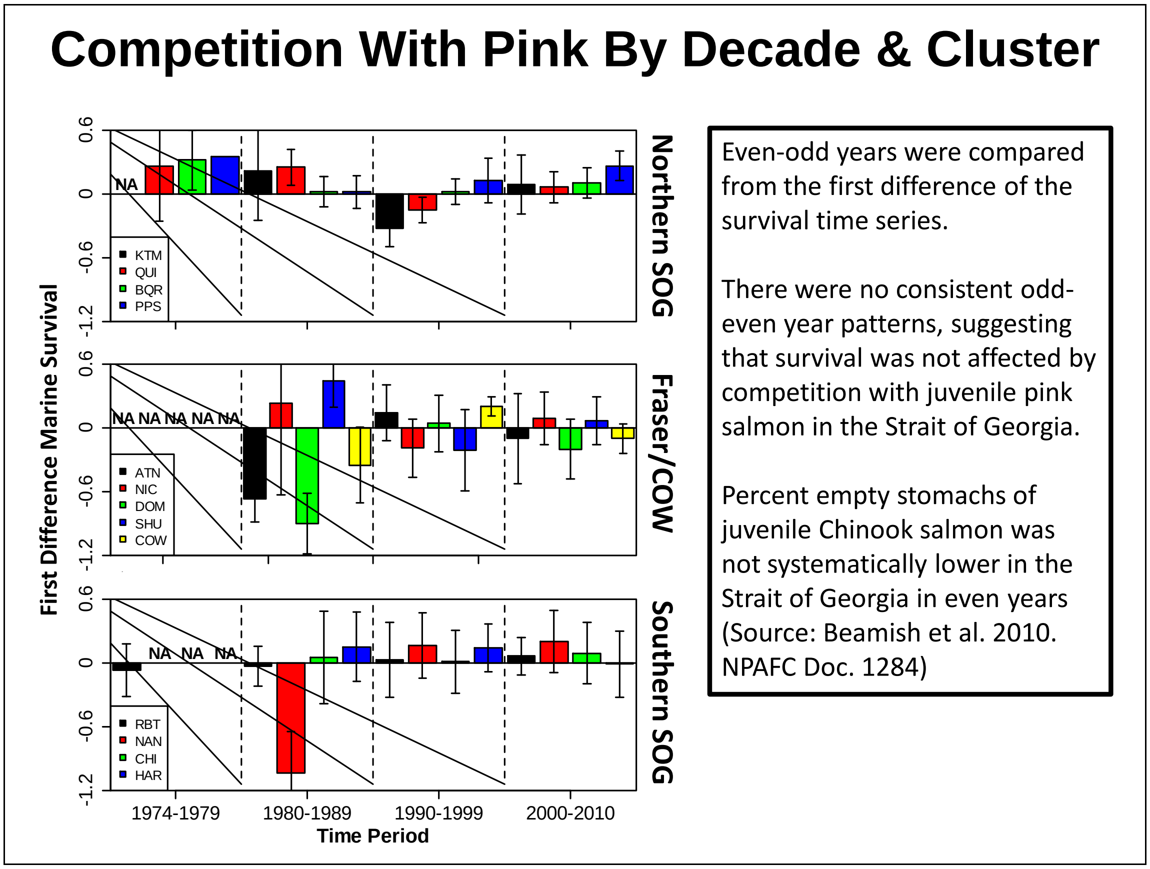


Figure MH-12. Analysis of effect of pink salmon on survival rates of British Columbia Chinook salmon. From Marc Trudel, DFO, presentation 1, slide 73.

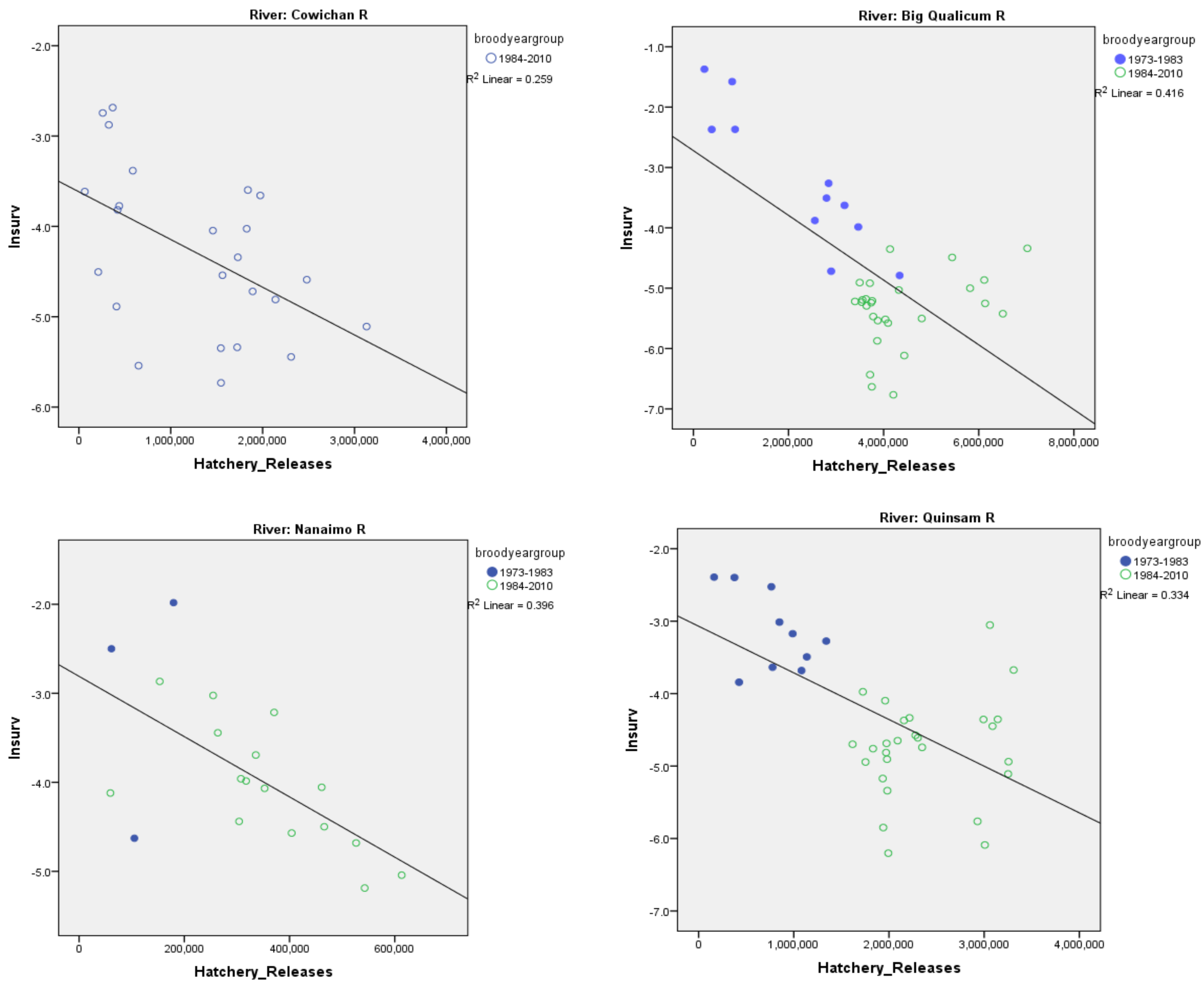


Figure MH-13. Marine survival of east coast Vancouver Island Chinook salmon stocks in relation to the number of hatchery fish released. From David Willis, DFO, presentation, slide 26.

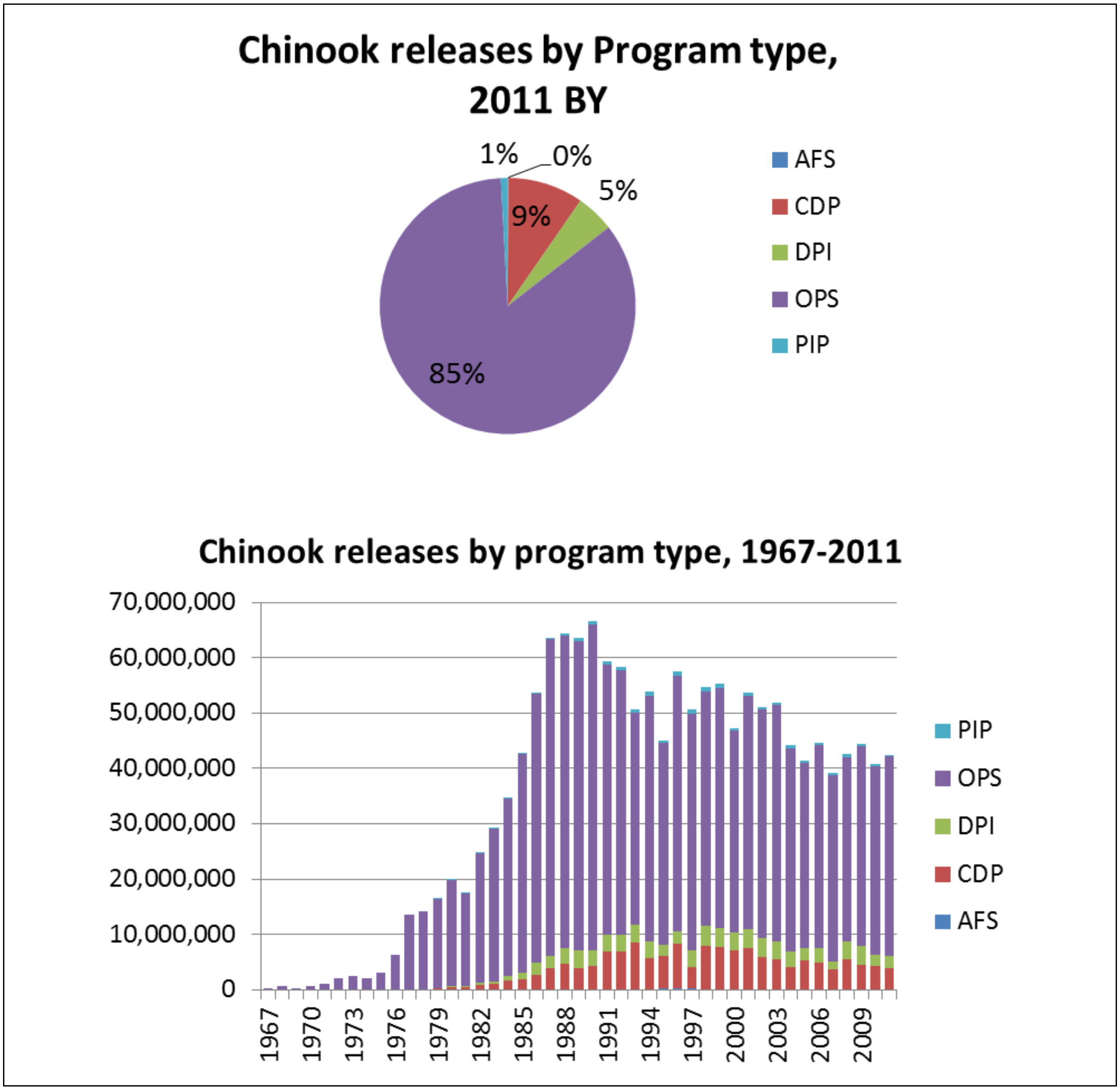


Figure MH-14. Chinook salmon smolt releases in British Columbia, 1967-2011. AFS: Aboriginal Fisheries Strategy (non-SEP). CDP: Contract hatchery, primarily operated by local First Nations. DPI: Designated Public Involvement (Larger volunteer hatcheries). OPS: DFO operated facilities. PIP: Public Involvement Program (volunteers). From David Willis, DFO, presentation, slide 5.

7 HATCHERIES

7.1 INTRODUCTION

This section provides a review of the Southern BC Chinook salmon hatchery programs with primary focus on hatchery risks to natural populations and hatchery impacts as a potential contributor to declines in the status of SBC Chinook salmon populations. We first characterize the types of hatchery programs and their associated potential benefits and risks based on their primary management objectives. We then present a framework for assessing hatchery performance and risks based on the multiple frameworks that have been utilized elsewhere for comprehensive hatchery reviews. Finally, we use the framework to evaluate hatchery programs for Southern BC Chinook based on information presented at the workshop and subsequently provided on hatcheries, genetics, straying and stock status and trends. The panel was not provided with adequate information to allow a comprehensive assessment of the degree to which hatchery programs could have contributed to the apparent widespread decline in abundance of southern BC Chinook salmon stocks. Considerable information gaps along with limited data quantifying potential effects of enhancement on natural populations made it challenging to conduct our assessment.

Nevertheless, the Panel noted causes for concern in specific CUs and that certain outcomes and risks of the SEP appear to be incompatible with Canada's Wild Salmon Policy (WSP). The WSP Goal is to:

- *"Restore and maintain healthy and diverse salmon populations and their habitats for the benefits and enjoyment of the people of Canada in perpetuity."*
- *"This goal will be advanced by safeguarding the genetic diversity of wild salmon populations, maintaining habitat and ecosystem integrity, and managing fisheries for sustainable benefits."*
- *"Conservation of wild salmon and their habitat is the highest priority for resource management decision making."*

Although the WSP focuses on wild salmon population protection and conservation, it does identify the use of hatchery enhancement for the purposes of rebuilding depressed CUs and meeting other management objectives through adoption of integrated and strategic fishery and production plans.

The WSP defines "wild fish' in the following manner:

- *"Salmon are considered "wild" if they have spent their entire life cycle in the wild and originate from parents that were also produced by natural spawning and continuously lived in the wild."*

This definition is somewhat inconsistent with and more conservative than the more typical usage of the term "natural origin" to describe "fish that were spawned and reared in the wild regardless of parental origin' (see **Figure Hat-1**). It is apparent, however, that the WSP definition of wild salmon as originating from the "second generation" of natural production was quite deliberate:

- *"The requirement in the definition that a wild salmon must complete more than one full generation in the wild safeguards against potential adverse effects resulting from artificial culture."*

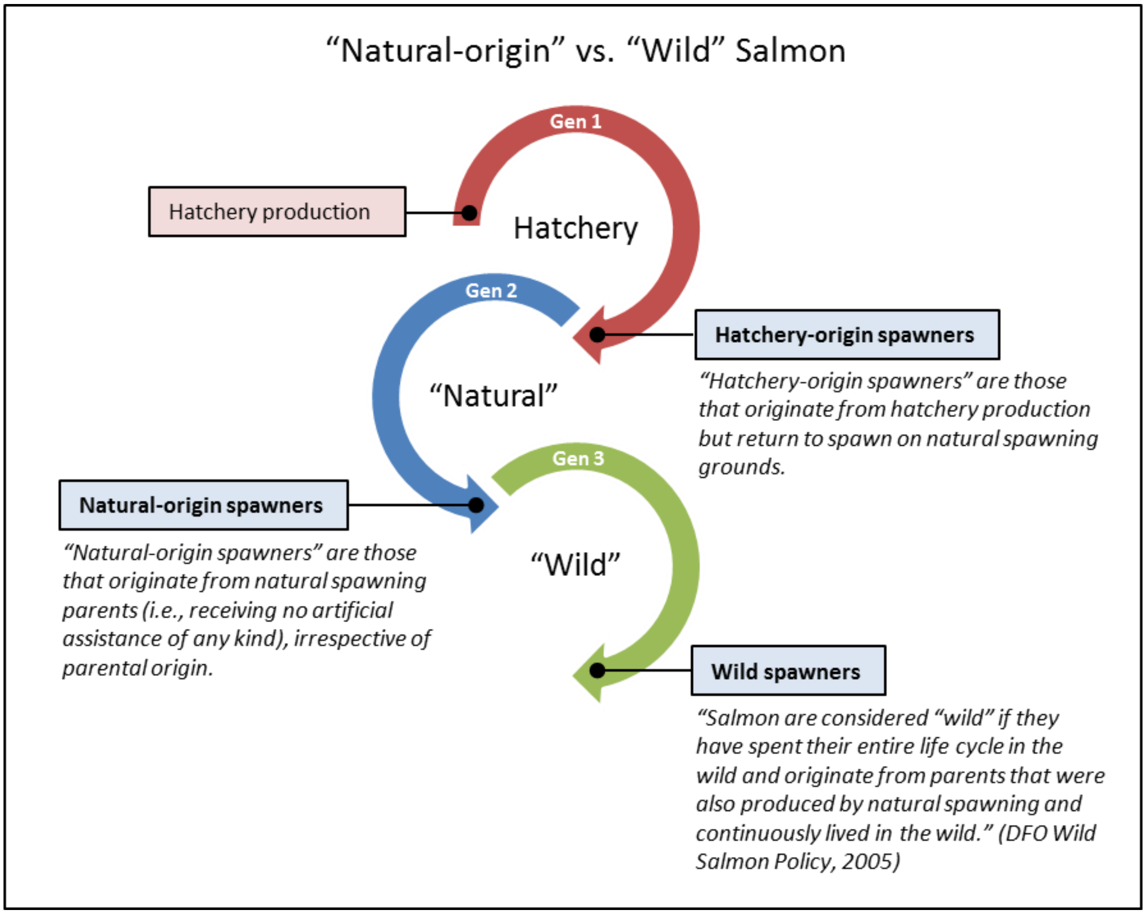


Figure Hat-1. Conceptual illustration of "wild" spawning salmon, as per the definition in Canada's Wild Salmon Policy (DFO, 2005), compared with natural-origin spawners and hatchery-origin spawners.

While the need to safeguard wild salmon populations is laudable and essential, the WSP definition of wild salmon raises three very serious issues. First, this definition is difficult to apply from a practical monitoring and evaluation perspective as it would seem to require either (a) parental-offspring DNA pedigree analyses to allow quantitative estimation of the percentage of wild salmon in a spawning population, or (b) assumption-based calculations concerning probabilities of matings among fish with differential parental origins. Second, the definition is at odds with usage elsewhere in the Pacific Northwest. Therefore, it is not necessarily a straightforward task to apply the current developing paradigms for evaluation of hatchery programs (e.g., HSRG 2004, CA HSRG 2012) to the BC Salmon Enhancement Program (SEP). Third, the definition raises very serious issues concerning the compatibility and coordination of certain aspects of DFO's enhancement programs with the objectives of the WSP. The unusual definition of "wild salmon" that has been adopted in the WSP complicates our assessment of the degree to which hatcheries have been an important "stressor" on SBC "wild" Chinook populations. A rigorous assessment of the effects on wild salmon would require distinguishing between three groups of fish: natural production originating from spawning of hatchery-origin fish, natural production originating from natural-origin (but not wild) fish, and wild production originating strictly from wild fish as defined under the WSP. The data required for such distinctions is far beyond what is currently available in BC, and indeed beyond the comparatively rich information base available in other areas of the Pacific Northwest.

Panel understanding of WSP definition and intent:

The Panel was made aware that the WSP definition of wild salmon was adopted from use in the North Atlantic Salmon Conservation Organization (NASCO, The Williamsburg Resolution, June 2003) and applied by ICES (International Council for the Exploration of the Sea). The intention under the WSP was similar to other agency policies that focus on protection and recovery of natural-origin salmon, and the maintenance of genetic fitness in wild salmon populations.

Below we summarize basic tenets of the current paradigms for evaluation of hatchery programs in the Pacific Northwest. This paradigm has been built around the above definition of "natural origin" rather than the WSP definition of wild salmon and has been designed to prevent hatchery programs from generating unacceptable reductions in the fitness of fish reproducing naturally in the wild, whether they are of natural or hatchery origin. In our conclusions we address the special issues that are raised by the WSP definition of wild salmon.

7.1.1 Types of Hatcheries and Roles in Salmon Management

Hatcheries have played an important and diverse role in management of Pacific salmon across the Pacific Northwest and Canada for many decades. In the Pacific Northwest, hatcheries were often built to mitigate for habitat degradation or loss due to anthropogenic activities (hydropower dams, water withdrawals, logging, etc.). The dominant role of hatcheries in British Columbia has been to restore and enhance commercial, recreational and First Nations fisheries. Due to declines in the status of natural populations there has been increased recent emphasis on using hatcheries for conservation and to enhance natural production. It is important to characterize specific management objectives for various hatchery program types because the desired benefits and associated risks can vary depending on the hatchery program type. ***In general***, hatchery programs can be categorized into four types based on their primary objectives, although some hatchery programs address multiple management objectives.

The four hatchery types are:

Harvest Augmentation: The use of artificial propagation to restore, enhance or sustain commercial, recreational or First Nations fisheries. The objective is to maximize harvest while minimizing the numbers of hatchery fish that spawn in nature so as to limit impacts to natural populations.

Supplementation: "The use of artificial propagation to maintain or increase natural production while maintaining long-term fitness of the target population, and keeping the ecological and genetic impacts on non-target populations within acceptable limits" (RASP 1992).

Genetic Conservation: The use of artificial propagation to prevent extinction and conserve important genetic resources for future use in restoration (typically captive broodstock programs).

Wild Stock Indicator: Hatchery produced fish used to provide surrogate information for wild fish for the purpose of assessing some aspect of performance (exploitation, catch distribution, etc.) of a wild population. This type of program is a somewhat unique and has similar benefits and risks as harvest augmentation hatcheries.

The management objectives and definitions for the Canadian Chinook hatcheries were provided following the workshop. We aligned the DFO hatchery categories with the general categories described above to allow for assessment of benefits and risks. The DFO categories are:

Harvest – enhancement for fisheries that are reliant on enhanced production, and that would disappear or become severely constrained in the absence of enhancement. This includes harvest opportunities for First Nations, recreational, or commercial fisheries. When the objective is to provide a targeted-fishery opportunity, production targets may be set to consider both natural spawning and harvest requirements. = **Harvest Augmentation**

Genetic Conservation – enhancement of a stock highly at risk of extirpation or extinction, or a vulnerable stock that has been identified as a regional priority (e.g. populations which have an approved conservation/recovery strategy). This includes re-establishing locally extinct populations and rebuilding populations at high risk of extirpation. = **Supplementation**

Rebuilding – enhancement of a stock that is below apparent carrying capacity. This includes rebuilding depleted populations and mitigating for habitat loss. = **Supplementation**

Assessment – fish produced for marking where stock assessment information contributes to Pacific region assessment priorities, such as the Pacific Salmon Treaty. The information may also contribute to assessment as defined under the regional stock assessment framework, Area stock assessment priorities and regional SEP assessment priorities i.e. those produced for program performance measurement. Fish produced for assessment generally address other objectives as well but, in a few instances, fish are produced solely for marking and assessment. = **Wild Stock Indicator**

Stewardship and Education - small numbers of fish produced to provide a stewardship or educational opportunity. Production for these purposes is assessed based on contribution to stewardship and educational goals and not on production levels or contribution to harvest or escapement. = **Educational** (not defined in general categories used in the Pacific Northwest)

7.1.2 *Framework for Assessment of Benefits and Risks of Hatcheries on Natural Production*

It is complex to evaluate the benefits and risks of hatchery programs, their success in achieving management objectives, and their effects on the viability of natural populations. Dealing with this complexity requires a structured framework with clear and specific scientific questions and performance metrics. There are numerous pathways through which hatchery programs can affect natural population abundance, productivity, genetic characteristics, life history diversity, and spatial structure within and outside target populations. We describe some of these pathways here.

Hatchery operations can have direct effects on abundance and productivity in target populations through removal of natural-origin adults for broodstock, increased pre-spawning mortality of adults handled and released to spawn naturally and delays in upstream adult migration resulting from weir encounters. Weirs and other collection facilities can alter spawning distribution of natural fish (RIST 2010).

The most significant potential impacts are associated with genetic effects that result from genetic introgression of hatchery and natural fish in the natural environment, as well as the effects of ecological interactions that can occur at multiple life stages. Numerous studies have shown that harvest augmentation programs using segregated broodstocks or non-local stock transfers have negative impacts on natural population productivity and abundance when hatchery fish spawn naturally with natural-origin fish (Chilcote 2003, Nickelson 2003, Hoekstra et al. 2007). Genetic introgression can result in alteration of locally adapted gene complexes in natural populations thus reducing the level of fitness by disrupting evolved compatibility between important fish life history traits and local environmental characteristics.

Studies have shown that supplementation hatchery programs using local integrated broodstocks can provide a significant demographic boost in total spawner abundance with the addition of hatchery fish to the natural spawners (Waples et al. 2007, Carmichael et al. 2011). However, there are no studies that have shown long-term sustainable increases in natural-origin abundance resulting from hatchery supplementation, although such studies are limited. Moreover, there is strong evidence that productivity can be reduced in natural populations that are supplemented with hatchery fish. In a before-after-control design study, Carmichael et al. (2011) found that adult spawner-to-spawner productivity of the Imnaha River Spring/Summer Chinook salmon population was reduced by 40% as a result of long-term hatchery supplementation.

The genetic mechanisms by which natural productivity is influenced by hatchery supplementation programs using local broodstock are also complex and not well understood. The genetic similarity and the rates of gene flow between fish produced in the hatchery and the natural environment influence the level of change in fitness that occurs in both natural and hatchery-origin fish over time (Ford 2002).

Most studies have shown that the relative reproductive success (RRS) in nature of hatchery fish is lower than that of their natural counterparts within 1-2 generations (Kostow et al. 2003, Berijikian and Ford 2004, Araki et al. 2008, Berntson et al. 2011, Ford et al. 2012). In some cases the reduction is severe with hatchery fish RRS less than 0.5 (i.e., half the reproductive success of natural origin fish). The causal mechanisms are somewhat unclear resulting in considerable uncertainty about the magnitude of effect on reduced performance from genetically based factors due to domestication effects or other factors like spawning distribution and redd site selection differences. Natural-spawning hatchery fish from non-local hatchery broodstocks appear to have lower RRS than do hatchery fish from local broodstocks.

Rates of gene flow between fish produced in the natural and the hatchery environments likely influence the degree of fitness change that occurs in each environment (Ford 2002). The proportion of natural-origin broodstock (pNOB) and the proportion of hatchery- origin spawners in nature (pHOS) are believed to be important factors influencing the natural spawner fitness changes because they are an indication of the dominant selecting environment influencing the aggregate natural spawner population. Busack et al. (2006) developed a metric that integrates pNOB and pHOS to index the degree of influence of the hatchery environment on the mixed hatchery and natural-origin spawners:

$$Proportionate\ Natural\ Influence\ (PNI) = \frac{pNOB}{pHOS\ + pNOB}$$

This metric is widely used in monitoring and evaluation of supplementation programs throughout the Columbia River basin (AHSWG 2008). The HSRG (2004) provided guidelines for PNI for various hatchery program types. A minimum PNI of 0.67 was recommended for supplementation programs using local integrated broodstocks in populations that are considered a high priority for conservation and recovery. **Table Hat-1** summarizes the HSRG (2009) criteria for different types of Chinook populations.

Table Hat-1. HSRG (2009; section 3.1) criteria for proportion of hatchery origin spawners (pHOS), natural influence (PNI), and natural origin broodstock (pNOB) in different types of Chinook populations. *Primary* populations are targeted for restoration to high productivity and abundance. *Integrated* populations are genetically integrated with natural populations. *Contributing populations* need small to medium improvements.

Type of Population	pHOS	pNI	pNOB
Primary	< 0.05		
Integrated	< 0.3	> 0.67	> 2.0 * pHOS
Contributing - natural	< 0.1	> 0.5	
Contributing - integrated	< 0.3	> 0.5	> pHOS

We developed the Panel's assessment framework from others that have been described and applied in the Columbia River Basin (Hesse et al. 2006; Carmichael et al. 2005 in Marmorek et al. (eds.) 2005; AHSWG 2008; Carmichael et al. 2011.) We describe high priority monitoring and evaluation questions for harvest augmentation, supplementation, and conservation-type hatchery programs. For this review of SBC Chinook, we combined the assessment hatcheries with the harvest augmentation hatcheries because of similarity in risks. **Tables Hat-2, Hat-3** and **Hat-4** also identify key performance metrics necessary to address high priority questions. We utilized these high-priority questions and metrics to assess the information provided on southern BC hatcheries, to determine the potential degree to which hatcheries have contributed to declines in southern BC Chinook populations, and to identify key information gaps with specific focus on the metrics that are important for assessing impacts to natural populations.

Hatchery production of Chinook salmon in BC was initiated in 1967 and expanded rapidly through 1970s and 1980s. Production peaked in 1990 with the release of about 66 million smolts and fed fry. Production levels were steadily reduced from 1990 to the early 2000s and stabilized near 40 million in recent years. A majority of the production comes from DFO operated programs. A total of 29 CUs have had direct hatchery enhancement since 1967, which is a high proportion (0.80) of the 35 CUs in the SBC Chinook domain. Currently there are 15 CUs being enhanced.

Production for harvest currently accounts for over 75% of the annual releases. Production for rebuilding is a distant second (about 10%), and the remainder of production is divided in small proportions among the other four program types. Although harvest production numbers dominate the annual releases, the distribution based on program types by number of stocks enhanced is much different with nearly equal proportions of harvest and rebuilding and a substantial proportion of stewardship programs (**Figure Hat-2**). A majority of the harvest production is from seven stocks on Vancouver Island.

A diversity of hatchery rearing-release strategies are utilized including the multiple life stages of fed fry, sub-yearling smolts and yearling smolts released directly from hatchery rearing facilities, direct stream off-station releases and seapen acclimation. Releases of smolts acclimated in seapens were initiated in the mid-1980s and rapidly increased to seven million in 1996. Seapen releases have been reduced slightly to six million or less in recent years.

Table Hat-2. Harvest augmentation hatcheries: hatchery performance and impacts questions, key information, needs and metrics. These questions and metrics address the extent to which hatcheries can be used in meeting harvest management goals while keeping impacts to natural populations within acceptable limits. The most important questions and metrics are indicated by non-italicized font and checkered shading.

Questions
What are the abundance and distribution of hatchery strays in natural populations?
What proportion of natural-spawning fish in natural populations within and outside the target watersheds are hatchery-origin strays?
What is the impact of hatchery strays on productivity of natural populations?
What are the impacts on viability of natural populations resulting from ecological interactions (predation, competition) at the juvenile life stage?
What is the impact of hatchery strays on life history diversity of natural populations?
What are the disease agents and pathogens in hatchery fish, and what are their impacts due to transmission to wild fish?
What is the level of genetic introgression of hatchery-origin strays into natural populations and what level of genetic change occurs?
To what degree do the hatchery fish mimic performance of the wild fish (for assessment programs only)?
What are optimum rearing and release, marking, and hatchery management strategies to maximize harvest management opportunities and minimize impacts to natural populations?
What are annual harvest contributions and catch distribution of hatchery produced fish?
To what degree does the hatchery program meet harvest objectives?
Key Information Needs and Metrics
Recruits-per-spawner for hatchery fish
Age-structure
Incidental harvest and mortality on natural fish from fisheries targeting hatchery-origin fish
Stray rates and abundance of strays in natural populations
Spatial distribution of strays
Proportion of natural spawners that are hatchery strays
Effect of strays on recruit, spawner and abundance of natural populations
Rates of juvenile residualism
Effects of strays on genetic characteristics of natural populations
Effects of strays on age-structure and run-timing of natural populations
Annual commercial, recreational, and harvest contributions by fishery
Catch and escapement distribution profile

Table Hat-3. Supplementation hatcheries: hatchery performance and impacts questions, key information needs, and metrics. These questions and metrics address to what extent hatcheries can be used to enhance viability of natural populations while keeping impacts to non-target populations within acceptable limits? The most important questions and metrics are indicated by non-italicized font and checkered shading.

Questions
What is the ratio of recruits per spawner for hatchery produced and natural produced fish?
What is the reproductive success of natural spawning hatchery fish relative to that of natural-origin fish?
What is the spawning distribution of hatchery and natural-origin fish, how do they differ and has the natural-origin distribution changed?
What are the effects of hatchery supplementation on natural productivity, total spawner abundance, and natural-origin abundance of the natural population?
What are the genetic characteristics of hatchery and natural fish in supplemented populations, and what is the degree and rate of change in genetic characteristics of supplemented populations?
What are the juvenile and adult life history characteristics of hatchery and natural fish and how do they differ?
What are the proportions of natural-spawning stray hatchery fish in non-target natural populations?
What are the distribution of strays and stray rates of hatchery fish?
What disease agents and pathogens occur in natural and hatchery fish, and what are the impacts to natural fish?
What is the spawning carrying capacity, and how does enhanced spawner abundance compare to the capacity?
What are the status and trends in abundance of naturally produced smolts?
What are the catch contribution and catch distribution of hatchery fish?
What are the effects of alternative hatchery production strategies on juvenile characteristics, survival rates, adult life history characteristics, and spawner distribution?
Key Information Needs and Metrics
Recruits per spawner for hatchery fish and natural fish
Hatchery and natural-origin spawner abundance
pHOS and pNOB
Proportionate Natural Influence (PNI) = pNOB / pNOB + pHOS
Age structure of hatchery and natural fish
Hatchery fish spawning distribution
Change in spawning range and distribution over time, pre and post hatchery influence
Change in smolts per spawner and adult recruits per spawner relationship post supplementation
Change in natural population age structure and size at age
Effective population size

Genetic disequilibrium, Fst, Heterozygosity, allelic richness
Genetic differences between populations and changes in population differentiation
Stray rates and distribution of strays
Disease profiles
Relative reproductive success of hatchery and natural fish using DNA pedigree analysis
Hatchery and natural fish pre-spawn mortality
Hatchery and natural fish harvest rates
Smolt to adult survival for natural and hatchery fish
Change in natural-origin adult run timing
Change in natural juvenile size at migration and age at migration
Change in natural juvenile migration timing
Hatchery and natural age-specific female fecundity
Hatchery adult run-timing
Hatchery and natural fish harvest rates

Table Hat-4. Genetic conservation hatcheries: hatchery performance questions, key information needs, and metrics. These questions and metrics address to what extent hatcheries can be used to conserve the genetic legacy of imperiled natural populations? All questions and metrics are high priority.

Questions
What is the degree of genetic similarity between the captive population and the natural population?
What is the effective population size of captive fish?
What are the best breeding strategies to maximize and maintain genetic characteristics?
What is the rate and magnitude of genetic change in the captive populations?
Key Information Needs and Metrics
Fst
Heterozygosity
Allelic richness
Genetic distance from source population
Effective populations size

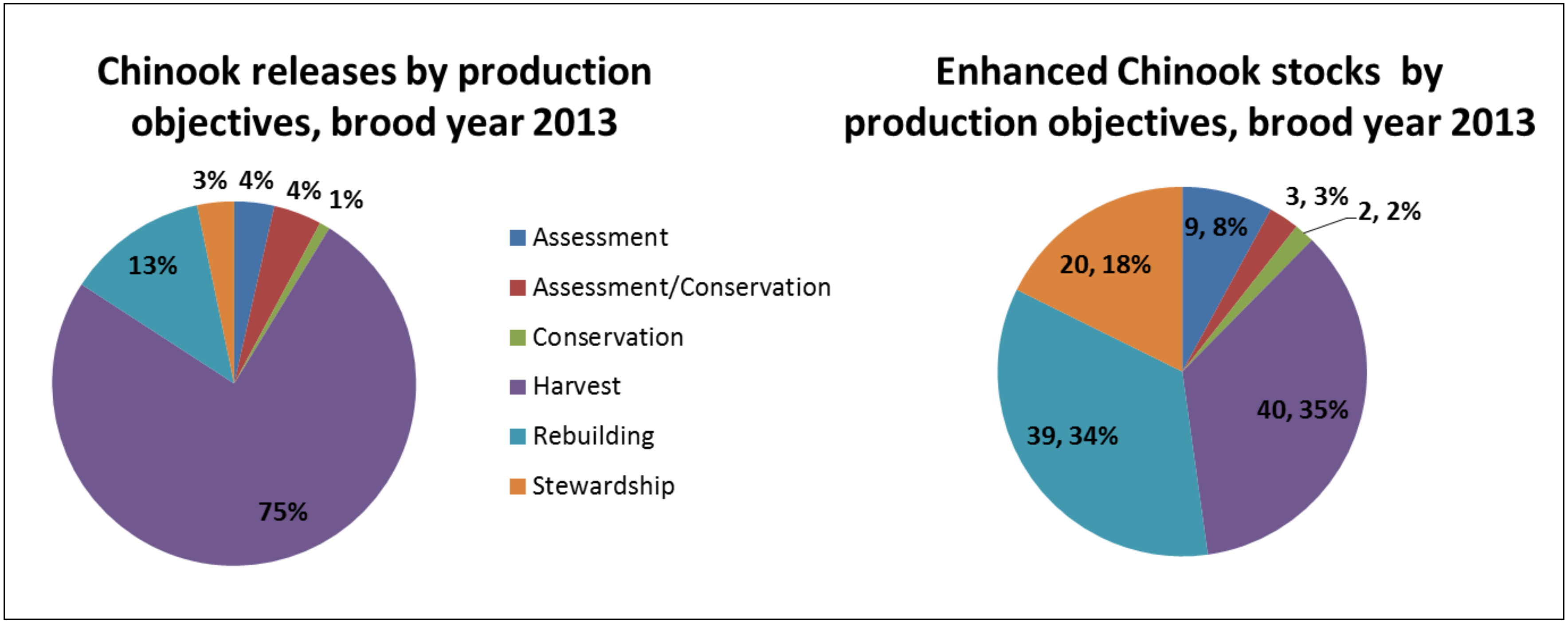


Figure Hat-2. Distribution of Southern BC Chinook salmon hatchery releases and enhanced stocks by program type. Source: David Willis, DFO, presentation, slide 6

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7.1.3 Middle and Upper Fraser River CU Group

The Middle-Upper Fraser River CUs are currently the least enhanced of the five CU groups, however there is a history of significant hatchery production. The Quesnel River facility, which was the only large-scale production facility, was operated from 1982-1994. The small-scale Penny hatchery was operated until 2005. Total smolt release numbers for Upper Fraser Spring Chinook, Middle Fraser Summer Chinook and Middle Fraser Spring Chinook peaked in 1987 at 3.8 million smolts. Since that time release numbers have been steadily reduced to zero in 2007. No information on broodstock sources or management protocols was provided to the Panel, however DFO has indicated these data are available. There also were no data presented or provided on the key metrics needed to assess whether the hatchery programs, when in operation, had impacted natural populations in this CU group.

7.1.4 Thompson River CU Group

Hatchery programs have operated within the Thompson River CU group since 1980. Release numbers peaked in 1989 at six million and were reduced substantially by 1994. Current production levels are at one million smolts annually and the number of stocks enhanced has been reduced from five to three. Enhancement in the North Thompson River has stopped and current enhancement is focused on the Nicola and Shuswap river watersheds. Hatchery production numbers are split roughly equally between rebuilding and stock assessment objectives (**Figure Hat-3**).

Very limited data were provided for the important metrics needed to address the potential impacts of the hatchery programs on natural populations. The pHOS (proportion of hatchery-origin spawners) in Nicola River has been at or below 0.4 since 1996, down from the peak of 0.8 in 1991, but still above the Columbia Basin criteria in **Table Hat-1**. The pHOS in the Lower Shuswap River has remained below 0.2 for the entire period of record from 1987-2011. In contrast, the pHOS in the Middle Shuswap River has been high, reaching levels of over 0.8 in 2001 and 2002, well above criteria in **Table Hat-1**. The absence of essential data for this CU grouping makes it difficult to assess the potential risks and impacts of the hatchery programs. In addition, no data were provided related to historical or current broodstock sources or management.

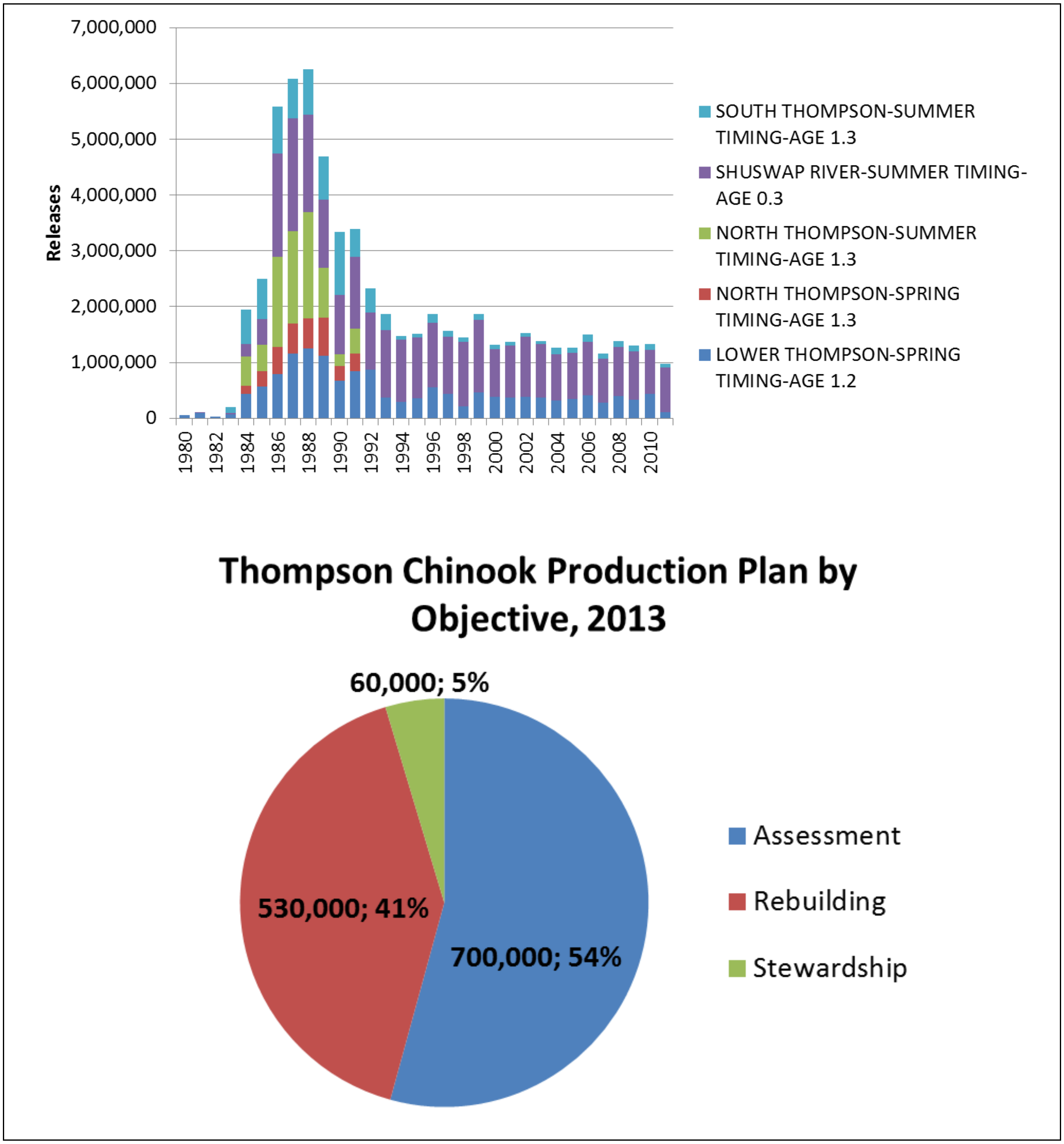
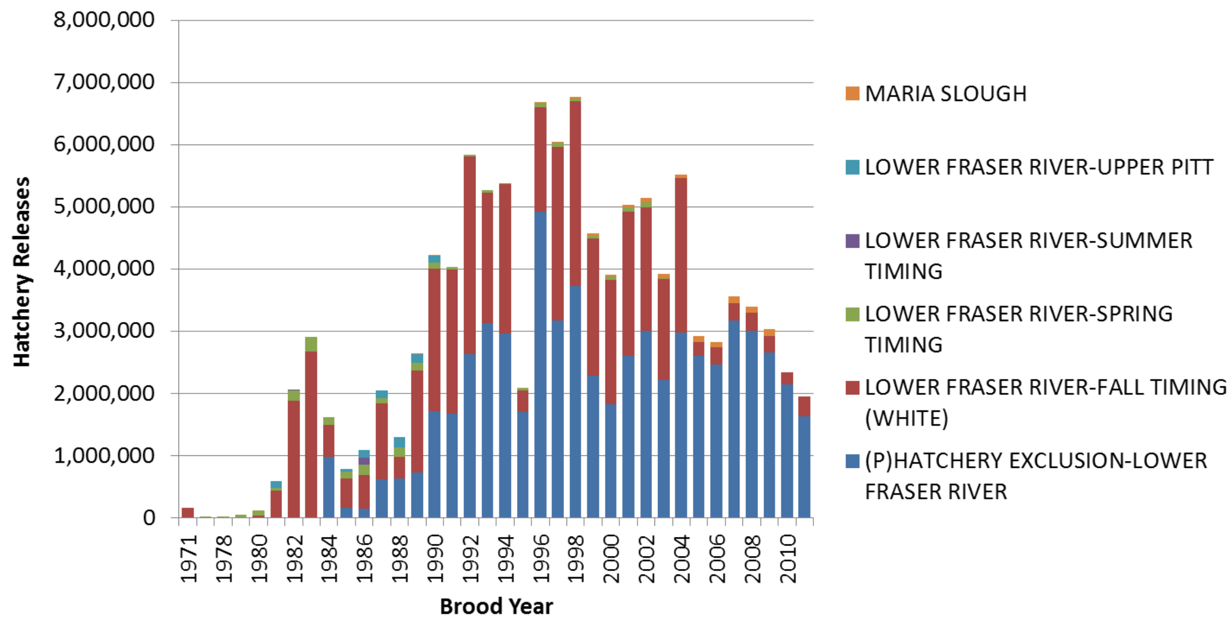


Figure Hat-3. Thompson River CU group release numbers by stock and program type. Source: David Willis, DFO, presentation, slides 13, 14.

7.1.5 Lower Fraser River CU Group

Hatchery programs have operated in the Lower Fraser River CU group since the early 1970s. Release numbers peaked in 1998 at over 6.5 million smolts. Production has been steadily reduced to about two million in 2012. There are three major hatcheries and two smaller scale facilities currently in operation. Hatchery programs in the Lower Fraser River are operated primarily for the purposes of providing harvest (**Figure Hat-4**). Enhancement in the Lower Fraser River has occurred primarily into systems that did not have Chinook salmon historically. Broodstock sources have been almost exclusively transplants from the Middle-Upper Fraser River, Chilliwack River, and Harrison River stocks. There were small short-term programs operated in the past for rebuilding in Maria Slough, Chilliwack River Summers and the Upper Pitt River. There were limited data provided to the Panel for the key metrics needed to assess potential impacts of hatcheries on the natural populations within the CU group. The pHOS in the Harrison River has declined since the mid-1990s to less than 0.02, consistent with criterion for Primary populations in **Table Hat-1.**



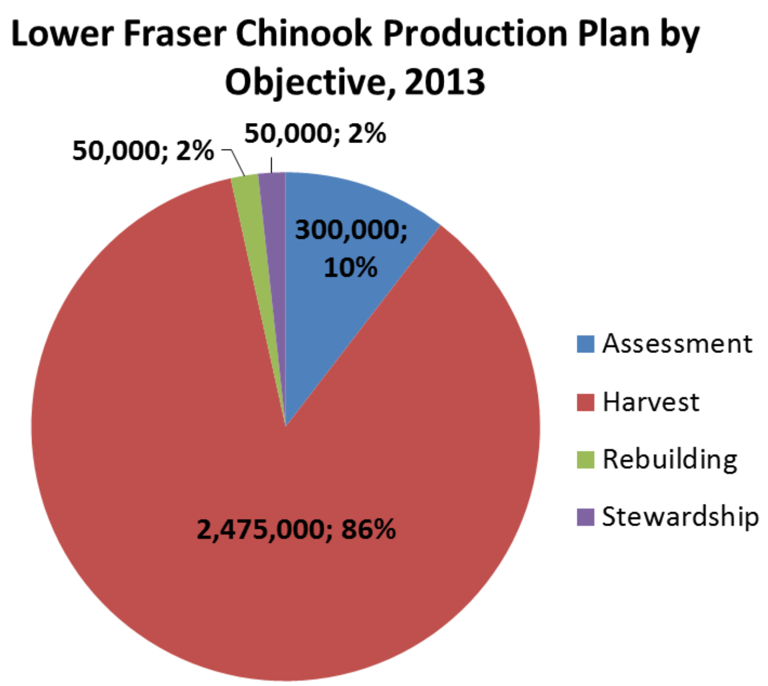


Figure Hat-4. Lower Fraser CU group Chinook salmon hatchery release numbers by stock and program type. Source: David Willis, DFO, presentation, slides 17, 18.

Withler et al. (workshop presentation and handout, May 2013) presented age structure comparisons between hatchery and (wild) origin adults from NBC troll samples and size-at-age comparisons for adult returns to the river. There was little difference between the small (wild) populations and the three major hatchery stocks. However, the age structure of the Harrison River (wild) stock was substantially older than the Chilliwack River hatchery stock for the 2002-2010 years. Additional age-at-return data for late Fraser River Chinook salmon for broodyear 2007 were provided by Parken following the workshop. Parken compared 2007 broodyear escapement age structure among Harrison River natural origin river, Harrison River hatchery origin (Chehalis Hatchery), and Chilliwack River hatchery origin adults. Parken's results indicated that the Harrison River hatchery age composition was older than the Harrison River natural age composition with fewer age-2 and greater age-4 adults. The Chilliwack River hatchery origin had the highest proportion age-3 and fewer age-2 and age-4 adults when compared with the Harrison River natural origin. These results are somewhat inconsistent with those presented by Withler et al., however, both indicated that Chilliwack River hatchery origin returns were younger than Harrison River natural origin returns.

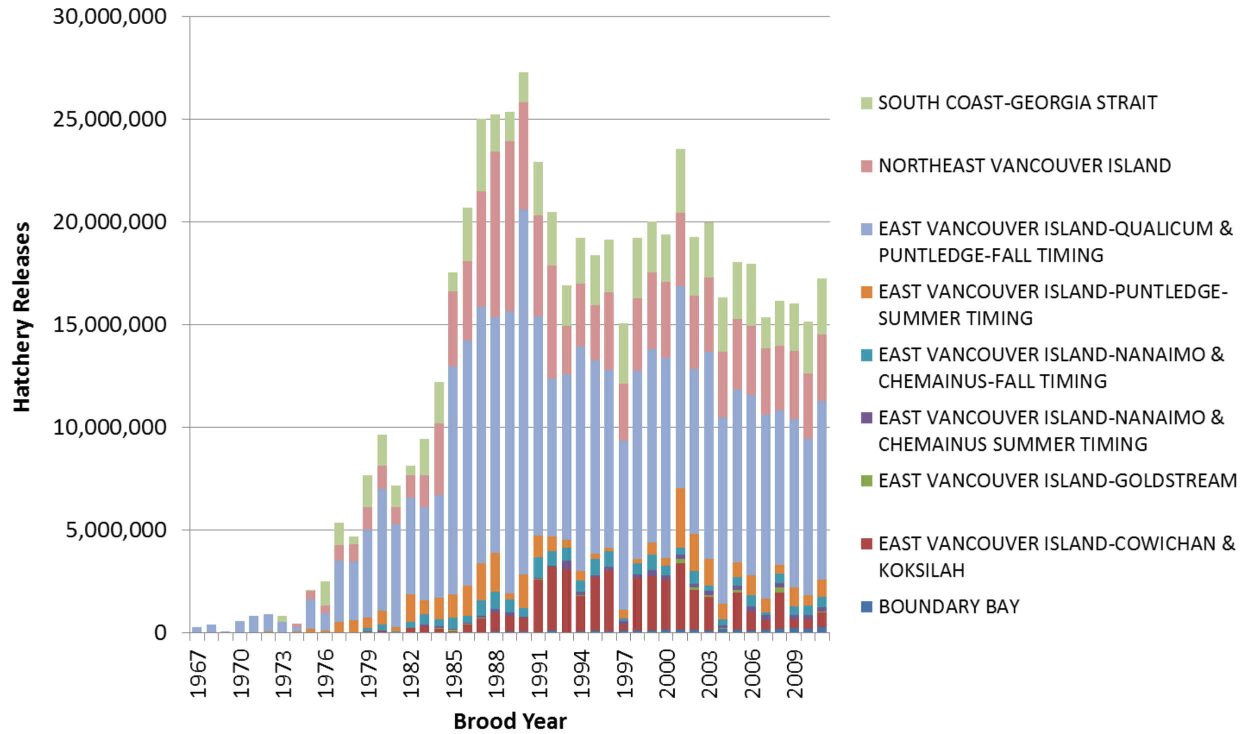
7.1.6 Georgia Strait CU Group

Hatchery programs have operated in the Georgia Strait CU group (includes ECVI) since 1967. Release numbers peaked in 1990 at about 27 million (**Figure Hat-5**). Production levels were decreased in 1993 and although there has been significant annual variability, recent production levels have stabilized at about 15 million. Hatchery production for harvest comprises over 75% of the releases with rebuilding and conservation production programs each accounting for about 10% annually. There are currently seven major Chinook hatcheries and 15 small-scale facilities in operation. Currently there are 22 stocks that are enhanced and the rebuilding programs are focused on the Cowichan River fall, Naniamo River summer, and Puntledge River summer stocks. The Qualicum/Puntledge River fall CU is the second most heavily enhanced CU in Southern BC. Broodstock history and current enhancement management are complex. Transplants were used to establish production into unoccupied areas throughout the Georgia Basin and successful naturalization has occurred. Intentional broodstock hybridization occurred in the past between the native Puntledge River stock and the Big Qualicum and Quinsam Rivers stocks. Seapen releases were utilized extensively through the 1990s and although reduced in scope now, over two million smolts are still acclimated in seapens and released annually.

Withler et al. concluded that there was a negative relationship between marine survival and hatchery release numbers in selected hatchery stocks in Georgia Strait . These results are however confounded by time, survival relationships with ocean conditions, trends in marine survival and potentially the degree of domestication. In addition, in the relationships that were significant, the data points for low numbers of released fish correspond to the earlier time period of 1973-1983, further confounding interpretations.

The pHOS in Big Qualicum and Puntledger river summers and Quinsam River have consistently been high (0.4 to 1.0, above the criteria in **Table Hat-1**) with substantial year to year variability (**Figure ST–8**). The pHOS in the Cowichan River fall stock was lower than the Columbia basin guideline of 0.43 (**Table Hat-1**) from 1981 – 2011, but has been above 0.3 in about half of the years from 1994-2011. As with the other stocks the annual variation in pHOS was substantial.

The Panel was provided with limited data related to key metrics needed for assessing potential impacts of hatcheries, especially related to pHOS in unenhanced populations, straying rates, and stray distribution. Withler et al. did however provide summary analyses of genetics data that were informative for assessing genetic introgression, stock structure, and loss of unique wild populations. Past broodstock management practices including transplantation and intentional stock hybridization in concert with the extensive enhancement and high proportions of hatchery spawners in nature has resulted in what appears to be the elimination of wild fall (ocean-type) Chinook salmon populations in this CU group. The fall Chinook salmon populations are genetically similar, potentially indicating a substantial degree of genetic homogenization. The summer Chinook salmon populations in the Puntledge and Nanaimo rivers are distinct from the fall populations and from each other, although to a lesser extent. Withler et al. did conclude that there had been introgression of summer stocks into the fall stocks within individual watersheds.



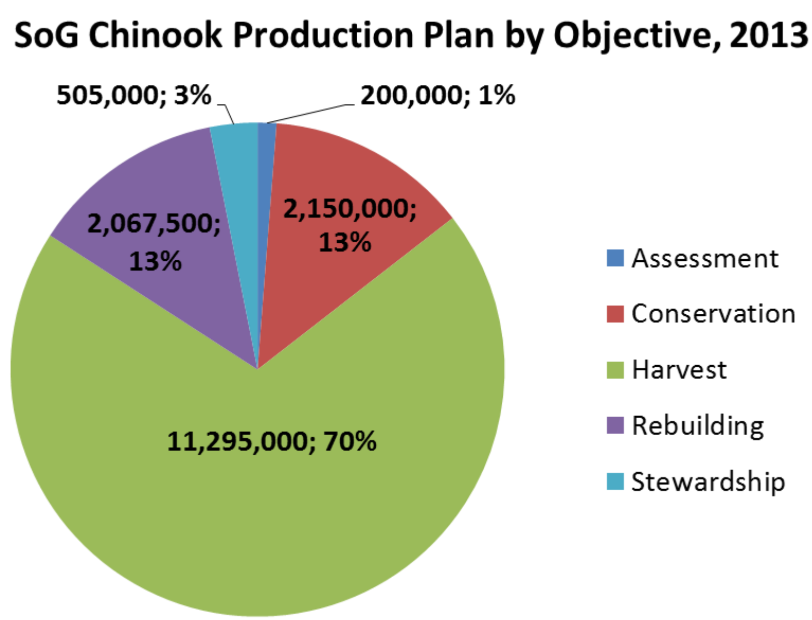


Figure Hat-5. Georgia Strait CU group Chinook salmon hatchery release numbers by stock and program type. Source: David Willis, DFO, presentation, slide 22, 23.

7.1.7 West Coast Vancouver Island CU Group

Hatchery programs have operated in the WCVI CU group since 1972. Release numbers peaked in 1988 at about 25 million smolts. Release numbers have been quite variable but generally decreasing since 1988. Recent annual production has stabilized around 15 million smolts. Hatchery production for harvest dominates the total release numbers, accounting for about 80% annually. Production for rebuilding objectives accounts for about 15% of the releases (**Figure Hat-6**). Three major hatcheries and nine smaller scale hatchery programs are operated within the CU group. A total of 23 stocks are currently enhanced. The SE Vancouver Island CU is the most extensively enhanced CU in BC with over 11 million smolts released annually.

Past broodstock development and management has focused on use of local native broodstocks with little or no transplantation history for the large enhanced populations (Nitinat River, Robertson Creek, Conuma River and Marble River). Some of the smaller systems did receive transplants in the mid-1980s through the mid-1990s. However, recent broodstock management strategies that collect broodstock from lower river reaches may be resulting in inclusion of a significant number of wandering strays from a mixture of stocks. Seapen releases were initiated with the 1984 broodyear and have steadily been increased to over three million annually. Seapen releases of the Conuma River stock comprises over 90% of the total seapen releases.

The pHOS is known to be high in some populations in the CU.. The pHOS in Robertson Creek was highly variable and above 0.6 for most all of the recent return years over the past three generations, well above the Columbia basin guidelines in **Table Hat-1**. The pHOS is high in the Nitinat and Conuma Rivers. Although few estimates were provided for pHOS, Withler et al. concluded that "Enhanced fish constitute a majority of spawners each generation" for the three highly enhanced populations in the Southwest and Nootka-Kyuquot CUs. In addition, Withler et al. concluded "smaller unenhanced or less enhanced Chinook salmon populations on WCVI have been extensively affected by transplantation from local or sometimes more distant, enhanced populations".

The three large hatchery stocks (Conuma River, Nitinat River, Robertson Creek) have maintained a high degree of genetic distinctiveness through time. The Marble River Chinook salmon, also highly enhanced, remains highly distinct from other populations in the CU group and may represent a unique genetic lineage within this group (Withler et al., Genetics Interactions Background Material).

Hatchery-origin strays with thermally marked otoliths that came from numerous hatcheries have been recovered throughout southern, central and northern WCVI in multiple unenhanced and low enhanced natural populations (**Figure Hat-7**). There were no hatchery-origin abundance or pHOS data presented for any of the populations where hatchery strays had been observed.

Time series analyses of genetic similarity between unenhanced-low enhanced populations and hatchery stocks indicates significant genetic introgression. Similarity of the Burman River, Tahsis River and Kaouk River populations with the Conuma River hatchery stocks increased substantially over time and there is now little or no genetic distinction between these small populations and the Conuma River hatchery stock (**Figure Hat-8**).

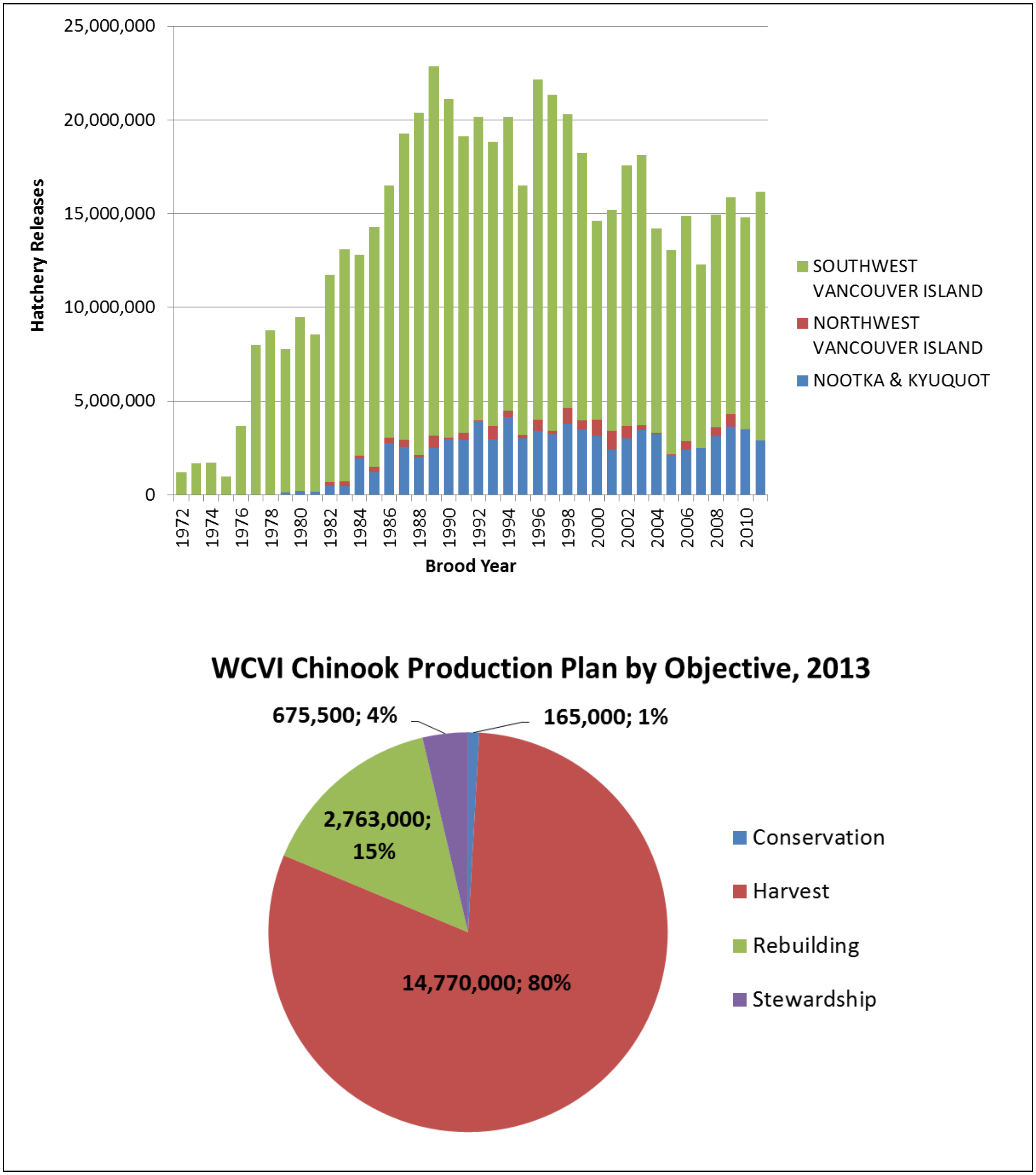


Figure Hat-6. West Coast Vancouver Island CU group Chinook salmon hatchery release numbers by stock and program type. Source: David Willis, DFO, presentation, slide 29, 30.

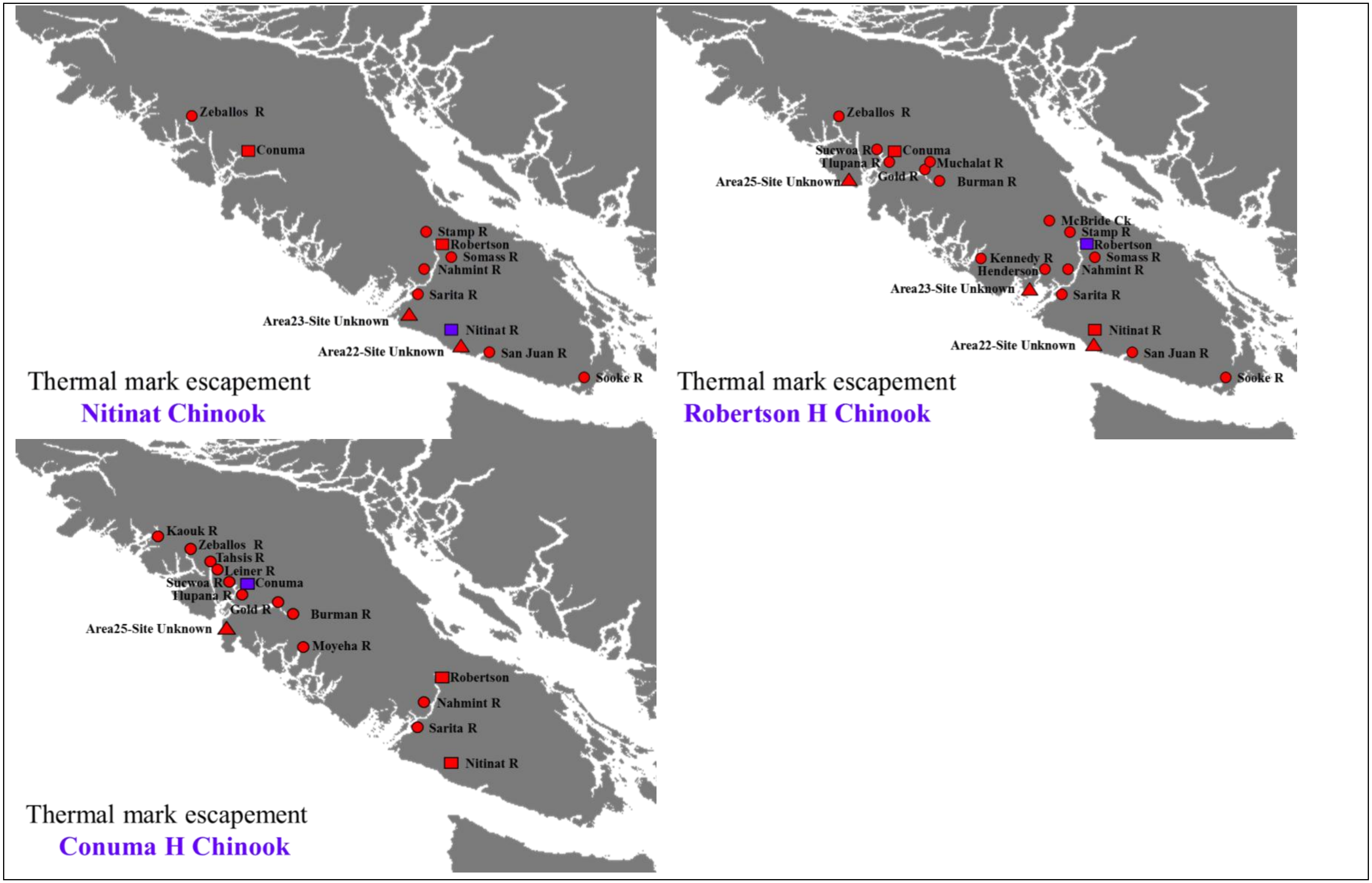


Figure Hat-7. Locations where thermal otolith marked hatchery strays were recovered on West Coast Vancouver Island. Locations shown include hatcheries (squares), known sites (circles) and unknown sites (triangles). Source: O'Brien et al. (2013).

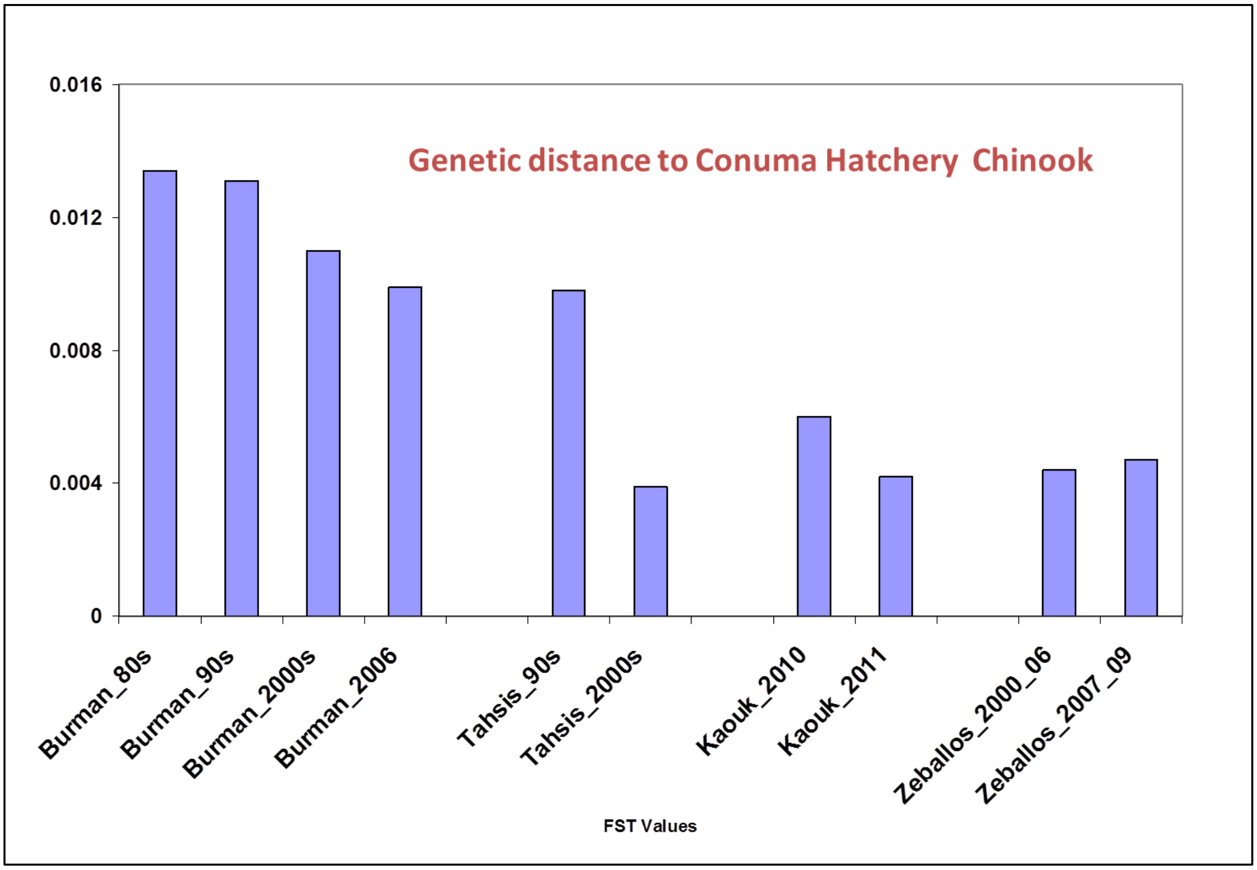


Figure Hat-8. Genetic distance between small unenhanced Chinook salmon populations on West Coast Vancouver Island and Conuma hatchery stock. Source: Ruth Withler, DFO, presentation, slide 57.

Similar results were observed for the Megin River genetic analyses with strong indication of genetic convergence with Conuma River, Nitinat River and Robertson Creek hatchery stocks. The most recent Megin River samples indicate that current spawners are primarily sourced from these three large hatchery stocks. Additional small natural populations show a strong genetic signal of extensive introgression or replacement by hatchery stocks. The genetic characteristics of the Toquart River are similar to the Nitinat hatchery stock whereas the Thornton River shows no distinction from the Robertson Creek hatchery stock. The Sarita River population data shows a strong signal of introgression from both the Nitinat River and Robertson Creek hatchery stocks. Genetic characteristics of the Gold River have changed significantly from the 1980s and now demonstrate no distinctiveness from the Robertson Creek hatchery stock.

7.2 Have Hatcheries Likely Been a Factor Responsible for Recent Trends in Abundance of Southern BC Chinook?

7.2.1 All Southern BC Hatcheries

Although essential assessment data are very limited, there are a number of factors that indicate that hatchery programs operated within the SBC Chinook salmon CU groups have likely had a negative effect on the productivity and viability of natural populations. The effect appears to be highly variable between CU groups, ranging from little or no impact to a substantial impact. The magnitude of annual releases, high proportion of CUs enhanced, broodstock history and management, straying and genetic changes all in combination contribute to the likelihood that hatcheries are a significant stressor in some CU groups.

The marine survival and CU abundance and productivity information cannot be used to compare status and trends between the enhanced and unenhanced populations or CUs for various reasons. Hatchery-origin fish are included in the abundance and productivity estimates for all of the enhanced CUs and the pHOS is highly variable in most of the enhanced populations.

7.2.2 Middle and Upper Fraser River CU Group

Hatchery programs have ceased in this CU group. However, there was no information provided on broodstock sources or management protocols, nor were data presented or provided on the key metrics needed to assess whether the hatchery programs, when in operation, had impacted natural populations in this CU group. However, given the low level of hatchery production during the past three generations (12 years), and the limited geographic distribution of natural populations in the Middle-Upper Fraser River CU, the hatchery programs are unlikely to have influenced population viability or trends in abundance of the natural populations in recent years. However, without information on broodstock sources, broodstock management, genetic characteristics, and straying of hatchery fish during the years of hatchery production, there is uncertainty about this conclusion. Since hatchery production has ceased within this CU group, the future risk of current hatchery programs to the viability of this CU group is negligible.

7.2.3 Thompson River CU Group

The absence of essential data for this CU group makes it difficult to assess the potential risks and impacts of the hatchery programs. In addition, no data were provided related to historical or current broodstock sources or management. Under the current production plan the risks have been reduced significantly from the late 1980s to mid-1990s due to the substantially reduced release numbers and the reduced geographic distribution of releases. However, the high pHOS values and lack of data for key metrics related to straying, pHOS, and genetic characteristics in non-enhanced populations creates considerable uncertainty. Withler et al. concluded "it is unlikely that direct effects from hatcheries have had a significant negative effect on Chinook salmon populations in the Thompson River watershed."

Given the large number of populations that have remained unenhanced and the broad geographic distribution of natural populations in this CU group, we agree with this conclusion, however, with considerable uncertainty.

7.2.4 *Lower Fraser River CU Group*

There were limited data provided for the key metrics needed to assess potential impacts of hatcheries on the natural populations within this CU group. However, current risks are reduced from the 1990s due to the substantial reduction in release numbers. The pHOS in the Harrison River has declined since the mid-1990s to less than 0.02. The influence of hatcheries on status and trends of natural populations is likely low. However, without data for the most important metrics for most CUs, including pHOS, hatchery fish stray rates and distribution, the degree of hatchery stock genetic introgression into natural populations, and genetic differentiation between natural populations, the level of impact is uncertain.

7.2.5 *Georgia Strait CU Group*

Limited data related to key metrics needed to access potential impacts of hatcheries were provided, especially related to pHOS in unenhanced populations, stray rates, stray distribution and genetic characteristics. Several lines of evidence indicate that the hatchery program has likely contributed substantially to reduced productivity and potentially to the declines observed in abundance because of the magnitude of enhancement, past and present broodstock management strategies, indications of significant genetic loss and homogenization, and the high pHOS in unenhanced wild populations. Unfortunately, data are unavailable to analyze potential differences in productivity and abundance responses of enhanced and unenhanced populations.

7.2.6 *West Coast Vancouver Island CU Group*

Although the most extensive relevant data were provided for this CU group, data were still quite limited. Key metrics needed to assess potential impacts of hatcheries, especially pHOS in unenhanced populations, stray rates, stock specific stray distribution, and genetic characteristics of populations were generally not available. There are a number of factors that indicate hatchery programs within this CU group are likely a significant stressor on natural populations and may have contributed substantially to reduced productivity. Release numbers are large and there are numerous hatchery programs distributed throughout the CU group. Hatchery strays have been found in many unenhanced populations throughout the CU group. Indications of significant genetic change and homogenization with large program hatchery stocks in the unenhanced populations due to straying suggest the loss of many locally adapted small populations. Unfortunately, data are unavailable to analyze potential differences in productivity and abundance responses of enhanced and unenhanced populations or to assess changes in productivity of unenhanced populations that have been impacted by hatchery fish.

7.3 Special Issues Raised by the WSP Definition of Wild Salmon: Effect of BC Hatchery Programs on Status of Wild Salmon

The material presented in this section was focused on our primary task -- assessment of the degree to which hatcheries may be responsible for declines in abundance or productivity of naturally spawning Chinook salmon in SBC. This assessment was seriously limited by the general absence of diagnostic metrics, however, the available information did not implicate hatcheries as a factor likely to have contributed to declines with the exceptions of the WCVI and Strait of Georgia CU groups.

As noted in the introduction to this section, however, a complete assessment of this issue must also grapple with the complications that are introduced by the definition of wild salmon that has been adopted by in WSP and the goals of the WSP to promote and protect wild salmon as opposed to the objective of promoting "natural production" as defined elsewhere. Under the (possibly unrealistic) assumption that all spawning Chinook salmon randomly mate with one another, regardless of whether they are of hatchery or natural origin, and given an assumed average level of pHOS, it is possible to calculate the percentage of a spawning population that would consist of "wild salmon" as compared to those spawners that would not meet this definition (i.e., originated from (a) natural spawning of hatchery fish x hatchery fish or hatchery fish x wild fish or (b) directly from enhancement, first generation hatchery fish). These calculated percentages of wild salmon are a non-linear decreasing function of pHOS, the proportion of first generation hatchery fish on natural spawning grounds (**Figure Hat-9**, for an explanation of the calculations see **Appendix HatA-1**).

Inspection of **Figure Hat-9** suggests that the relatively high levels of pHOS that have been documented in a number of SBC streams are probably seriously incompatible with WSP goals. For example, based on **Figure ST-8**, average percentages of pHOS over the past ten years have been about 60%, 90%, 70% and 70% in the Big Qualicum, Puntledge summer, Quinsam, and Robertson Creek populations, respectively. These high pHOS values imply that the corresponding expected proportions of populations that would today be considered wild (under the WSP's definition of wild salmon) are only about 9.1%, 0.2%, 4.2% and 4.2% of total abundance, respectively, in each of these populations. To the extent that these streams originally supported natural populations that remain worthy of protection under the WSP, such low expected proportions of wild salmon in heavily enhanced populations are incompatible with the WSP goals, even though they are operating under an approved integrated strategic fishery and production plan. Even when hatchery-origin (enhanced) fish do not constitute a majority of the spawning population, there may still be substantial reduction in the proportion of spawners that would be "wild". For example, for pHOS = 40%, the associated proportion of wild adults is only about 27% of the total spawning population.

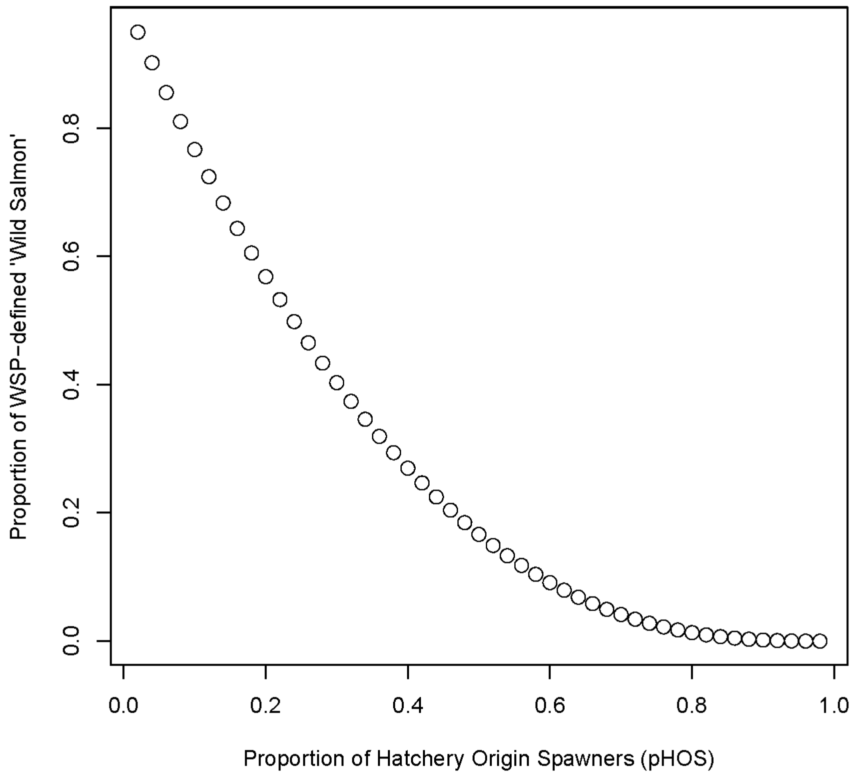


Figure Hat-9. Hypothetical expected proportion of a spawning population that would be considered "wild" (y-axis) under the WSP definition of wild salmon (i.e., DFO 2005) under the following assumptions: (a) the percentage of enhanced fish (direct hatchery origin) is constant from year to year (pHOS on x axis) , and (b) all matings are at random and are independent of the origin of spawning adults. See **Appendix HatA-1** for explanation of calculations and assumptions.

7.4 Uncertainties, Critical Information Gaps and Recommendations

7.4.1 Information Gaps

In general there was very limited information provided to address the highest priority questions and to allow assessment of the degree to which hatcheries have been a stressor and contributor to observed declines in SBC Chinook salmon. This paucity of information was consistent and somewhat alarming for the harvest augmentation, supplementation, and wild stock indicator hatchery programs. There appears to be additional information that was not provided, however presenters were specifically asked during the workshop about availability of data for high-priority metrics (i.e. PNI, pHOS, pNOB, stray rates, and hatchery vs.natural-spawner recruits per spawner), and our impression is that such data are not broadly available. It appears that the SEP is largely operating in isolation independent of the other evaluation and management programs.

Assessment of the overall contribution of hatcheries at the SBC Chinook salmon geographic scale relies on hierarchical synthesis of assessment data from the CU group, individual CUs and individual population level hatchery program and natural populations. Clearly the hatchery risks vary considerably between CU groups. In the Middle-Upper Fraser River, Thompson River, and Lower Fraser CU groups hatchery programs have been reduced to levels where risk is limited and additional hatchery and monitoring evaluation efforts would yield little contribution to understanding hatchery impacts. In contrast, hatcheries appear to be a major factor influencing many aspects of Chinook salmon natural population ecology and dynamics in the Strait of Georgia and WCVI CU groups. Although the WCVI CU group appears to have the most relevant data, a substantial expansion in monitoring and evaluation of hatchery programs and natural populations are needed to provide data for essential metrics.

Given the number and diversity of hatchery programs, their broad geographic area of influence, and the large number of natural populations, it is clear that it would be logistically challenging to extensively monitor all hatchery programs and natural populations within these CU groups. In this type of situation a stratified standardized monitoring framework might be used to provide data that could be aggregated upward for inference to the CU and CU group level. Hatchery programs could be stratified according to program type, program size, broodstock sources and management, Chinook race (spring, summer, fall) and rearing-release strategies. All of these factors have been shown to influence hatchery effectiveness and potential impacts to natural populations. Within each constructed stratum randomly selected or representative populations and hatchery programs could be monitored carefully for the metrics identified in **Tables Hat-2, Hat-3,** and **Hat-4.**

7.4.2 Recommendations

Here we make recommendations for monitoring and evaluation programs that, if implemented under a stratified monitoring framework, would substantially improve the basis for assessing SBC hatchery program benefits and risks. The primary scale of monitoring recommended is at the individual hatchery program and natural population level. Program and population level assessments can be aggregated for assessment at the CU scale. The recommendations focus on the highest priority and most informative metrics that are also where the greatest information gaps and uncertainties exist. These recommendations are most relevant to the Strait of Georgia and the WCVI CU groups which appear to be the most impacted by hatchery programs.

The recommendations are:

- Document the number of natural and hatchery-origin broodstock collected and spawned annually. Determine the total number of natural and hatchery spawners in nature within target populations where hatchery programs operate. Estimate pHOS, pNOB and proportion of natural-origin returns collected for broodstock. Determine annual and mean generational PNI values to characterize the dominant selection environment.

- Determine age-structure of hatchery and natural-origin fish within target populations. Estimate and compare adult recruits-per-spawner productivity for hatchery and natural spawners to assess the full life cycle survival advantage provided by taking natural-origin adults into the hatchery program. Assess differences in age-structure between hatchery and natural fish as well as their changes through time. Document and compare adult run timing between hatchery and natural-origin adults and determine changes through time.

- Document and compare annual spawner distribution for hatchery and natural origin-adults within target populations to assess differences and changes through time.

- Identify and select reference natural populations that have minimal or no hatchery influence but that share common characteristics that influence abundance and productivity with the hatchery enhanced population (race, geographic location, ocean migration patterns, etc.). Monitor abundance and productivity in reference populations to provide spatial and temporal comparisons with enhanced populations.

- Identify and select non-target, unenhanced natural populations to monitor hatchery fish straying with a stratified framework (distance from enhanced population, within and outside adult migratory pathways). Determine hatchery and natural-origin abundance and calculate pHOS estimates. Determine hatchery stock specific stray sources, abundance, and stray rates. This would require a significant expansion of marking and tagging above the current approach of applying coded-wire-tags only to indicator stocks. Characterize the stock specific distribution and abundance of strays.

- Expand the current genetics monitoring program to better assess genetic characteristics of "wild" unenhanced populations, assess the degree of hatchery stock introgression into "wild" populations, and assess the origin of broodstock in programs collecting adults in lower river reaches and bays near the ocean. Design and conduct an evaluation of the influence of seapen acclimation on stray rates and distribution.

The previous set of recommendations is technical in nature and specific to each hatchery program and population. Below we provide higher level recommendations that we believe also warrant consideration.

- There was very limited assessment or discussion of the degree to which the current hatchery programs and outcomes are consistent with the WSP goals and objectives, although the WSP was generally discussed throughout the workshop and within the documents provided. The WSP clearly establishes a foundation and a need for managing hatcheries in a manner that is consistent with conservation of wild salmon populations, however the Policy provides little specific guidance for hatchery management. Hatchery programs appear to be operating at serious odds with sound wild salmon population conservation principles as well as the WSP goals in the WCVI and Georgia Strait CU groups. Of particular concern was the lack of demonstrated adaptive management changes in the hatchery program in response to information that suggests serious impacts to "wild" populations.

> **Comment**: B. Riddell noted that during the development of the WSP, it was recognized that some CUs were heavily invested in major enhancement programs and have had significant interactions with natural populations within them. However, beyond those CUs, the conservation of wild salmon and their habitats was to be the first priority in management, and the risks associated with hatchery production were to be assessed through the development of a biological risk assessment framework (like described above for the Pacific Northwest). Although a draft biological risk assessment framework is available, the use of the framework for assessments was not apparent in presentations to the Panel.

- There is a clear need for a thorough and critical programmatic assessment including evaluation of the role hatcheries serve, the consistency with which hatchery programs meet WSP goals, and an accounting of the contributions of hatchery produced fish to fisheries. We recommend an independent assessment of hatchery programs within the SBC Chinook salmon domain. The Pacific U.S. has examples of such reviews: the Columbia River basin (HSRG 2009), Puget Sound (HSRG 2004) and by the California HSRG (CA HSRG 2012) as a template.

There appeared to the Panel to be limited integration of information between SEP and the assessment programs responsible for data collection and analyses of the hatchery and natural population performance information. Development of integrated assessment teams from multiple disciplines (including hatchery evaluation, population dynamics, stock assessment, harvest management, and science) would improve sharing of data, increase collaboration in analyses, and integration of hatchery and wild production in management.

8 PATHOGENS

8.1 PLAUSIBILITY OF PROPOSED MECHANISMS

A pathogen is an infective agent (e.g., virus, bacteria, fungi, or parasite) that has the potential to cause disease. Pathogens and disease are ubiquitous in natural and cultured populations of animals, but animals may carry pathogens without the expression of disease. Disease is commonly expressed due to the interactions of an individual, a pathogen, and their environmental conditions; conditions that induce stress in an animal increase the likely expression of disease. However, in the context of this review (i.e., to explain the trend in declining returns of SBC Chinook salmon) the expression of disease must contribute to population-level impacts, have occurred over a period of years, and have involved infectious agents known to cause mortality (directly or indirectly). There is no doubt that pathogens and disease cause mortality in Chinook salmon individuals, but evidence of population level impacts in southern BC Chinook salmon is very limited and largely inferred from experience in cultured populations (both in federal hatcheries and the salmon farming industry, also see Hershberger et al. 2013). Cultured fish are intrinsically more vulnerable to disease epizootics than wild fish as a result of the culture environments (e.g., density of animals, exposure of fish, artificial environments), and if moribund fish remain within a cultured environment they can be a source of pathogens to the rest of the population (although it is acknowledged that fish culture practices will attempt to minimize this risk). However, the existence of genetic variation between populations in resistance to pathogens certainly infers that disease can be an important factor in individuals and populations in the wild (e.g., Beacham & Evelyn 1992 a, b). In certain circumstances, wild fish can also encounter high densities and be exposed to moribund fish, e.g., returning adults in a stream with low flows and elevated temperatures. There is little doubt that pathogens can contribute to variation in Chinook abundance both between populations and over time, but the monitoring of disease impacts on wild populations is now largely non-existent in BC thus the extent to which disease contributes to variation in Chinook abundance both between populations and over time is not known.

Further, a pathogen may be endemic to Chinook, meaning that they shared a geographic range over time, and Chinook may then develop an inherent resistance to the expression of disease caused by the pathogen. Alternatively, a pathogen may be exotic to Chinook salmon, meaning that they have not overlapped geographically in the past. An exotic pathogen introduced (naturally or through human interaction) pose additional risks to Chinook salmon because the species (or geographic segment of the species) may not have resistance to the specific agent (although resistance to other similar pathogens can provide some ability for the animal to minimize the effect of an exotic infection).

8.2 KEY EVIDENCE

There was no quantitative evidence presented to the panel, but the authors summarized their understanding in the following paragraph (workshop submission by Higgins et al., May 2013), and provided a table of known pathogens reported for Chinook salmon generally (**Table P-1**):

> **"Impacts of Disease in Chinook Salmon**
>
> Based on our knowledge of infectious diseases of fish, potential impacts on salmon populations can occur directly through mortality of individuals or indirectly through changes in various performance parameters including, but not limited to, swimming ability, growth, and reproduction. However, quantification of these disease impacts in wild fish can be difficult. We anticipate that fish mortality due to disease goes unnoticed or underestimated in wild populations due to the difficulties in finding and recovering carcasses. Only in certain cases where large numbers of fish all succumb to a pathogen at once (e.g. VHSv and *Ichthyophonus hoferi* in Pacific herring) do we see the results of large scale die offs. It is more likely that the impacts of disease are indirect and result from the interactions of numerous factors that may be difficult to tease apart (i.e. infectious disease increases susceptibility to predation due to reduced swimming performance). This also implies that the severity of disease will vary among members of a population. The impacts of an infection in an apparently healthy population can be difficult to assess because the relationship between 'infection' and 'disease' is often unknown. Thus predicting a disease consequence based only on the observation of a pathogen is rarely possible. "

Higgins et al. did acknowledge that three pathogens (*R. salmoninarum, A.salmonicida, and V. anguillarum*) have the "the potential to contribute to changes in Chinook salmon productivity". Three slides were provided that summarize what is known (**Figures P-1a, b, c**). The federal hatchery system is able to control the incidence and effect of these pathogens through culture practices and vaccination treatments.

Regarding the risks of open net-pen salmon aquaculture to wild Chinook salmon, Higgins et al. stated that "we expect that there is a low risk of transmission of pathogens from farmed Atlantic salmon to wild Chinook salmon because of differences in susceptibility to various disease organisms as well the related husbandry practices ... that minimize the occurrence of disease in farmed salmon." Those authors had previously suggested minimal risk of infection from aquaculture-reared Chinook salmon due to their small numbers in the industry currently.

The Panel also noted the presenters' inclusion of *Piscine reovirus* as an endemic pathogen in BC (footnote to **Table P-1**). Given the recent publication by Kibenge et al. (2013), the panel questioned the designation of this virus. The authors clarified that the listed pathogens in **Table P-1**, with the exception of (PRV), are known to occur in wild salmonids and non-salmonids, and are considered by fish disease experts to be endemic to the Northeast Pacific. Further, they noted that PRV has now been identified in multiple species and multiple areas of the western coast of North America, including Washington and Oregon. This issue is beyond the immediate expertise of our panel members but will clearly require continued research. However, in our opinion, any concern that a pathogen may be exotic to the Pacific coast must be treated with extreme caution and merits immediate attention.

The authors' concluded:

"Pathogens are a natural component of all ecosystems and not all infections lead to disease. Often endemic pathogens are 'well-adapted' in that they do little to harm their host, however, the incidence and severity of disease from such pathogens may increase if abnormal conditions and/or adverse factors ("stressors") occur. "

8.3 Have Pathogens Likely Been a Factor Responsible for Recent Trends in Abundance of Southern BC Chinook?

Given the paucity of information contained in this presentation, it is not possible to comment on whether pathogens and associated diseases have contributed to the reduction in Chinook abundance and catches in southern BC. Based on the presenters' comments and support from the scientific literature, the panel concludes that a number of the pathogens identified in **Table P-1** are likely to result in reduced survival and growth of Chinook salmon individuals. The fact that hatcheries and aquaculture sites must use vaccinations to control the few diseases that occur under culture conditions certainly suggests that disease could be a significant mortality factor. However, extension to natural populations is uncertain. Extrapolation to natural populations would require exposure of individuals to infective agents, environmental conditions allowing for expression of the disease, and a lack of compensatory mechanisms (i.e.; mechanisms that could compensate for small to moderate losses due to disease) over the life of animals.

8.4 Uncertainties, Critical Information Gaps, and Recommendations

1. Monitoring and reporting of pathogens and disease occurrence in cultured and natural populations is inadequate and should be increased. While the authors note that the existence of pathogens cannot be equated to the presence of disease, we certainly know that disease seldom occurs without pathogens. Therefore, monitoring for pathogens is a first step in the identification of infectious agents and the potential risk of disease in Chinook populations.

2. Interpreting the presence of pathogens in terms of the risk to natural populations requires more research into the dynamics of disease expression, interactions with environmental conditions (particularly in light of climate change effects), and the potential role of freshwater hatcheries and marine net pen operations in the persistence of pathogens and risk of transmission to natural populations. Further, we know that different species and populations of Pacific salmon have different susceptibilities to specific pathogens, and that different strains of a pathogen can have very different virulence in expression of disease; these complications make these studies multi-factorial and requiring specialized research facilities and collaborations.

3. The Panel also recommends more in-depth consideration of the interaction of salmon farms with the hatchery and natural populations of Chinook salmon. These studies should be integrated with surveillance of wild salmonids and environmental conditions, but the abundance and concentration of aquaculture fish in southern BC generates public concern for the extent of risk posed by them. Concern about the potential interaction between cultured and wild will simply continue without direct investigations.

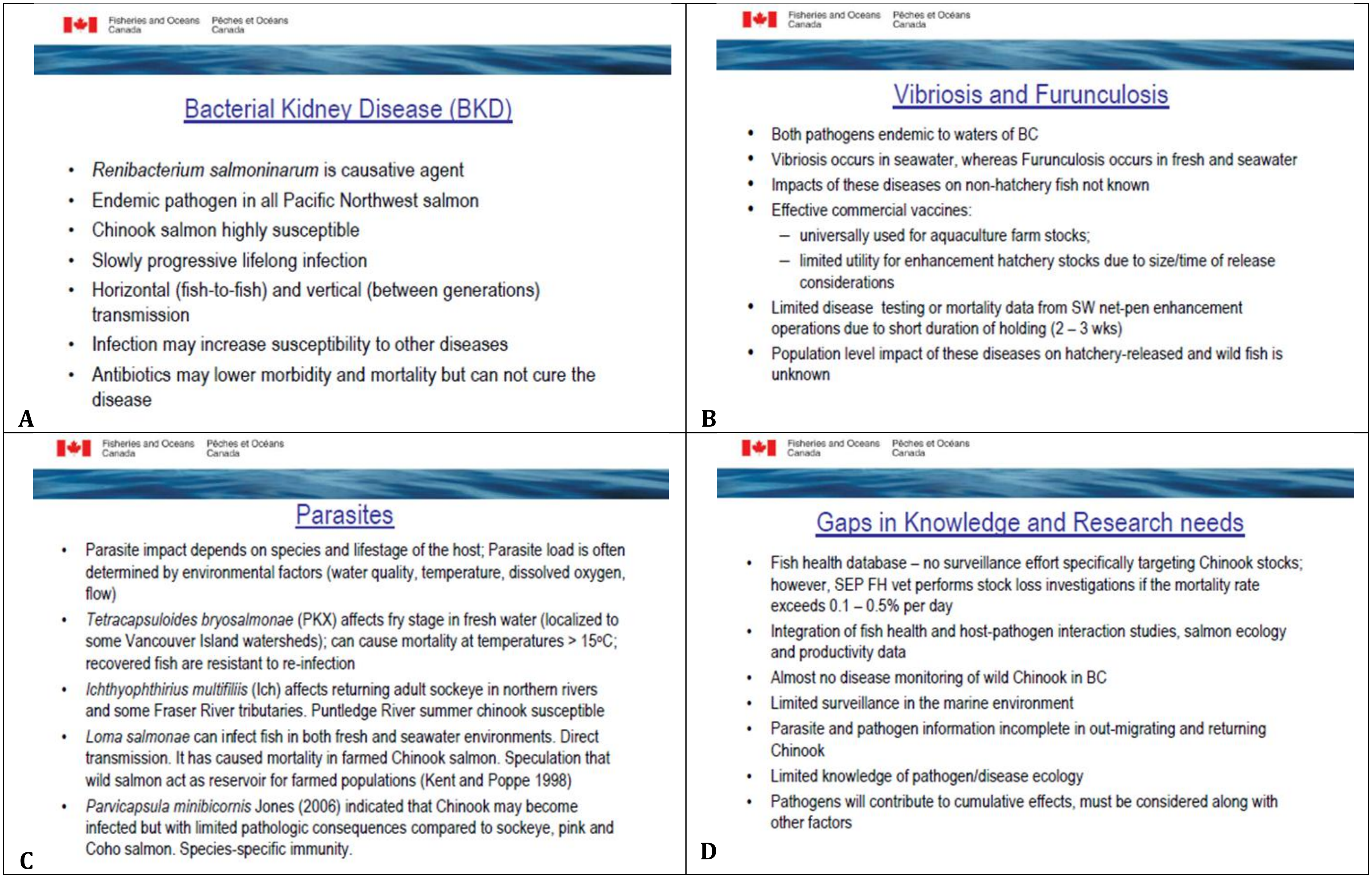


Figure P-1. Known disease concerns for Chinook salmon in Southern BC (panels A, B, and C) and gaps in knowledge and research (panel D). Source: Mark Higgins et al., DFO, workshop presentation, May 2013.

Table P-1. Pathogens reported from Chinook salmon, those documented to cause disease in BC Chinook populations are highlighted in red italics. Source: Mark Higgins et al., DFO workshop handout, May 2013.

Type	Pathogen	Disease
Bacteria	*Renibacterium salmoninarum*	Bacterial Kidney Disease (BKD)
	Aeromonas salmonicida	Furunculosis
	Yersinia ruckeri	Enteric Redmouth Disease (ERM)
	Flavobacterium branchiophila	Bacterial Gill Disease (BGD)
	Vibrio Spp.	Vibriosis
	Pseudomonas Spp.	
	Piscirikettsia salmonis	
	Flexibacter	Columnaris disease
Viruses	Infectious hematopoietic necrosis virus	Infectious hematopoietic necrosis (IHN)
	Viral Erythrocytic Necrosis virus	Erythrocytic necrosis (VEN)
	Erythrocytic Inclusion Body Syndrome (EIBS)	
	Viral Hemorrhagic Septicemia virus (VHSv)	
	Pacific Salmon Paramyxovirus (PSPV)	
	Piscine reovirus (PRV) †	‡
	Salmonid herpesvirus	
Parasites	*Parvicapsula kabatai*	
	Ichthyophthirius multifiliis	Ich or white spot disease
	Loma salmonae	
	Eubothrium salvelini	
	Tetracapsula bryosalmonae	Proliferative kidney disease (PKX)
	Ceratomya shasta	Ceratomyxosis
	Lepeophtheirus salmonis	
	Caligus clemensi	
	Cryptobia salmositica	
	Myxobolus cerebralis	
	Nucleospora salmonis	
Fungus	*Icthyophonus hoferi*	
	Phoma herbarum	
	Sphaerothecum destruens	

† Piscine reovirus is included here as a new finding - it has yet to be determined how widespread its distribution is or its origin. ‡ *Piscine reovirus* has been associated with Heart and Skeletal Muscle inflammation (Palacios et al. 2010) in farmed Altantic salmon.

9 Future Climate Change

"Indigenous Peoples of British Columbia have always had to accommodate and respond to environmental change. Oral histories, recollections of contemporary elders, and terms in indigenous languages all reflect peoples' responses to such change, especially since the coming of Europeans. Very recently, however, many people have noted signs of greater environmental change and challenges to their resilience than they have faced in the past: species declines and new appearances; anomalies in weather patterns; and declining health of forests and grasslands. These observations and perspectives are important to include in discussions and considerations of global climate change." (Abstract, Turner and Clifton 2009)

9.1 Plausibility of Proposed Mechanisms

Given the numerous and interconnected pathways that changes in climate (meaning trends in climate patterns as opposed to cycles or random variation in annual conditions) could affect production of Chinook salmon in southern BC, it is highly likely that climate change has affected production of these fish and that it will have increased effects in the future. Effects are likely mediated through changes in temperature (Ferrari et al 2007, Morrison et al 2002), stream flow volume and seasonality (Dery et al 2012), reductions in glaciers (Stahl et al 2008, Schiefer et al 2007[13]), pathogens and non-indigenous species, disease, and contaminants (Walker and Winton 2010, Noyes et al 2009, Sanderson et al 2009, Harvell et al 2002), plus changes in the marine environment (Rensel et al 2010, Mooney et al 2009, Moore et al 2008). In southern BC, most assessments of climate change have been within the Fraser River and largely focused on mainstem temperature and flows due to impacts on up-stream migration rate and survival on sockeye salmon (**Figures CC-1, CC-2**); but also see Sykes et al (2009) for an example of the potential effect on Chinook smolt behaviour. These figures are simply two of many examples available that demonstrate an earlier freshet in the Fraser (data from Environment Canada), and the increase in summer temperatures (Patterson et al 2007). Presently, over half of the Fraser flow volume passes Hope in the lower Fraser Basin before July 1st. The record-high flow volume past Hope was in 2007, the year that resulted in the extremely poor 2009 Fraser sockeye return. Increases in temperature in the lower Fraser have been significant ($P<0.001$) since 1953 with the largest increase of 1 °C for the summer minimum temperature.

While climate likely has an impact on southern BC Chinook through a number of these pathways, no evidence was presented to the workshop that could attribute some portion of the decrease for the period 1995 to 2012 to this mechanism.

[13] Glacier recession in BC accounts for 8.3% of the global contribution from mountain glaciers and ice caps to sea level change. The recent rate of loss in southern BC Coastal mountain glaciers (17 km^3 / annum) is approximately double the rate of the previous two decades!

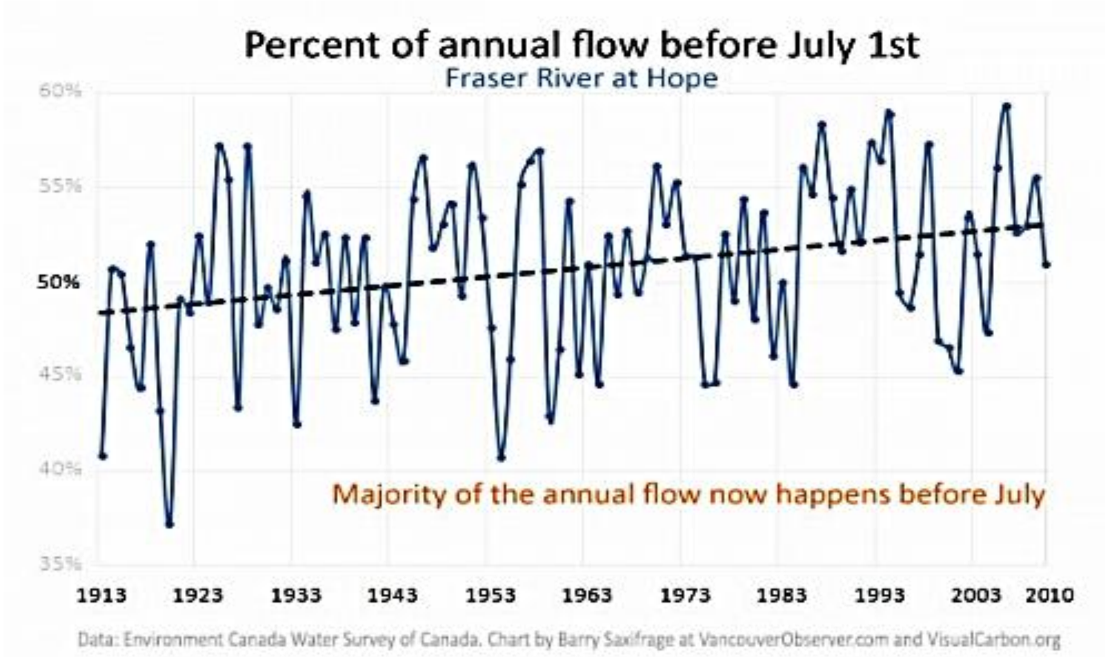


Figure CC-1. Percent of total annual Fraser River flow that occurs before July 1st. Source: data from Environment Canada Water Survey of Canada, chart by Barry Saxifrage, at VancouverObserver.com and VisualCarbon.org

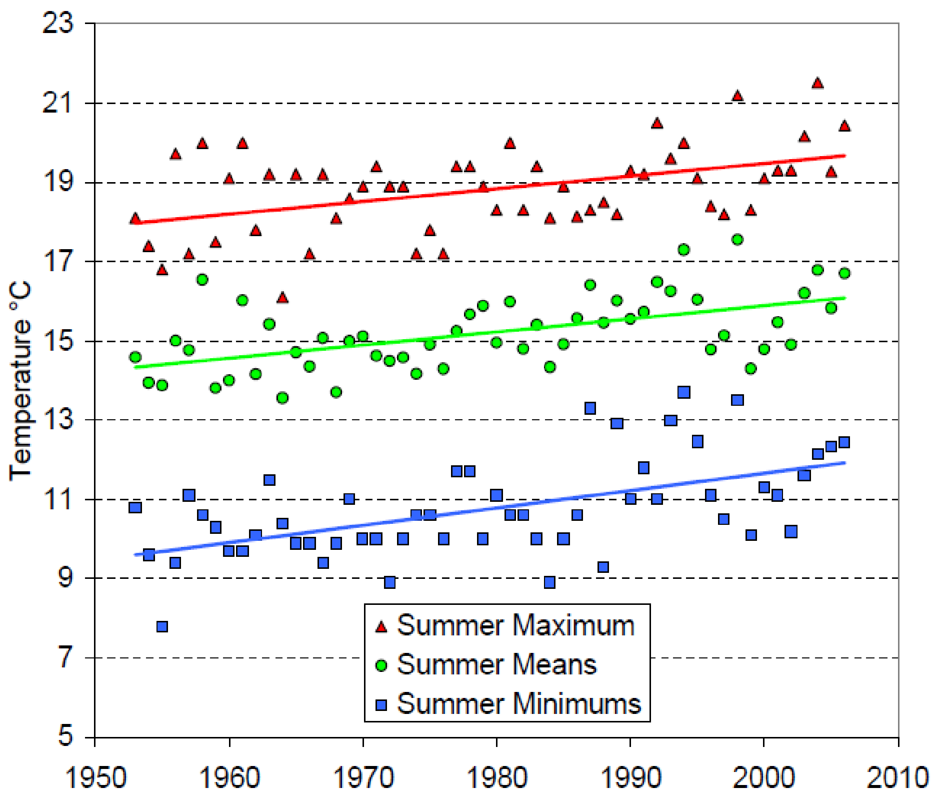


Figure CC-2. Daily mean, yearly maximum and minimum temperatures in lower Fraser River, for summer season (June 1st to September 30th) for 1953 to 2006 (n=54 years). Source: Patterson et al. 2007

9.2 KEY EVIDENCE

Evidence presented to the review panel regarding climate variability and change (CVC) was more focused on the future than the past. The presentation included forecasted climate change plots for four parameters, examples of 'Pathways of Effect' models as a tool for understanding impacts of CVC on Chinook salmon, a projection of changes in sea surface temperature (SST) in the Strait of Georgia, and conclusions. Unfortunately, the utility of the materials was limited by a lack of explanatory text supporting the PowerPoint presentation (limiting our understanding of plots and terms applied in plots), no information at all on the period of interest in the Status and Trends assessment (1995 to 2012), and a limited scope of consideration (temperature and precipitation).

The climate-change presentation at the workshop suggested the following projected future impacts (to 2050s) relative to the period (1961-1990) (note that these projections were made without reference to which climate model or climate change scenario was used to generate these values):

1. Change in average maximum air temperature in summer of +1.0 to +2.7°C for the area of interest for southern BC Chinook (maximum change in southeastern BC).
2. Change in average winter air temperature of zero to +4.0°C for the area of interest for southern BC Chinook (based on visual interpretation of slide presented).
3. Change in total precipitation in the winter of +5 to +20% for the area of interest for southern BC Chinook (based on visual interpretation of the slide presented).
4. Change in total precipitation as snow (mm) of -100% to zero for the area of interest for southern BC Chinook (based on visual interpretation of the slide presented).

Based on the materials presented, the Panel could not assess whether climate impacts have contributed to the change in southern BC Chinook production, although the graphic provided of the salmon life cycle certainly indicated numerous potential sources of impact (**Figure CC-3**).

9.3 HAS CLIMATE CHANGE LIKELY BEEN A FACTOR RESPONSIBLE FOR RECENT TRENDS IN ABUNDANCE OF SOUTHERN BC CHINOOK?

While climate change effects on southern BC Chinook salmon are highly likely given the diversity of possible interactions, there are no quantitative conclusions that can be drawn from the workshop presentation. Such broad overviews as was presented overlook the diversity of life history types of Chinook in southern BC (not all types will be equally affected), the complex topography of southern BC and diversity of stream types involved, and the potential for behavioural adaptation of Chinook to change. Each of these factors limits what can be concluded at a broad geographic scale, as has been determined in more in-depth (or localized) evaluations (for examples: Isaak et al 2012, Thorne and Woo 2011, Fleming et al 2007, Tolimieri and Levin 2004).

Further, given the investment by DFO Science in the Ecosystem Research Initiative, an in-depth consideration of the Strait of Georgia and the potential impact on southern BC Chinook was noticeably absent.

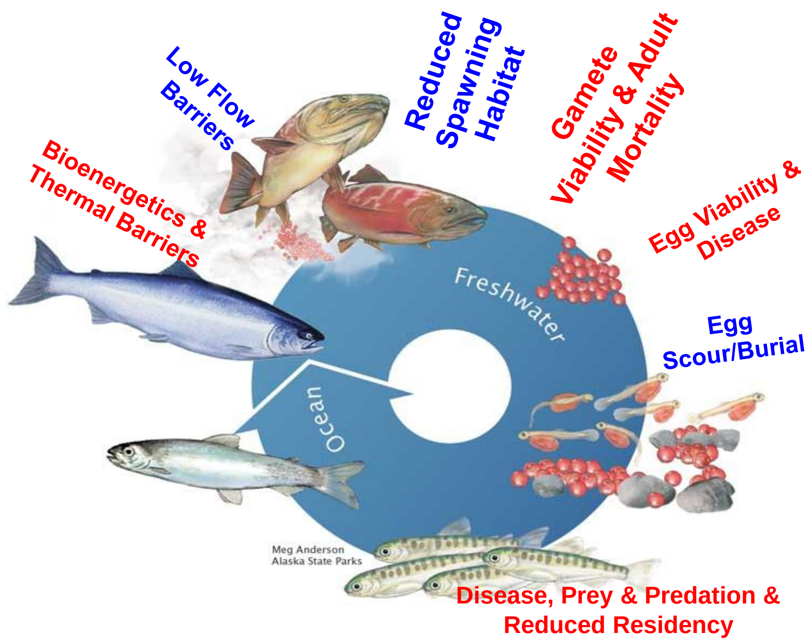


Figure CC-3. Salmon life cycle and potential characters that may limit salmon production due to climate change impacts on their habitat and spawning success. Source: Kim Hyatt, DFO, presentation, slide 7. Figure attributed to Meg Anderson, Alaska State Parks.

9.4 Uncertainties, Critical Information Gaps, and Recommendations

- The ability to determine how environmental conditions affect Chinook salmon production is currently inadequate. Initially, an analysis should be conducted of how climate change for the period 1995-2012 might be associated with southern BC Chinook production. This assessment should also consider the geographic scale for future assessments, accessibility to necessary environmental data, and analytical models and methods to apply (e.g., coded-wire tagged indicator stocks, life cycle models, etc.). Essentially, an experimental design should be developed for monitoring and assessing the impact of climate change on BC's Pacific salmon.

- The complexity of BC's topography, diversity of life history types for BC Chinook salmon, and the numerous pathways for climate change to affect Chinook production argues for a new and more holistic approach to monitoring and assessments related to climate change. The effects of climate variation and change will be pervasive across Pacific salmon throughout BC and the

Yukon. A multi-disciplinary team involving government departments, academia, First Nations and NGOs may be the appropriate model for integrated research, monitoring and evaluation rather than a few people working independently in different organizations.

- The effects of climate change can occur throughout the life cycle of Pacific salmon. To isolate the effects of climate change over time on salmon, the other factors that will also impact Chinook salmon abundance will have to be accounted for. The latter requires accounting for annual variation in freshwater and marine survival; exploitation including total fishing mortality by age; quantitative monitoring of spawning escapements by age (including losses during up-stream migration, retention of eggs and pre-spawning mortality of females); and accounting for any hatchery produced first-generation returns. This level of detailed assessment information is costly and will require the designation of 'indicator stocks or populations' strategically placed to represent the major life history types of Chinook salmon (i.e., consistent with Step 3,Strategy 1 of Canada's Wild Salmon Policy (DFO 2005, see: http://www.pac.dfo-mpo.gc.ca/publications/pdfs/wsp-eng.pdfhttp://www.pac.dfo-mpo.gc.ca/publications/pdfs/wsp-eng.pdf).

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APPENDICES

Appendix I-1: Agenda of the Southern BC Chinook Salmon Science Workshop

Fisheries and Oceans Canada Pêches et Océans Canada

Fraser River Aboriginal Fisheries Secretariat

Southern BC Chinook Science Workshop

May 22-24, 2013

Sheraton Vancouver Airport Hotel
7551 Westminster Highway
Richmond BC

Strategic Planning Objective:

The Southern BC Chinook Science Workshop results will be used to inform and guide on-going work to develop an Integrated Strategic that accounts for the biological status of southern BC Chinook conservation units, their habitat and the ecosystem, that addresses the causes of any declines, and identifies the management actions necessary to remedy their status where possible. The Integrated Strategic Planning process will depend on the collaboration of First Nations, interest groups and DFO to identify rebuilding actions related to fisheries management, salmonid enhancement and habitat restoration.

Deliverables from the Integrated Strategic Planning process will provide guidance to annual Integrated Fisheries Management Plans, fish culture production plans, habitat restoration work plans and community partnership agreements where possible. It may also inform Pacific Salmon Treaty discussions between Canada and the United States.

This strategic plan will be developed in a manner consistent with Strategy 4 of the Wild Salmon Policy, the Rebuilding Guidelines of the Precautionary Approach Framework and the Species at Risk Act.

Workshop Objectives:

1. Review status and trends of southern BC Chinook salmon Conservation Units (or management units where applicable) and associated component populations.
2. Synthesize evidence and associated insights regarding :
    a. The impact, relative importance and potential for mitigation of factors hypothesized to limit the productive capacity of Chinook salmon originating from southern BC rivers?
    b. The future risks associated with climate change and potential adaptation strategies?
3. Recommend additional research and monitoring to address gaps and support future planning.
4. Review existing management/assessment tools that could be used to incorporate risks into a management decision making framework and offer suggestions for improvement

Day 1 – May 22, 2013

1. INTRODUCTION 8:30 am – 9:10 am

40 minutes

Welcome and Opening Prayer
Wade Grant (Musqueam)

Workshop welcome, panel introductions, and overview of structure
Dave Marmorek (ESSA Technologies)

Planning Context and Background: Rationale for workshop and how the outputs from the science workshop will be used
Mark Saunders (DFO) and Ken Malloway (FRAFS)

2. STATUS AND TRENDS 9:10 am – 10:20 am

2 hours (1 hr 10 minutes for presentation; 50 minutes for discussion)

Theme: What are the patterns in Southern BC Chinook stocks that we seek to explain?
Sub-topics to be covered in presentation:

- Status and trends of Southern Chinook stocks within and across different conservation units
- Changes in productivity, survival, escapement
- Changes in productivity of hatchery stocks
- High level overview of life history differences across CUs and variation in stressors by CU
- Broader scale examination of trends in productivity and survival from Oregon to Alaska

Presenters: Gayle Brown (DFO), Mary Thiess (DFO), Steve Baillie (DFO)
Contributors: Southern BC Chinook Technical Working Group, Brigitte Dorner, Randall Peterman

BREAK – 15 minutes 10:20 am – 10:35 am

STATUS AND TRENDS (cont'd) 10:35 am – 11:25 am

50 minutes discussion

3. HARVEST 11:25 am – 12:35 pm

1 hour 10 minutes (40 minutes for presentation; 30 minutes for discussion)

Theme: Has fishery-caused mortality contributed significantly to observed patterns over time and space in the abundance or productivity of Southern Chinook stocks?

Sub-topics to be covered in presentation:

- Effects of harvest on the abundance and trend of Southern Chinook stocks and distribution of harvest across space and time (based on CWT data)

Presenters: Chuck Parken (DFO)

Contributors: Richard Bailey (DFO) Terry Beacham (DFO), Gayle Brown (DFO), Diana Dobson (DFO), Wilf Luedke (DFO), Larrie Lavoy (NOAA), Marla Maxwell (DFO), Mike Staley (IAS), Ivan Winther (DFO), Antonio Velez-Espino (DFO), Dave Willis (DFO)

LUNCH – 1 hour	12:35 pm – 1:35 pm

4. FRESHWATER HABITAT 1:35 pm – 3:25 pm

1 hour 50 minutes (1 hour for presentation; 50 minutes for discussion)

Theme: Do changes in the suitability or productivity of the freshwater habitat used for spawning, rearing, and migration explain the observed patterns over time and space in the abundance and productivity of Southern Chinook salmon stocks?

Sub-topics to be covered in presentation:

- Habitat pressure indicator scorecards for Southern Chinook
- Analyses of correlations between Habitat Pressure Indicators and Chinook escapement trends over space and time
- Watershed-scale potential habitat stressors
- Past changes in freshwater flow and thermal patterns over space and time, and potential implications for historical changes in Southern Chinook populations

Presenters: Erland MacIsaac (DFO), Dave Patterson (DFO)

Contributors: Louise de Mestral Bezanson (DFO), Marc Porter (ESSA), Melody Farrell (DFO-retired), Lisa Thompson (DFO)

BREAK – 15 minutes	3:25 pm – 3:40 pm

5. MARINE HABITAT 3:40 pm – 5:00 pm

2 hours 20 minutes (1 hr 20 min for presentation; 1 hour for discussion [on Day 2])

Theme: Have changing ocean conditions (physical and biological) increased mortality rates of Southern Chinook salmon smolts, and contributed to observed patterns over time and space in the abundance or productivity of Southern Chinook stocks?

Sub-topics to be covered in presentation:

- Evidence of changing distribution and survival of Chinook with changing ocean conditions, including harmful algal blooms
- Changes in marine survival rates from CWT information
- Biologically relevant changes in ocean conditions, and potential influences of global warming
- Predation of Southern Chinook by marine mammal predation
- Integrated ecosystem perspective, including predators of juveniles and adults, and invasive species

Presenters: Marc Trudel (DFO)

Contributors: Dick Beamish (DFO), Bill Crawford (DFO), Sophie Johannessen (DFO), Dave Mackas (DFO), John Ford (DFO), Chrys Neville (DFO), Carrie Holt (DFO), Chuck Parken (DFO), Ian Perry (DFO), Strahan Tucker (DFO), Jim Irvine (DFO)

WORKSHOP SOCIAL 5:30 pm

Day 2 – May 23, 2013

MARINE HABITAT (cont'd) 8:30 am – 9:30 am

1 hour of discussion, continued from Day 1

6. HATCHERIES 9:30 am – 10:30 am

2 hours (1 hour for presentation; 1 hour for discussion)

Theme: Has productivity of hatcheries changed over time, and has the productivity or abundance of wild stocks been affected by hatchery releases?

Sub-topics to be covered in presentation:

- History and function of Chinook hatcheries in the study area, including source populations and outplanting locations
- Changes in hatchery stock productivity and genetic diversity over time
- Analyses of Southern Chinook stock productivity and evidence for hatchery effects on wild stocks

Presenters: Ruth Withler (DFO), David Willis (DFO)

Contributors: John Candy (DFO), Carol Cross (DFO), Chuck Parken (DFO), Doug Lofthouse (DFO), Gayle Brown (DFO), Cheryl Lynch (DFO), Terry Beacham (DFO), Nick Komick (DFO), Marc Labelle (DFO)

BREAK – 15 minutes 10:30 am – 10:45 am

HATCHERIES (cont'd) 10:45 am – 11:45 am

1 hour of discussion, continued from before break

7. PATHOGENS 11:45 am – 12:15 pm

60 minutes (30 minutes for presentation; 30 minutes for discussion)

Theme: Has mortality from pathogens (including from hatcheries and aquaculture) during either freshwater or ocean phase contributed to changes in productivity or abundance of Southern Chinook salmon stocks?

Sub-topics to be covered in presentation:

- Known and hypothesized mechanisms and relationships
- Critical information gaps

Presenters: Mark Higgins (DFO)

Contributors: Kyle Garver (DFO), Chris MacWilliams (DFO), Stewart Johnson (DFO), Simon Jones (DFO), and Kristi Miller-Saunders (DFO)

LUNCH – 1 hour	12:15 pm – 1:15 pm

PATHOGENS (cont'd) 1:15 pm – 1:45 pm

30 min of discussion, continued from before lunch

8. FUTURE CLIMATE CHANGE 1:45 pm – 2:25 pm

40 minutes (20 minutes for presentation; 20 minutes for discussion)

Theme: What are the implications of climate change projections for Southern Chinook stocks?
Presenter: Kim Hyatt (DFO)
Contributors: Howard Stiff (HW Stiff Consulting), Marc Nelitz (ESSA),

BREAK – 15 minutes	2:25 pm – 2:40 pm

9. REFINING RELATIVE IMPORTANCE OF STRESSORS
2:40 pm – 5:00 pm

2 hours 20 min

Sub-group Discussion:
- Sub-groups will each examine a major grouping of CUs
  - e.g., lower Fraser River, middle/upper Fraser River, north/south/lower Thompson River, lower south coast and other, and west coast Vancouver Island and upper south coast
- Discussion of the relative importance of stressors by CU within the group, based on:
  - initial table of stressors by CU presented at the beginning of the workshop (revise as required)
  - presentations and discussions on each major theme
  - regional expertise and knowledge of CUs and stocks within group

Plenary Discussion:
- Sub-groups report back on discussions and conclusions to all participants

Day 3 – May 24, 2013 (Expert Advisory Panel Only)

*NOTE: 8:30 am – 5:00 pm (including **2 15-minute breaks** and **1 hour for lunch**)*

EXPERT ADVISORY PANEL EVALUATION OF THE AVAILABLE EVIDENCE

7 hours

1. **Review and adjustment of task process (0.5 hours)**
2. **Plenary review of information and evidence presented (4.0 hours):**
    a. Evidence for/against alternative factors and processes within each theme
    b. Evaluation of likelihood of different stressors for explaining observed patterns
    c. Identification of key uncertainties
    d. Recommendations
3. **Individual and team writing of draft sections for the report (2.5 hours)**

APPENDIX I-2: SOUTHERN BC CHINOOK CONSERVATION UNITS

List of the southern BC Chinook Conservation Units (CUs), the predominant Chinook life history type, the predominant run timing of adult returns, and major Chinook watersheds within each CU.

CU Name	Predominant juvenile life history type	Predominant adult return run timing	Major watersheds within CU (may not be exhaustive)
Lower Fraser River			
CK-03: Lower Fraser – fall	Ocean type	Fall	Lower Harrison River between Harrison Lake and Fraser River
CK-04: Lower Fraser – spring	Stream type	Spring	Alouette River, Birkenhead River, Chehalis River, Chilliwack River – Upper, Coquitlam River, Green River, Ryan River, Stave River
CK-05: Lower Fraser – Upper Pitt	Stream type	Summer	Upper Pitt River + tribs (above Pitt Lake)
CK-06: Lower Fraser – summer	Stream type	Summer	ChilliwackRiverBig Silver Creek, Cogburn Creek, Sloquet Creek, Douglas Creek, Tipella Creek
CK-07: Maria Slough	Ocean type	Summer	Maria Slough to confluence with Fraser River
CK-9000: Chilliwack Hatchery – Harrison transplants	Ocean type	Fall	Chilliwack/Vedder River (100% enhanced stocks)
Middle & Upper Fraser River			
CK-08: Fraser Canyon – Nahatlach	Stream type	Spring	Nahtlach River, Anderson River
CK-09: Middle Fraser – Portage	Stream type	Fall	Portage Creek
CK-10: Middle Fraser – spring	Stream type	Spring	Baker Creek, Bridge River (incl. Yalakom), Cariboo-Upper, Chilako River, Chilcotin River, Churn Creek, Cottonwood River (incl. Ahbau, Lightning, Swift River), Driftwood River, Endako River, Horsefly River, Minton Creek, Nadina River, Narcosli Creek, Naver (Hixon) Creek, Stein River, Taseko Lake, West Road River (incl. Baezaeko, Clisbako, Coglistiko, Euchiniko, Nazko, Snaking)
CK-11: Middle Fraser – summer	Stream type	Summer	Baptiste Creek, Cariboo River, Chilko River, Elkin Creek, Kazchek Creek, Kuzkwa

CU Name	Predominant juvenile life history type	Predominant adult return run timing	Major watersheds within CU (may not be exhaustive)
			River, Leo Creek, Mitchell River, Nancut Creek, Natazutlo Creek, Nechako River, Necoslie River, Ormond Creek, Pinchi Creek, Pitka Creek, Quesnel River, Seton & Cayoosh Creeks, Seton River, Stellako River, Stuart River, Taseko River
CK-12: Upper Fraser – spring	Stream type	Spring	Bowron River (inc. Haggen Creek,, Indianpoint Creek, Sus Creek), Dome Creek, East & West Twin Creeks, Fraser River – Above Tete Jaune Cache, Goat River, Holliday Creek, Holmes River, Horsey Creek, Kenneth Creek, Herrick-McGregor (incl. Bad River (James Creek), Captain, Fontoniko, Ice, Otter, Seebach, Spakwaniko) McKale River, Morkill River (incl. Forget-me-not Creek), Nevin Creek, Ptarmigan Creek, Robson River, Salmon River, Slim Creek, Small Creek, Snowshoe Creek, Swift Creek, Willow River (incl. Wansa Creek)
North/South/Lower Thompson River			
CK-13: South Thompson - summer (age 0.3)	Ocean type	Summer	Adams River, Little River, Thompson River – Lower, South Thompson
CK-14: South Thompson - summer (age 1.3)	Stream type	Summer	Eagle River, Salmon River, Scotch Creek, Seymour River
CK-15: Shuswap River – summer	Ocean type	Summer	Shuswap River – Lower, Shuswap River – Upper, Wap Creek
CK-16: South Thompson – Bessette	Stream type	Summer	Bessette Creek, Duteau Creek, Harris/(Nicklen) Creek, Creighton Creek
CK-17: Lower Thompson - spring (age 1.2)	Stream type	Spring	Bonaparte River, Deadman River, Louis Creek, Nicola River, Coldwater River, Spius Creek
CK-18: North Thompson - spring (age 1.3)	Stream type	Spring	Albreda River, Blue River, Finn Creek, Lyon Creek, Mad River, Mud River, North Thompson River – Upper, Thunder River
CK-19: North Thompson – summer (age 1.3)	Stream type	Summer	North Thompson River, Lemieux Creek, Mann Creek, Barriere River, Raft River, Clearwater River, Mahood River
CK-82: South Thompson – Adams River Upper	Ocean type	Summer	Adams River - upper
Lower South Coast & Other			
CK-01: Okanagan	Stream type	Summer	Okanagan River from Okanagan Falls to the US border

CU Name	Predominant juvenile life history type	Predominant adult return run timing	Major watersheds within CU (may not be exhaustive)
CK-02: Boundary Bay	Ocean type	Fall	Sepentine River, Mahood Creek, Campbell River
CK-20: South Coast* - Georgia Strait (*includes watersheds managed out of Lower Fraser DFO office)	Ocean type	Fall	Indian River, Seymour River, Lynn Creek, Capilano River, Squamish River (and tribs – Mamquam, Cheakamus, Chuk-Chuk Creek, Ashlu Rivers, Branch 100 Creek, July Creek, Mashiter Creek, Shovelnose Creek, Spring Creek, Tenderfoot Creek), Chapman Creek (Sechelt),Tzoonie River, Lang Creek, Sliammon Creek, Theodosia River, Skwawka River, Toba River (incl. Little Toba and Klite Rivers), Quatam River, Brem River, Brothers Creek, Richards Creek
CK-21: East Coast Vancouver Island – Goldstream	Ocean type	Fall	Goldstream River, Tod Creek
CK-22: East Coast Vancouver Island – Cowichan/Koksilah	Ocean type	Fall	Cowichan/Koksilah rivers and tributaries
CK-23: East Vancouver Island – Nanaimo spring timing	Stream type	Spring	Upper Nanaimo River (and tribs)
CK-24: East Vancouver Island –summer timing	Ocean type	Summer	Nanaimo summer timing CU includes Nanaimo Lakes portion of the Nanaimo River, and Mid Puntledge River between Supply Creek and Morrison Creek
CK-25: East Vancouver Island – Nanaimo & Chemainus - fall timing	Ocean type	Fall	Nanaimo River (and tribs – Haslem Creek, Napoleon Creek), Chemainus River
CK-27: East Vancouver Island – Qualicum & Puntledge fall timing	Ocean type	Fall	Willow Creek, Oyster River, Simms Creek, Puntledge River (Lower, incl. Tsolum River, Morrison Creek), Tsable River, Qualicum River, Little Qualicum River, Englishman River
West Coast Vancouver Island & Upper South Coast			
CK-28: South Coast – southern fjords	Ocean type	Fall	Orford River, Southgate River, Teaquahan River, Phillips River, Apple River, Stafford River, Heydon Creek, Fulmore River, Kwalate River, Kakweiken River, Ahnuhati River, Franklin River, Sim River, Kingcome River, Wakeman River, Warner Bay Creek
CK-29: Northeast Vancouver Island	Ocean type	Fall	Quinsam River, Salmon River, Adam & Eve Rivers, Amor de Cosmos River,

CU Name	Predominant juvenile life history type	Predominant adult return run timing	Major watersheds within CU (may not be exhaustive)
			Campbell River, Cluxewe River, White River, Kokish River, Menzies Creek, Mohun Creek, Nimpkish River, Tsitika River, Quatse River
CK-31: Southwest Vancouver Island	Ocean type	Fall	Bedwell System, Carnation Creek, Caycuse River, China Creek, Coeur d'Alene Creek, Coleman Creek, Cous Creek, Cypre Creek, Effingham River, Franklin River, Gordon River, Henderson Lake Creek (incl. Clemens Creek), Ice River, Kennedy River (incl. Clayoquot River, Muriel Lake, Sand River), Klanawa River, Macktush Creek, Megin River, Mercantile Creek, Moyeha River, Nahmint River, Nitnat River, San Juan River (incl. Harris Creek, Lens Creek), Sarita River, Sooke River (incl. Ayum Creek, Charters River, De Mamiel Creek, Lens Creek, Rocky Creek), Somass-Sproat-Great Central System (incl. Ash River, Deer Creek, Drinkwater Creek, Gracie Creek, McBride Creek, Stamp River – Above Falls, Sproat River, Taylor River), Smith Creek, Sidney River, Thornton Creek, Tofino Creek, Toquart (and Little Toquart) Creeks, Tranquil Creek, Uchuk Creek, Warn Bay Creek, Watta Creek
CK-32: Nootka & Kyuquot	Ocean type	Fall	Amai Creek, Artlish River, Battle Bay River, Brodick Creek, Burman River, Canton Creek, Chamiss Creek, Chum Creek, Clanninick Creek, Conuma River, Deserted Creek, Easy Creek, Eliza Creek, Espinosa Creek, Gold River (incl. Muchalat River, Oktwanch River), Hoiss Creek, Houston River, Jacklah River, Kaouk River, Kashutl River, Kauwinch River, Kleeptee River, Leiner River, Malksope River, Mamat Creek, Marvinas Bay Creek, McKay Cove Creek, Mooyah River, Narrowgut Creek, Nasparti River, Ououkinsh River, Park River, Power River, Silverado Creek, Sucwoa River, Tahsis River, Tahsish River (incl. Silburn Creek), Tlupana River, Tsowwin River, Zeballos (and Little Zeballos) Rivers
CK-33: Northwest Vancouver Island	Ocean type	Fall	Goodspeed River, Mahatta River, Keith River, Klaskish River, East Creek, Colonial and Cayeghle Creeks (incl. Utluh Creek) , Marble River (incl. Benson River)
CK-34: Homathko	Stream type	Summer	Homathko River (incl. Cumsack Creek)
CK-35: Klinaklini	Stream type	Summer	Klinaklini River (incl. Devereux Creek)

Appendix STA-1: Summary Review of Spawning Escapement Data

Review of spawning escapement data provided by DFO in source file:

CUxEnhRank and Allsites TimeSeries_05Jun.xls

This summary was compiled so that the Panel could better understand the context of the analyses presented by the Department of Fisheries and Oceans. Those analyses were based on spawning escapements over the period 1995 to 2012. Departmental staff had been able to review methods and consistency of data during for that period. However, the mid-1990s was also a period of strong Chinook production along the coast. Trends in spawning abundance since then may not be representative of longer term trends in Chinook production.

The data contained in this file included all Conservation Units in southern BC and involved a total of 420 Chinook spawning sites, but data quality varies significantly between sites. The source data file provided indicates categories of data quality for these 420 sites as:

Persistent data (basis of analyses, data available for >50% of years) = 140 sites

Aggregated sites (accounted for within Persistent sites) = 86 sites

Data Deficient sites (no assessment) = 101 sites

Deleted data sets (< 25 fish a year, considered unlikely a local spawning group) = 80 sites

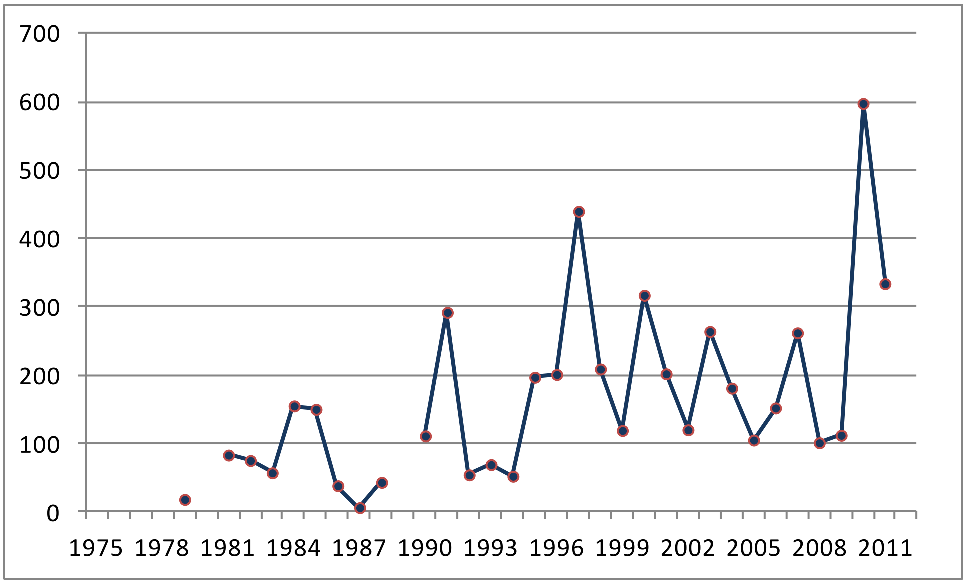
Extirpated sites (persistent data in past years but declined to few or no fish observed in recent years) = 13 sites.

Within the Persistent sites used in the analysis, the streams were also categorized based on the extent of enhancement activity within them (Unknown levels = 61 sites (assumed to be Low to no enhancement but could include some level of straying), Low enhancement = 22 sites, Moderate enhancement = 9 sites, High levels of enhancement = 44 sites, and 4 sites included stock transfers between Conservation Units, designated as High-Cross_CU).

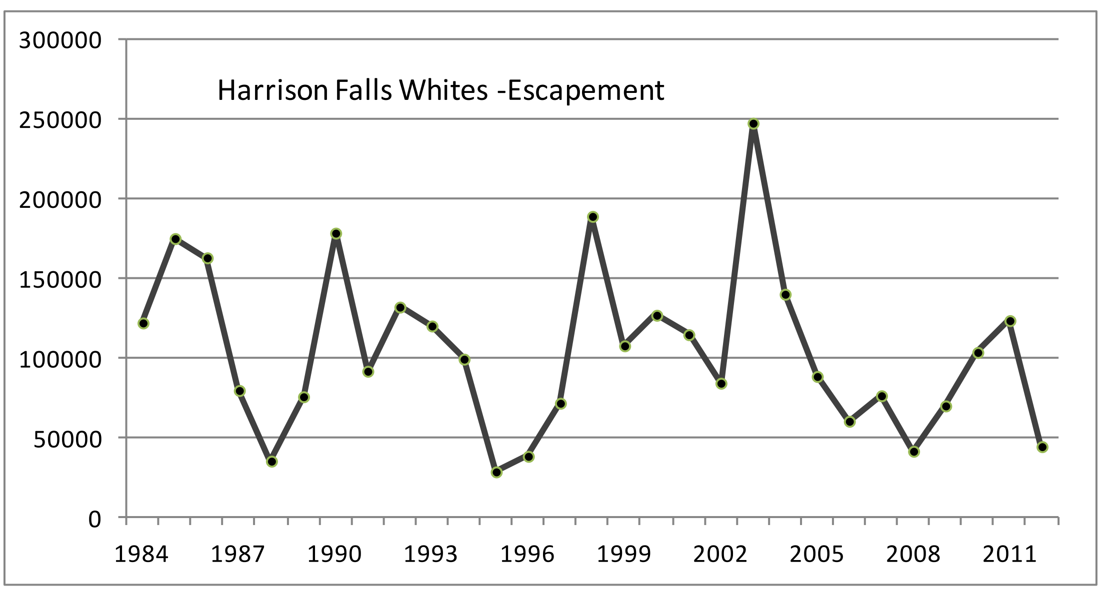
This appendix was NOT the basis for analyses conducted in the Status and Trends section of this report. These plots were prepared to better inform those who were not very familiar with Chinook salmon populations in southern BC; including members of this panel who were selected for their expertise in the topics that may help explain the observed trends in spawner data. These plots present the original data by streams without in-filling for missing data. This was intended to demonstrate the actual data available for analyses without the confusion of in-fill periods of missing data (which always involves a decision on the method to use for in-filling).

CK-01, Okanagan ... no historical data & data provided was very limited, not assessed

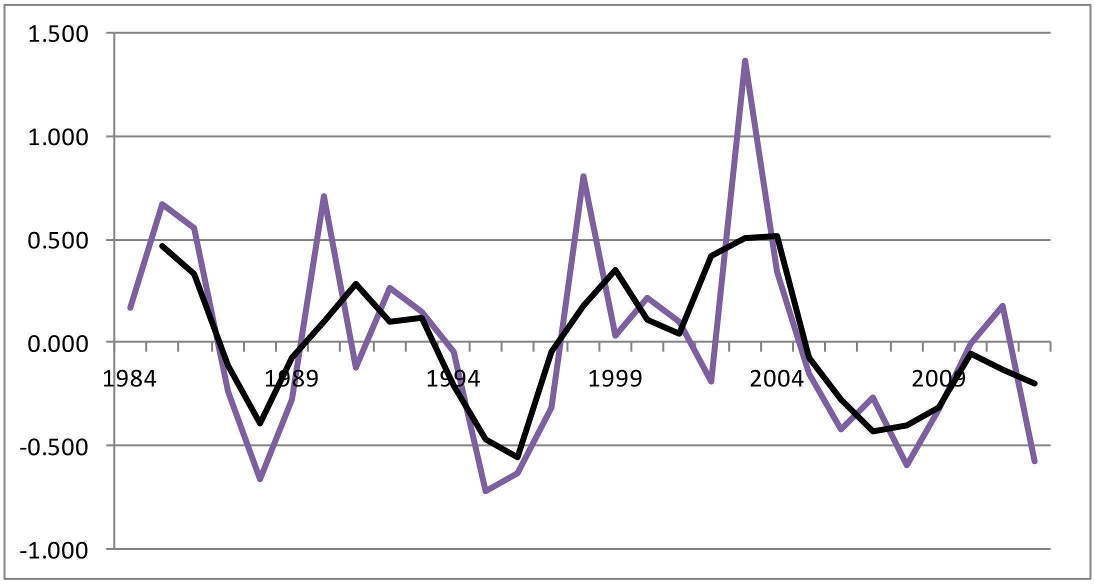
CK-02, Boundary Bay ... very limited data. Data for Campbell River only, stream is heavily enhanced. Since mid-1990s, returns have been variable but not declining. Plot presents the numbers of Chinook spawners by return year.



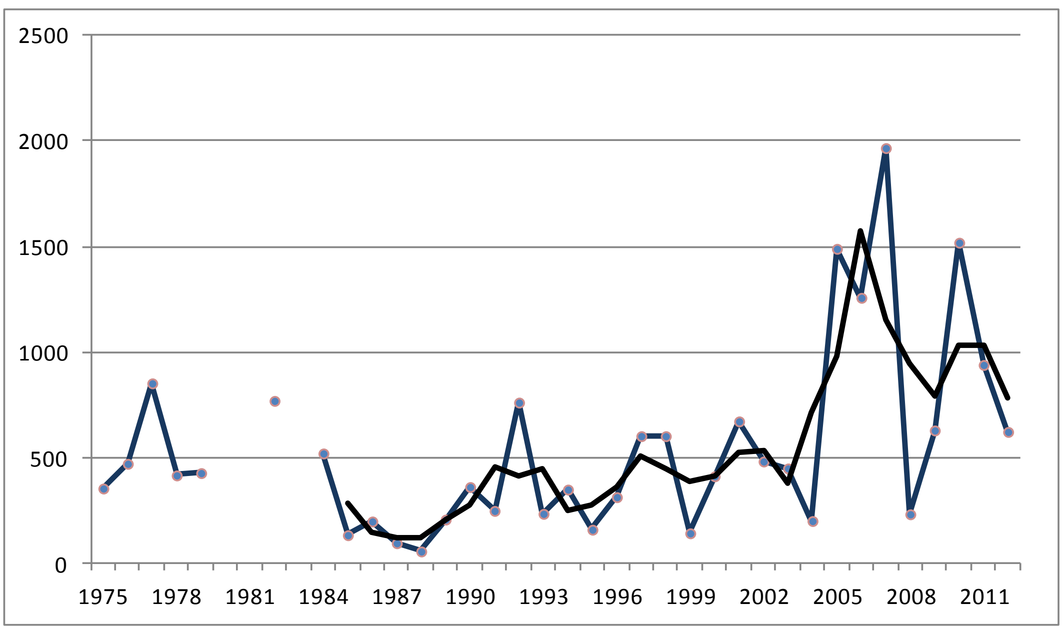
CK-03, Harrison River Fall Chinook (Indicator stock program and monitoring since 1984, annual mark recapture estimates, low enhancement). Reported spawning escapement (natural spawners + broodstock removed) for 1984 through 2012. Age 2 Jacks enumerated but not included.



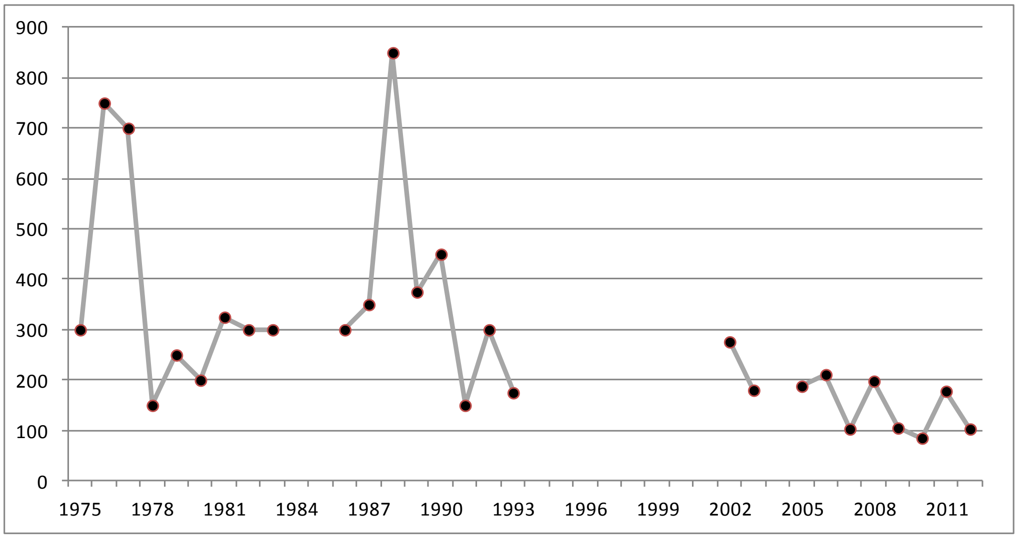
Standardized deviations based on average spawning values since 1984 (blue line); since only 3 age classes contribute to the spawning population, a 3-Point Moving average was applied to the Standardized Deviations (black line). *Escapement has been below average since the mid-2000s, there is not long term decline.*



CK-04, Lower Fraser River – Spring run timing. Birkenhead River only, others (n=3) have insufficient data for assessment or heavily enhanced. Increasing trend since mid-1990s; black solid line is a 3-point moving average of the reported numbers of spawners. *Escapement trend is increasing.*

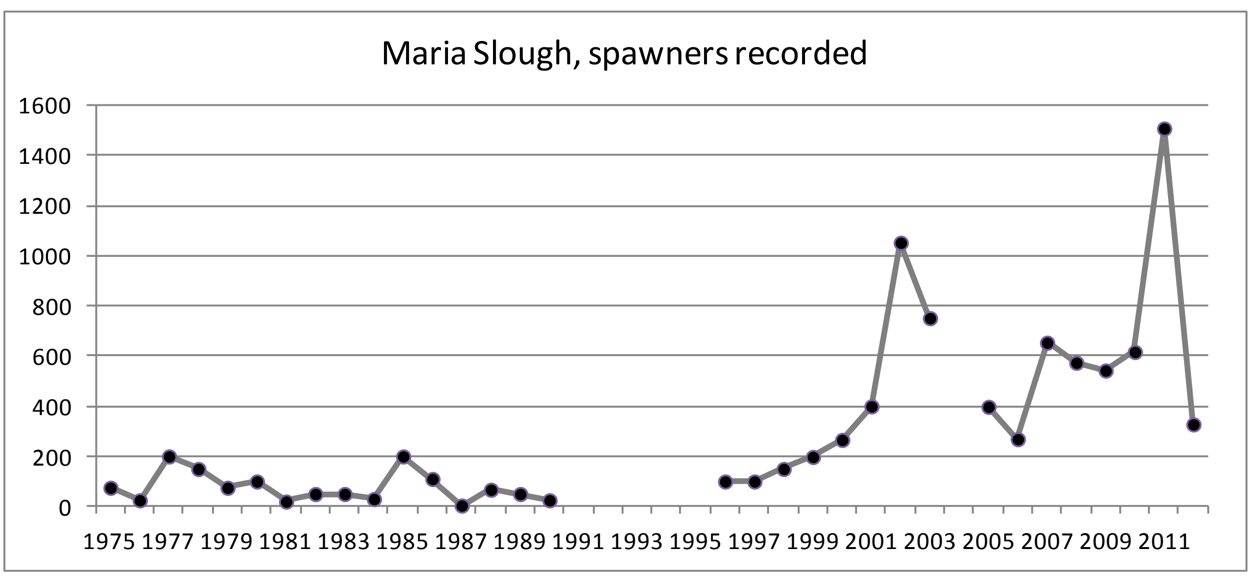


CK-05, Upper Pitt River ... inadequate data for assessment, no trend analysis due to missing data through the 1990s. Escapement values are a concern given only 100-200 spawners recently ... however, this Conservation Unit is assessed with visual surveys only (i.e, values are uncertain).

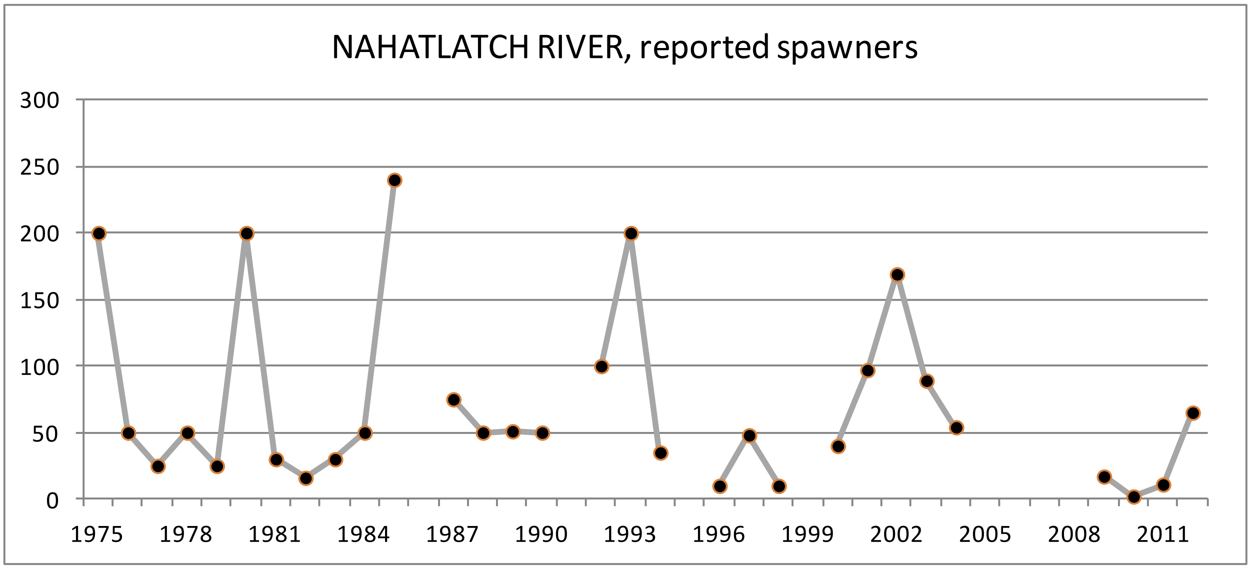


CK-06, Lower Fraser River – Summer run timing; no data presented. NOTE: pdf files provided to review panel indicated data for Big Silver Creek (Harrison Lake; data in-filled for 1987 to 2004) and Chilliwack River summers (no data after 1984) but the Excel file 'CUxEnh Rank and AllSites TimeSeries-05June' did not contain data for inclusion of this CU.

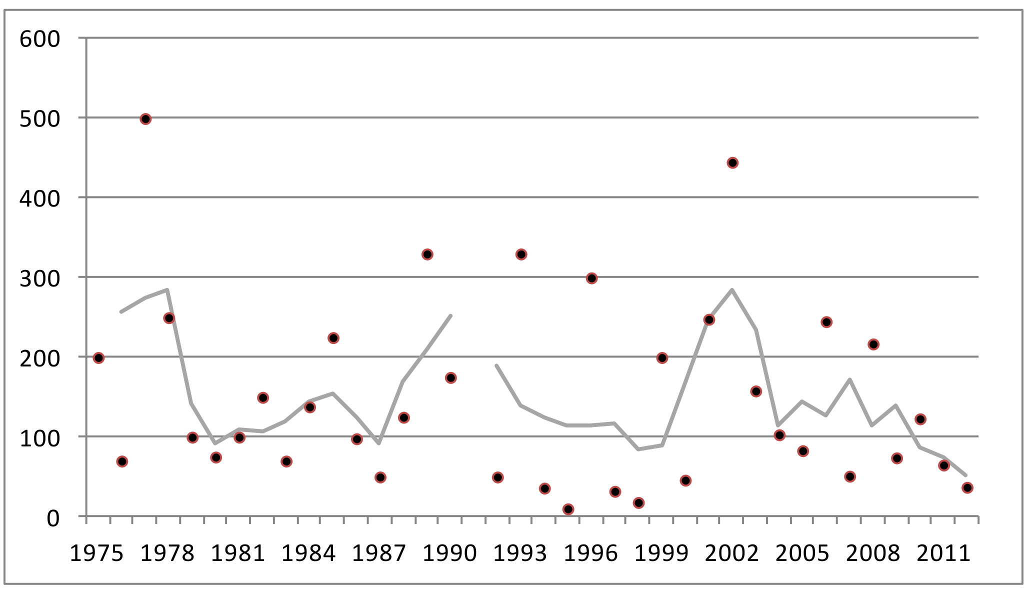
CK-07, Maria Slough, heavily enhanced, fragmented data. *Data available indicates increasing trend until the significant decrease in 2012 returns.*



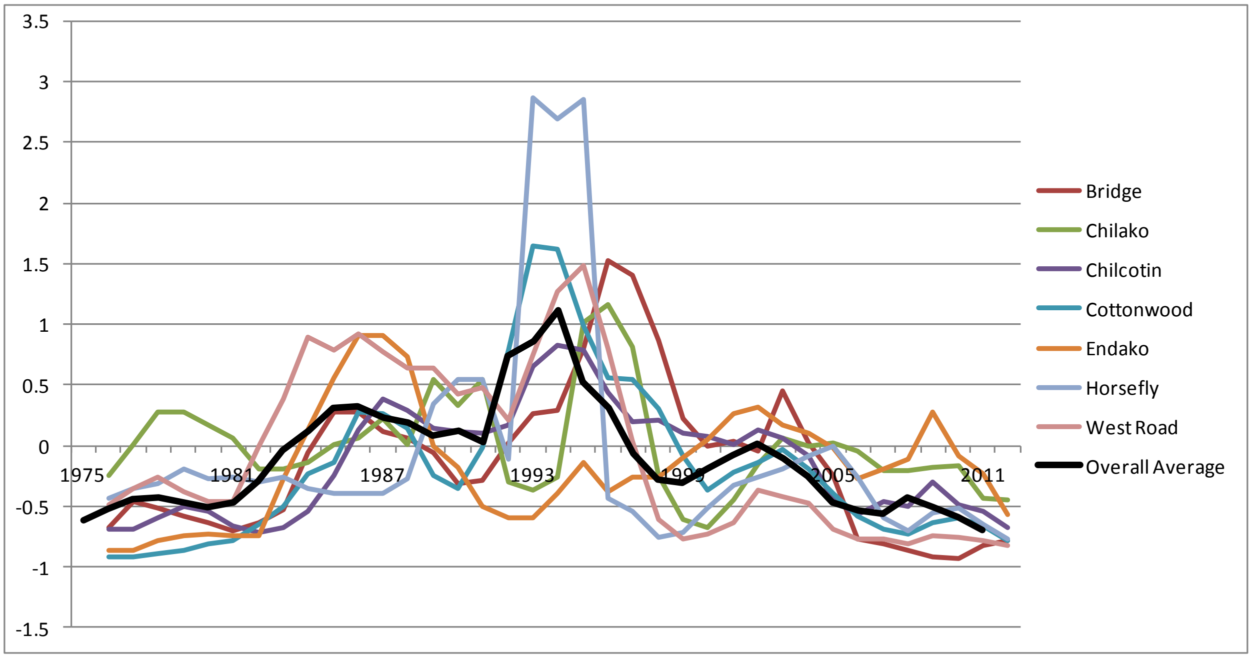
CK-08, Fraser Canyon, Nahatlatch River ... inadequate data, no trend 1995-2012 but concern for small population size.



CK-09, Middle Fraser River - Portage Creek , data highly variable. Data points (grey dots) represent reported spawners in Portage Creek and line is 3-point moving average for Portage Creek (1975-2012). *1995 to 2012 would not indicate a decline but certainly variable & small returns; more recent years indicate a decline.*



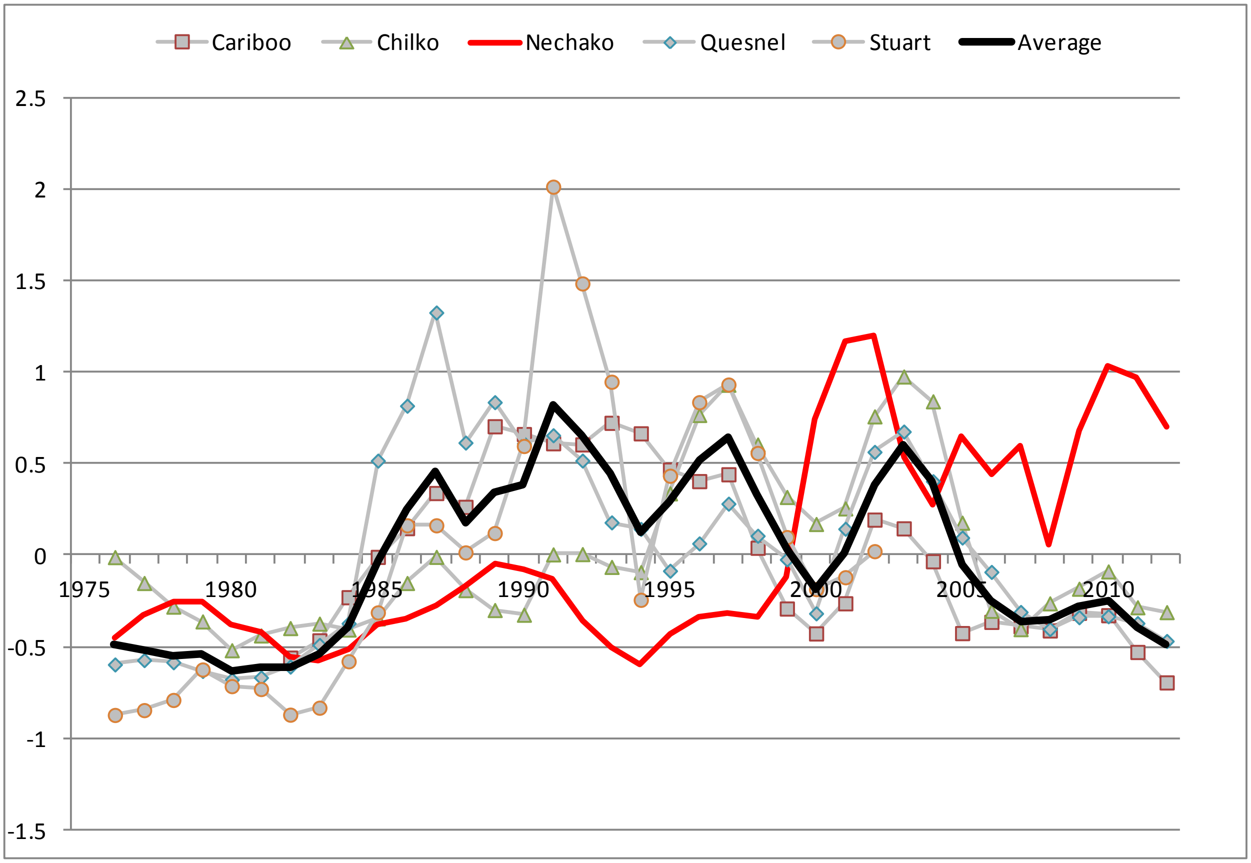
CK-10, Mid-Fraser River Spring Chinook, 7 streams with data, 18 streams in total. The 7 streams presented represent 7 of the 10 'Persistent" data sets provided, 3 were excluded due to extensive in-filling in recent decade. Plots of 3-point moving average of annual deviations calculated within streams. Overall average is the averaged deviations across streams within each year. *Data supports a decline in returns throughout the CU since mid-1990s, however, the Endako shows weaker correlations.*



Simple pair-wise correlations:

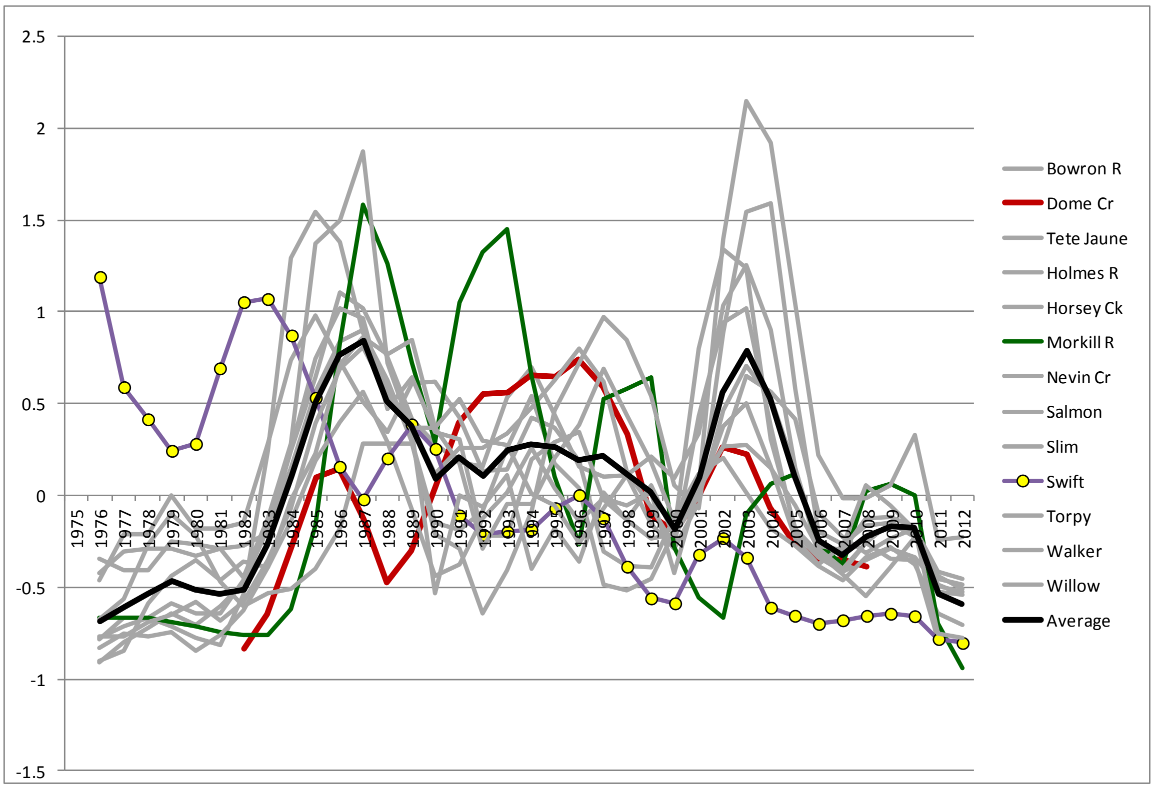
Corr Matrix	Bridge	Chilako	Chilcotin	Cottonwood	Endako	Horsefly	West Road
Bridge		0.3769	0.5074	0.5607	0.1292	0.0221	0.3570
Chilako			0.1527	0.0137	0.0441	0.0830	0.4140
Chilcotin				0.7882	0.3697	0.5657	0.5414
Cottonwood					0.1982	0.5107	0.5837
Endako						0.0580	0.2569
Horsefly							0.4506

CK-11, Mid Fraser River Summers, five streams presented out of 17. Pinchi Creek and Kuzkwa River omitted due to insufficient data. After trying several plots for clarity, this plot presents the 3-point average of the standardized deviations per steam and year (colour points); the Averaged trend for Cariboo, Chilko, Quesnel, and Stuart rivers; and the trend for the Nechako River which is clearly different. *The 'Average' line demonstrates a strong decline but since the mid-2000s but a longer term decline is apparent since the early 1990s, but Nechako has been increasing since mid-1990s (may be confounded with a change in methods used in estimation of annual escapements in the Nechako).*



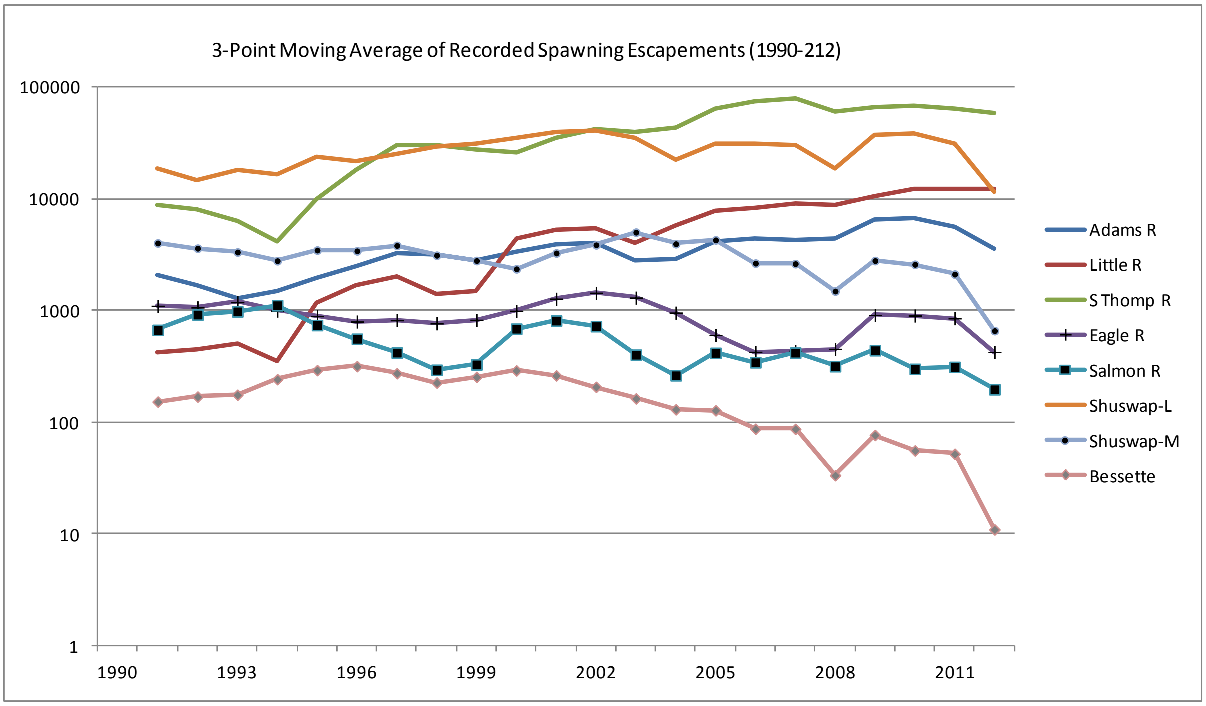
Corr Matrix	Chilko	Nechako	Quesnel	Stuart
Cariboo	0.2927	-0.2414	0.6035	0.2665
Chilko		0.1289	0.3464	0.5391
Nechako			0.0311	0.0985
Quesnel				0.3927

CK-12, Upper Fraser Spring Chinook, 13 streams out of 36; *all Low or UNK enhancement except for Moderate enhancement in Dome Creek*. Swift Creek has a very different trend showing an almost continuous decline over this time period. The other 12 streams are largely coherent in their trends and indicate a decline since a peak in the early 2000s' (similar to CU-11). Excluding Swift Creek, the overall correlation co-efficient of escapement trends amongst these steams was 0.52. Plot of 3-point moving average of the standardize deviations within streams, Average = average annual value over the 12 streams. Streams with differing patterns (Dome and Morkill) have been highlighted.



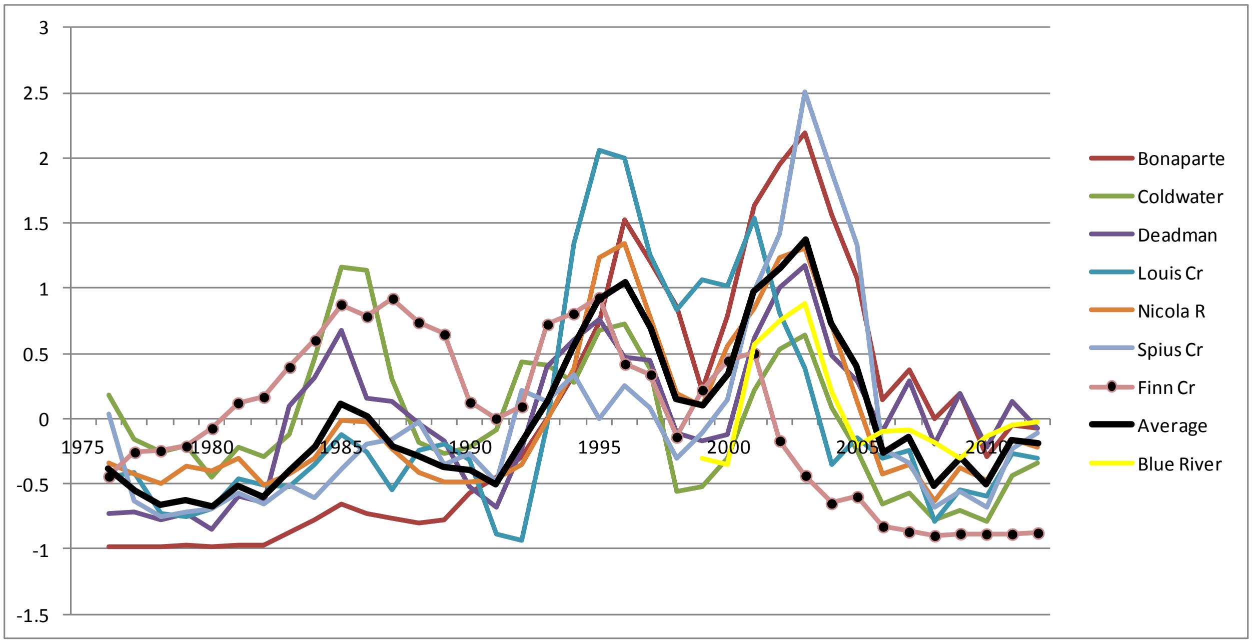
	Dome	Tete Jaun	Holmes R	Horsey Cr	Morkill R	Nevin Cr	Salmon	Slim	Swift	Torpy	Walker	Willow
Bowron	0.437	0.615	0.782	0.686	0.588	0.603	0.464	0.717	-0.137	0.807	0.544	0.754
Dome		0.276	0.609	0.286	0.259	0.195	0.249	0.343	-0.271	0.297	0.120	0.282
Tete Jaune			0.559	0.638	0.148	0.129	0.004	0.737	0.277	0.412	0.425	0.368
Holmes				0.771	0.471	0.639	0.552	0.719	-0.105	0.761	0.619	0.732
Horsey Cr					0.171	0.563	0.258	0.258	-0.014	0.617	0.526	0.491
Morkill						0.352	0.287	0.352	-0.270	0.541	0.517	0.563
Nevin							0.746	0.430	-0.295	0.778	0.479	0.581
Salmon								0.362	-0.315	0.629	0.327	0.685
Slim									0.007	0.583	0.623	0.700
Swift										-0.268	0.036	-0.237
Torpy											0.626	0.692
Walker												0.522

Summary of CK-13, 14, 15, 16, Thompson River Summers (both 0.3 and 1.3), involving 8 of 15 streams and the vast majority of the annual spawning escapements and data. However, this plot differs from previous as it is a simple 3-point average of the reported spawners plotted on a log_{10} scale due to the large differences in magnitude of the escapements between rivers. *Trends amongst these Conservation Units differ with four streams increasing and four declining but at differing rates. A significant drop in numbers of spawners was recorded for the Shuswap and Bessette populations in 2012.*



Corr Matrix	Adams R	Little R	S Thomp R	Eagle R	Salmon R	Shuswap-L	Shuswap-M	Bessette
Adams R		0.7451	0.7897	0.3224	-0.1269	0.7661	0.4836	0.1153
Little R			0.8883	0.0083	-0.2032	0.4289	0.1964	-0.1407
S Thomp R				0.0580	-0.2604	0.6215	0.3809	-0.0560
Eagle R					0.4384	0.5710	0.6317	0.5599
Salmon R						0.0107	0.0386	0.4330
Shuswap-L							0.7026	0.4119
Shuswap-M								0.5338
Bessette								

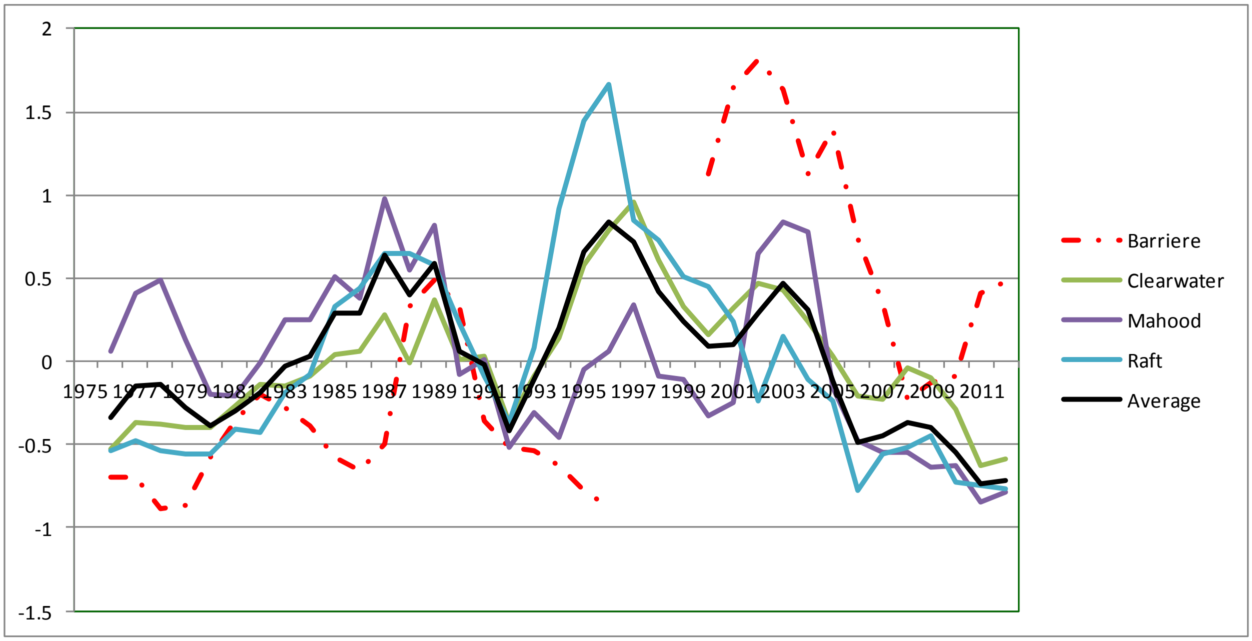
CK-17 & 18, Lower Thompson Springs (age 1.2) and North Thompson Springs (1.3). Seven streams out of 11 presented, all streams excluded were in CK-18 (North Thompson). The Blue River was rated as Persistent by DFO but excluded in the correlation matrix due to extensive missing data in early years; it is shown in the plot (Yellow line). *Declining escapement numbers since early 2000s, possibly earlier decline evident in Finn Creek.*



Corr Matrix	Coldwater	Deadman	Louis Cr	Nicola R	Spius Cr	Finn Cr
Bonaparte	0.1186	0.6281	0.5683	0.7413	0.6220	-0.0661
Coldwater		0.3905	0.1980	0.5535	0.4136	0.3292
Deadman			0.4593	0.6611	0.4867	0.2929
Louis Cr				0.6268	0.2325	0.3194
Nicola R					0.5743	0.2071
Spius Cr						-0.0287
Finn Cr						

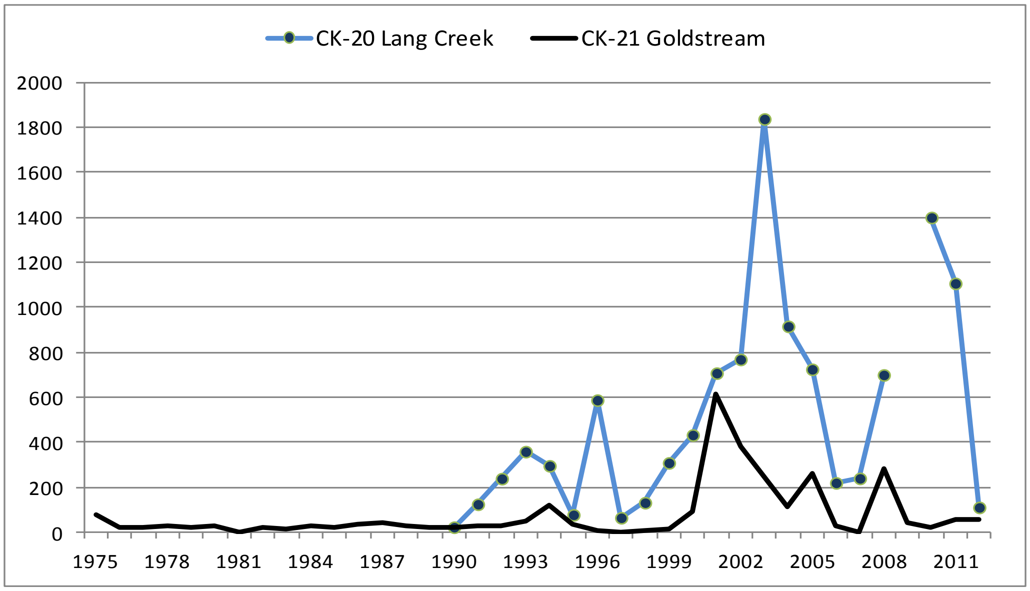
CK-19 North Thompson Summers (age 1.3), four streams presented out of seven total. Data for Clearwater, Mahood, and Raft presented as 3-point moving averages of the standardized deviations. Barriere was presented separately as the data in the 1990s were incomplete.

Recorded escapements for CK-19 support a steady decline in spawners since the mid-1990s; with the exception of an increase to Barriere River in 2011 and 2012. However, escapements reported for Barriere are only a few hundred Chinook and less.



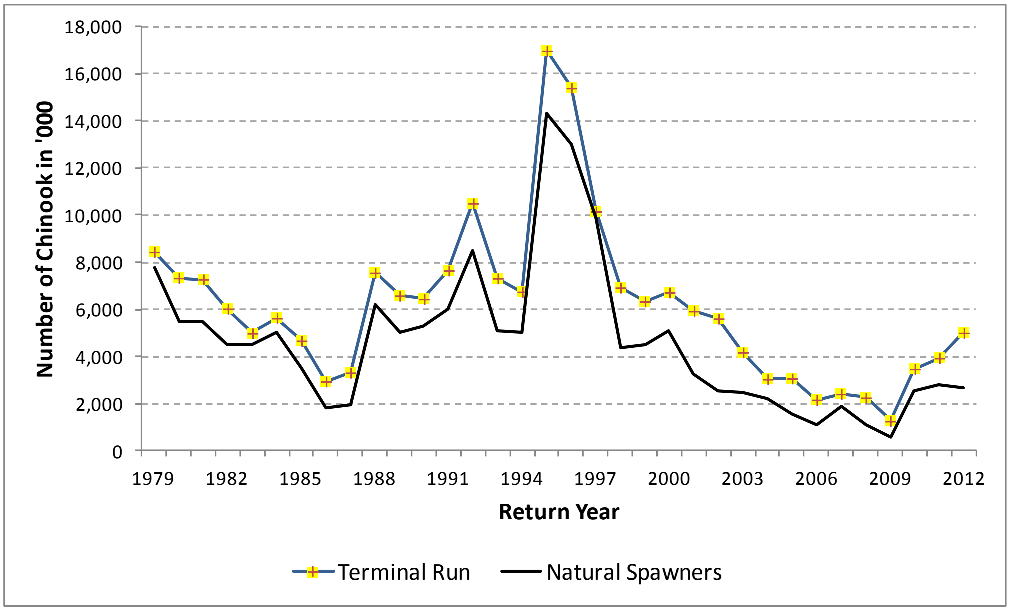
Corr Matrix	Clearwater	Mahood	Raft
Barriere	missing values		
Clearwater		0.521108	0.581638
Mahood			0.196624
Raft			

CK-20 South Coast – Georgia Strait & **CK-21 South Coast – Goldstream.** There are 16 streams associated with CK-20 but those with a 'Persistent' rating for the escapement time series were all associated with HIGH hatchery production. Lang Creek is presented as the recent escapement data are based on fence counts, however, other data within the CU are generally of poor quality. The Goldstream River is the only stream in CK-21 and is also heavily enhanced.



CK-22 East Vancouver Island – Cowichan and Koksilah rivers.

The Cowichan River has been quantitatively monitored since the early 1980s, rated with High level of enhancement. Koksilah River does not have an escapement entry since 1993 and is omitted from the plot. Shawnigan Creek was included in the data file but has only 4 data points. *Clearly concern for declining numbers of natural spawners, increased terminal removals since late 1990s.*

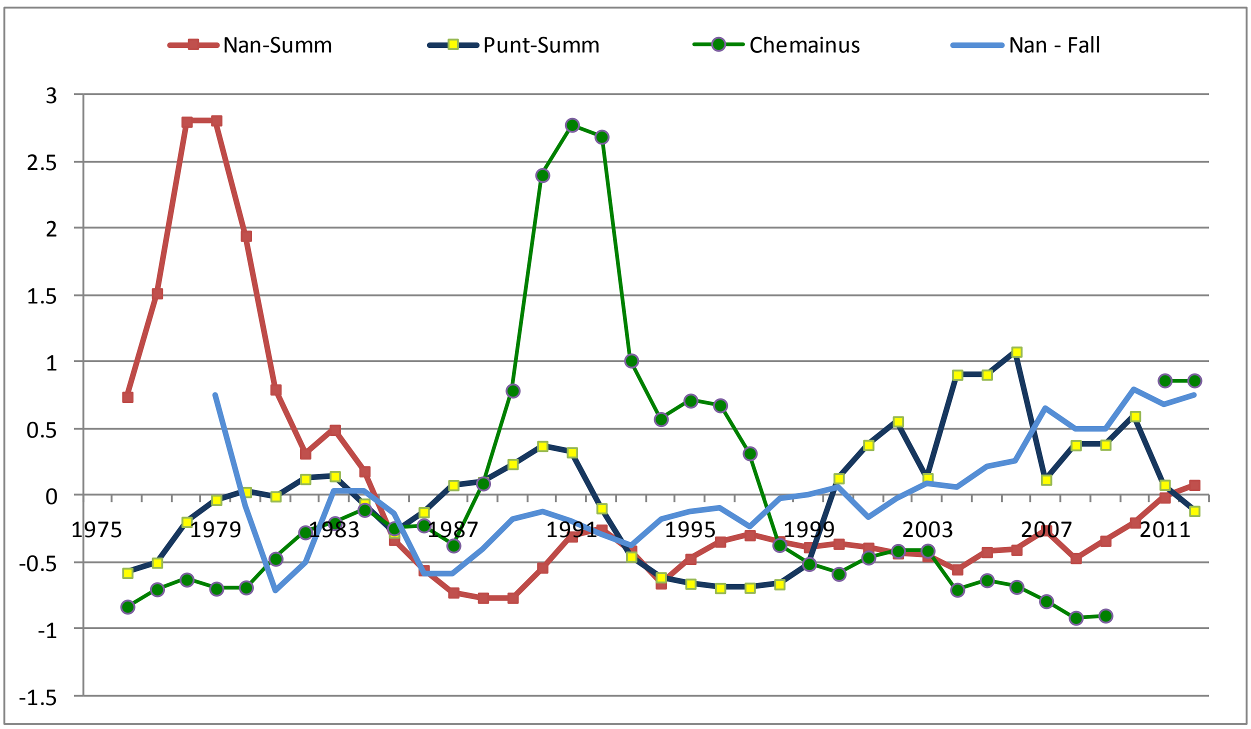


CK-23 East Coast Vancouver Island – Nanaimo Spring Chinook. This plot is omitted. DFO rated this escapement time series as Persistent, but there are only nine data points (1995-2012) and eight missing data points. The data or missing data also occur in strings and gaps, making extrapolations for missing data highly uncertain; and there is only one stream in the CU so there are not other means of filling-in.

CK-24 East Coast Vancouver Island (EVI) –Summers (Nanaimo summers) & CK-26 (Puntledge Summers) were **merged** and documented in SSRP (CU Review, February 2013)

CK-25 East Coast Vancouver Island – Nanaimo & Chemainus – Fall timing.

The combination of CK-24 and CK-25 involves four highly enhanced streams; the following plot (3-point moving average of standardized deviations within streams) *indicates different trends for each stream*.



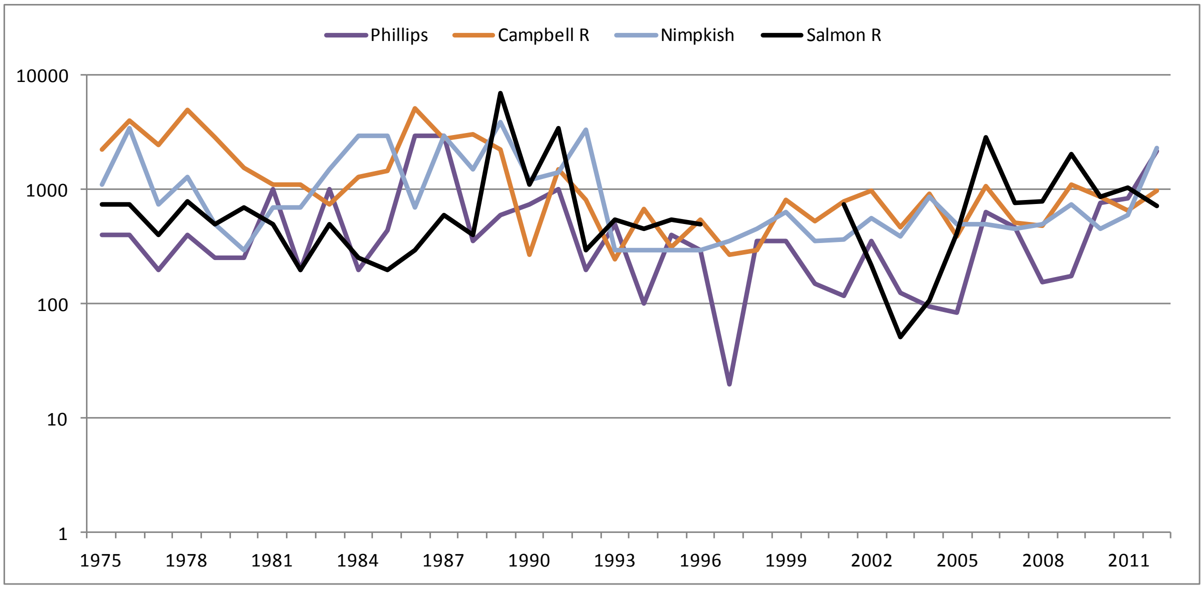
CK-27 East Coast Vancouver Island – Qualicum and Puntledge Fall timing (6 streams)

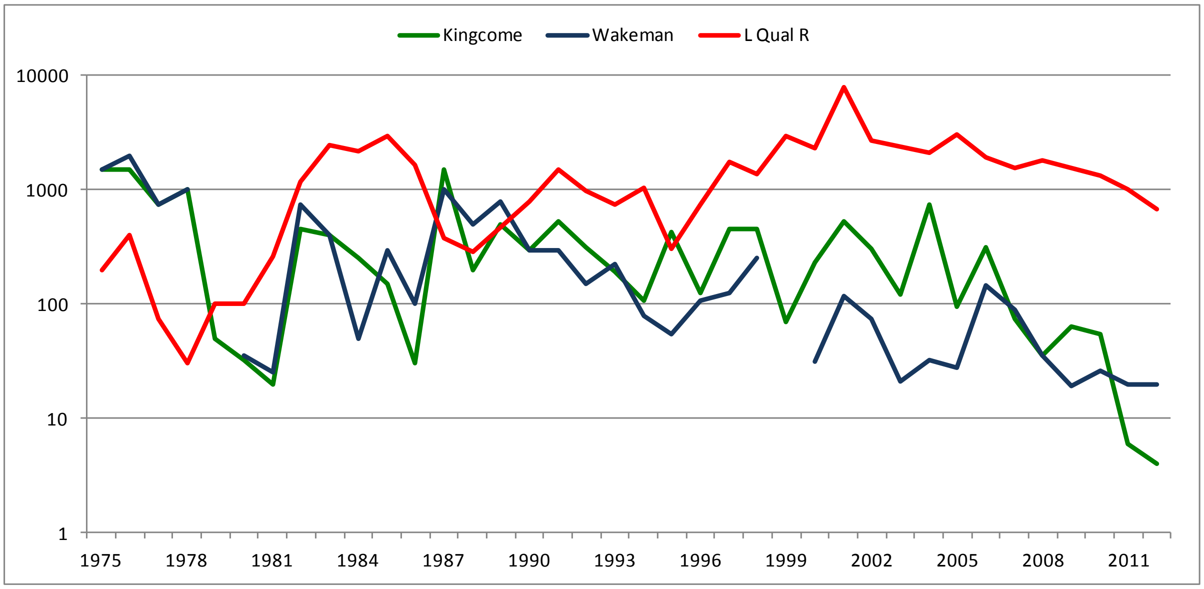
CK-28 South Coast – Southern Fjords (12 streams)

CK-29 Northeast Vancouver Island (10 streams)

Summarizing returns to these 28 streams is difficult due to large differences in the scale of enhancement programs and generally poor quality of data in the unenhanced systems (data is especially limited in CK-28). A sample of seven streams was selected for completeness of their data time series and distribution across the three conservation units. Marine survival rate information based on coded-wire tagging is available for Big Qualicum, Puntledge, Quinsam/Campbell rivers.

Time series for these seven streams indicate a group of four streams with modest increasing trend and three streams with declining returns over the past decade or longer.





CK-31 Southwest Vancouver Island (34 streams, includes aggregated tributaries in the main stream). **CK-32 Nootka & Kyuquot** (41 streams, includes aggregated tributaries in the main stream). **CK-33 Northwest Vancouver Island** (8 streams, includes aggregated tributaries in the main stream)

CK-30 was merged into CK_31 after review of available life history, genetic and other information as documented in a DFO Special Science Report of Feb 2013.

As with the previous grouping of three conservation units, summarizing this large aggregate of streams is difficult (83 streams in total). Monitoring these systems has been a challenge for the Department for many years due to the rugged nature of the region and the heavy fall rainfall, plus the use of hatcheries has been extensive through these conservation units. To summarize the Units, plots include the major enhancement systems separately from the un-enhanced and separated CK-31 from the combined presentation of CK-31 and CK-33.

CK-31 Southwest Vancouver Island ... a highly enhanced unit. CK-9001 was merged with CK-31 after the DFO Special Science Report of Feb 2013.

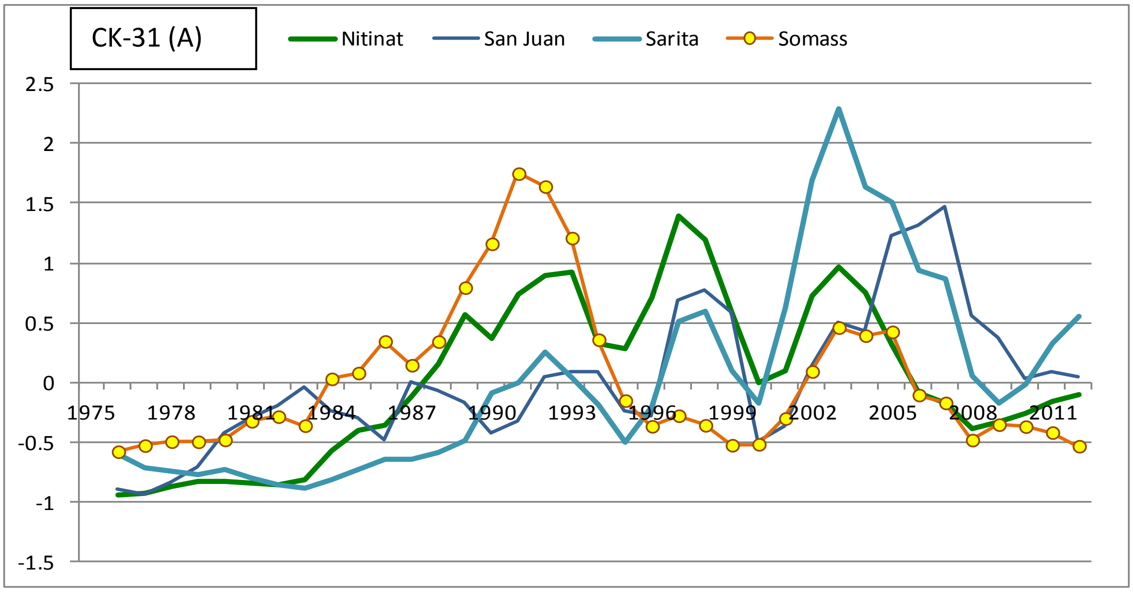
Four systems associated major enhancement projects (CK-31(A);San Juan, Nitinat, Sarita, and Somass) are plotted separately from three smaller enhanced systems in Clayoquot Sound (CK-31(B);, and three small, unenhanced systems also in Clayoquot Sound (CK-31(C); Bedwell, Megin, Moyeha) . For the latter, data is only presented for 1995-2012 as information through this time period had been reviewed by DFO.

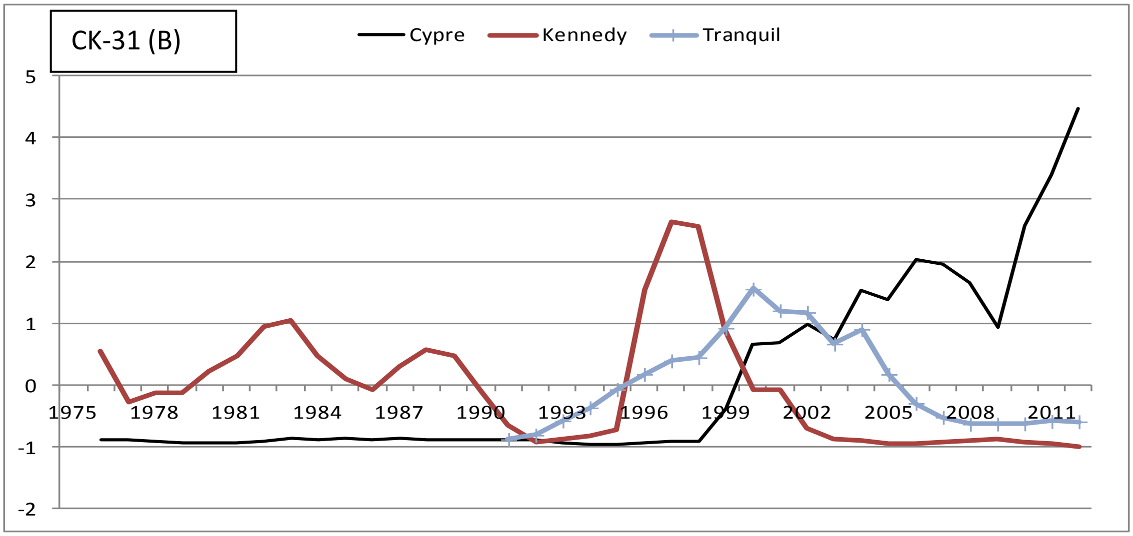
While the natural populations (CK-31(C)) due indicate a decline since the mid-1990s, the other seven enhanced production streams do not demonstrate a declining trend. However, the trends in the enhanced systems are also NOT very similar over time.

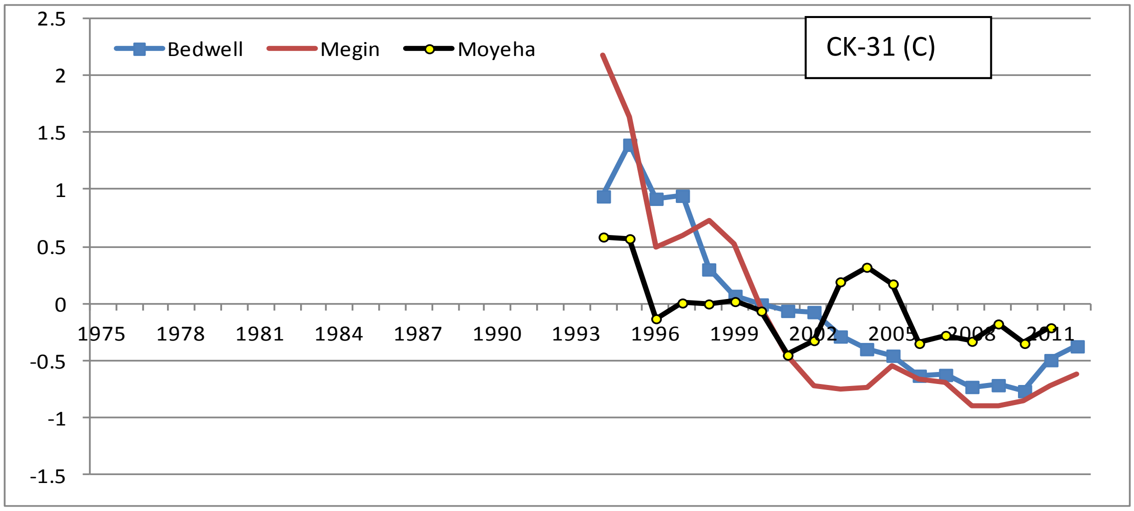
CK-32 Nootka & Kyuquot and CK-33 Northwest Vancouver Island ... mixed enhanced and un-enhanced systems.

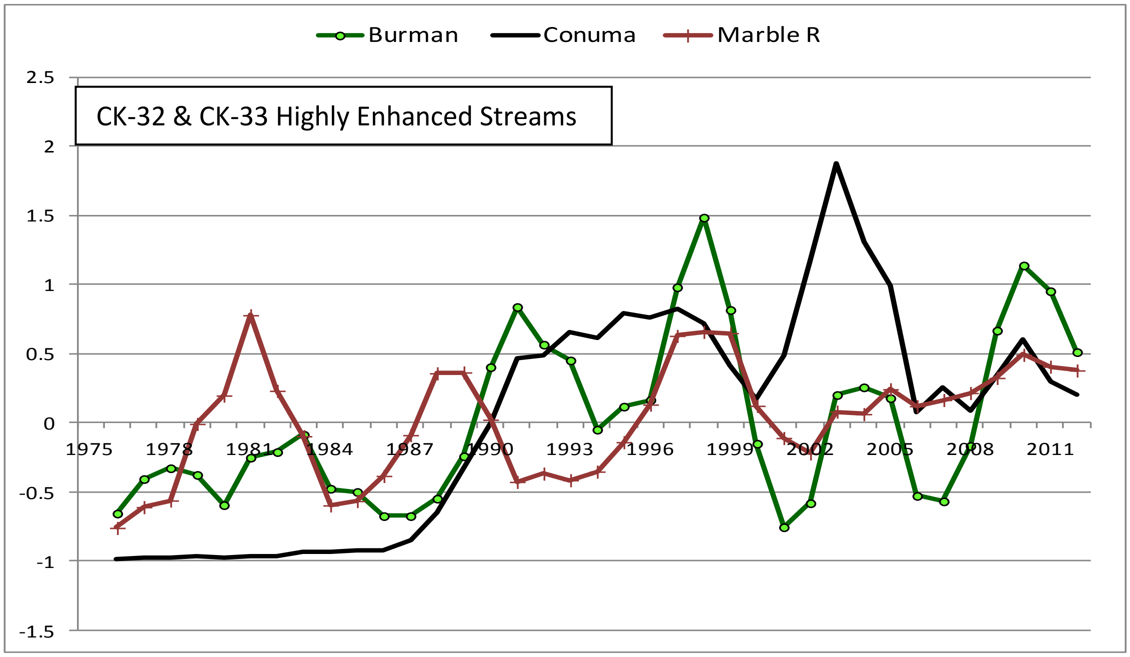
Since the mid-1980s, DFO has used a suite of streams to provide an index of natural-spawner trends for Chinook salmon along the west coast of Vancouver Island (the index was developed for use in the Pacific Salmon Treaty assessments). The streams included in that index are: Marble, Burman, Tahsis, Artlish, Kaouk, Tahsish. The annual value of this Index is the sum of adult Chinook spawners over these six streams. However, within this Index, there are two highly enhanced systems (Burman and Marble) that have a significant effect on the trend. In the plots following, these two systems have been removed from the "Natural Index" and plotted separately. The "Natural Index" used for this plot includes: Artlish, Kaouk, Leiner, Tahsis, Tahsish, and Zeballos ... all within Nootka Sound. The Combined (Sucwoa and Tlupana) in the same plotted are two systems very near the Conuma Hatchery (also in Nootka Sound system) and were to originally be included in the enhanced set of rivers to be treated through that hatchery. However, given their poor production response, they were treated separately and demonstrate an interest and opposite trend from the Natural Index.

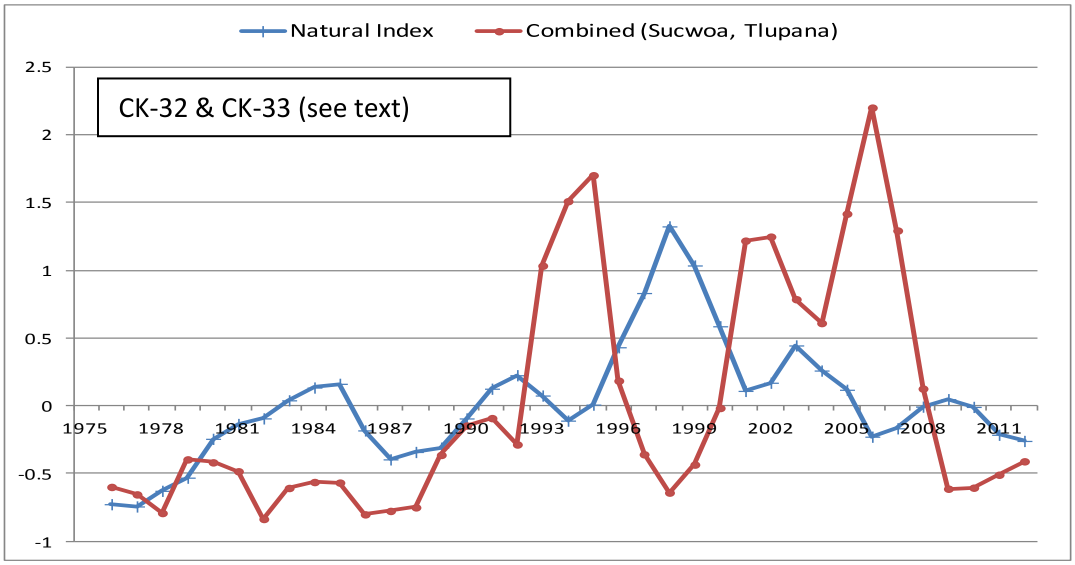
For these systems in CK-32 and CK-33, the enhanced streams show substantial variability over time but an increasing trend in escapement in recent years. The combined Sucowa and Tlupana also high variability but no obvious trend; and the Natural Index does indicate a declining trend in escapement since a peak in returns in the 1990s.





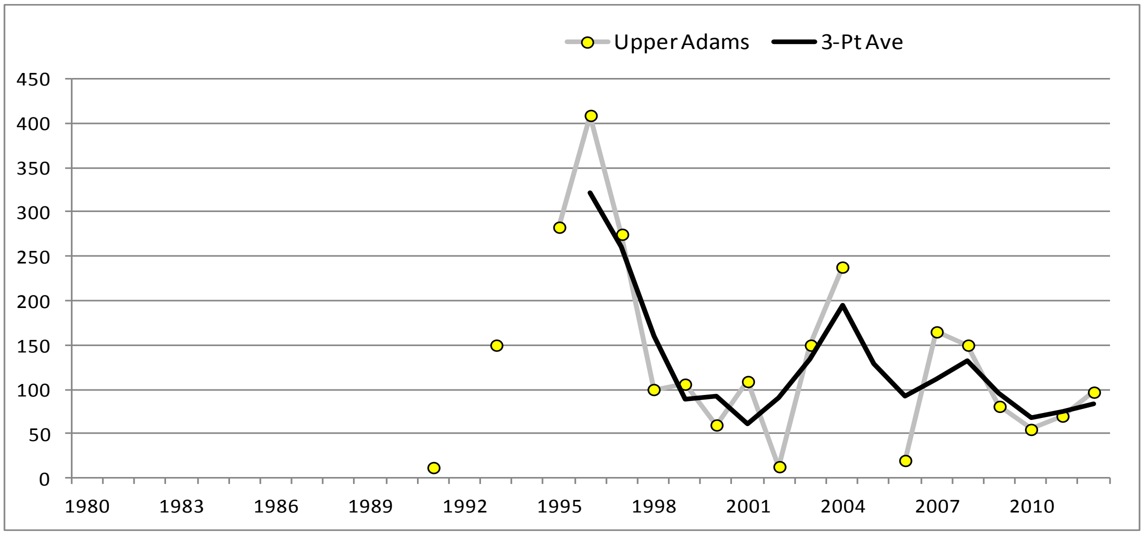

CK-31 (C)
Bedwell
Megin
Moyeha
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005
2008
2011


Burman
Conuma
Marble R
CK-32 & CK-33 Highly Enhanced Streams
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005
2008
2011

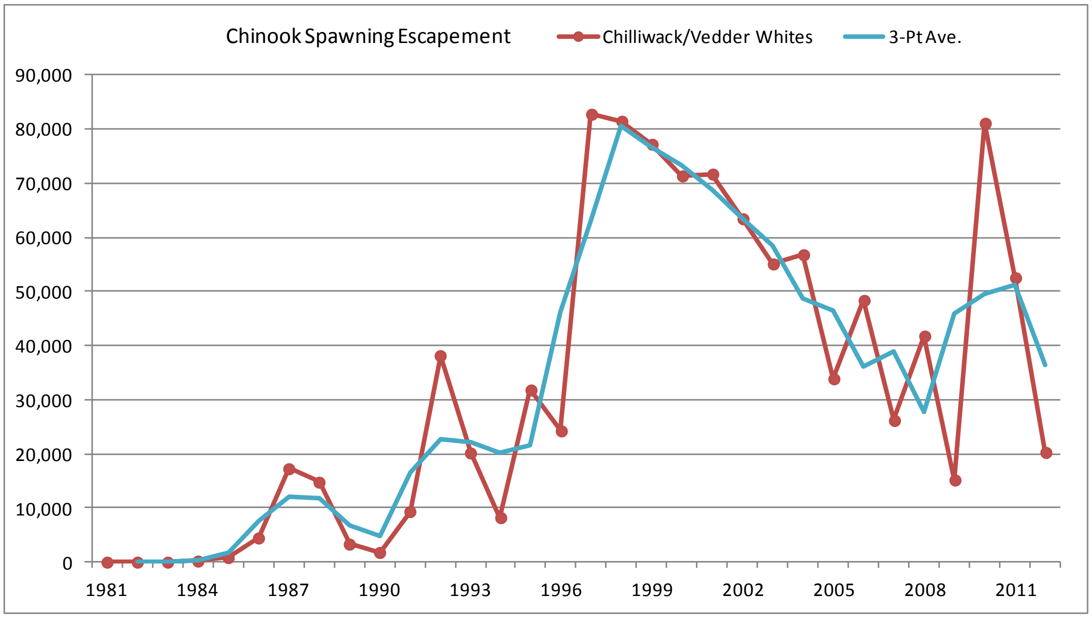


CK-34 Homathko and CK-35 Klinaklini ... both these Units are highly data deficient, plus CKI-35 has involved a short period of enhancement in the past (Devereux Creek). *No assessment is present* but the Pre-COSEWIC review by DFO indicates a strong increase in escapement in CK-35 from the 1990 through to the early 2000s (no data after that time). This increase corresponds with an effort to quantitatively estimate the total system escapement using fish wheels and mark-recapture methods.

CK-82 Upper Adams River ... Chinook returns to this system are notable as salmon were excluded from Adams Lake in the early 1900s by a logging dam. These spawning escapement returns do indicate a decline from the mid-1990s peak observed throughout the upper Fraser system. The decline however was most consistent with Spring Chinook trends; the life-history of this population is believed to be an Ocean-type with summer run timing.



CK-9000 Chilliwack/Vedder system ... transplanted White Chinook salmon from the Harrison River. This population is not endemic to the Chilliwack system but has become a productive supplementation to the production of late-run, white Chinook in the lower Fraser River. The pattern of returns is not consistent with CK-03 Harrison White Chinook but the juveniles are released at much larger sizes than downstream migrants from the Harrison, which are fry migrants.



APPENDIX STA-2: PERCENT CHANGES IN SPAWNER ABUNDANCE

Percent changes in spawner abundance over the last 3 generations based only on data without any missing values for estimates of spawner abundance, in contrast to **Figure ST-1**, which was based on $\log_e$(spawner abundance) data, including years with missing data that were filled in via an algorithm mentioned in the text.

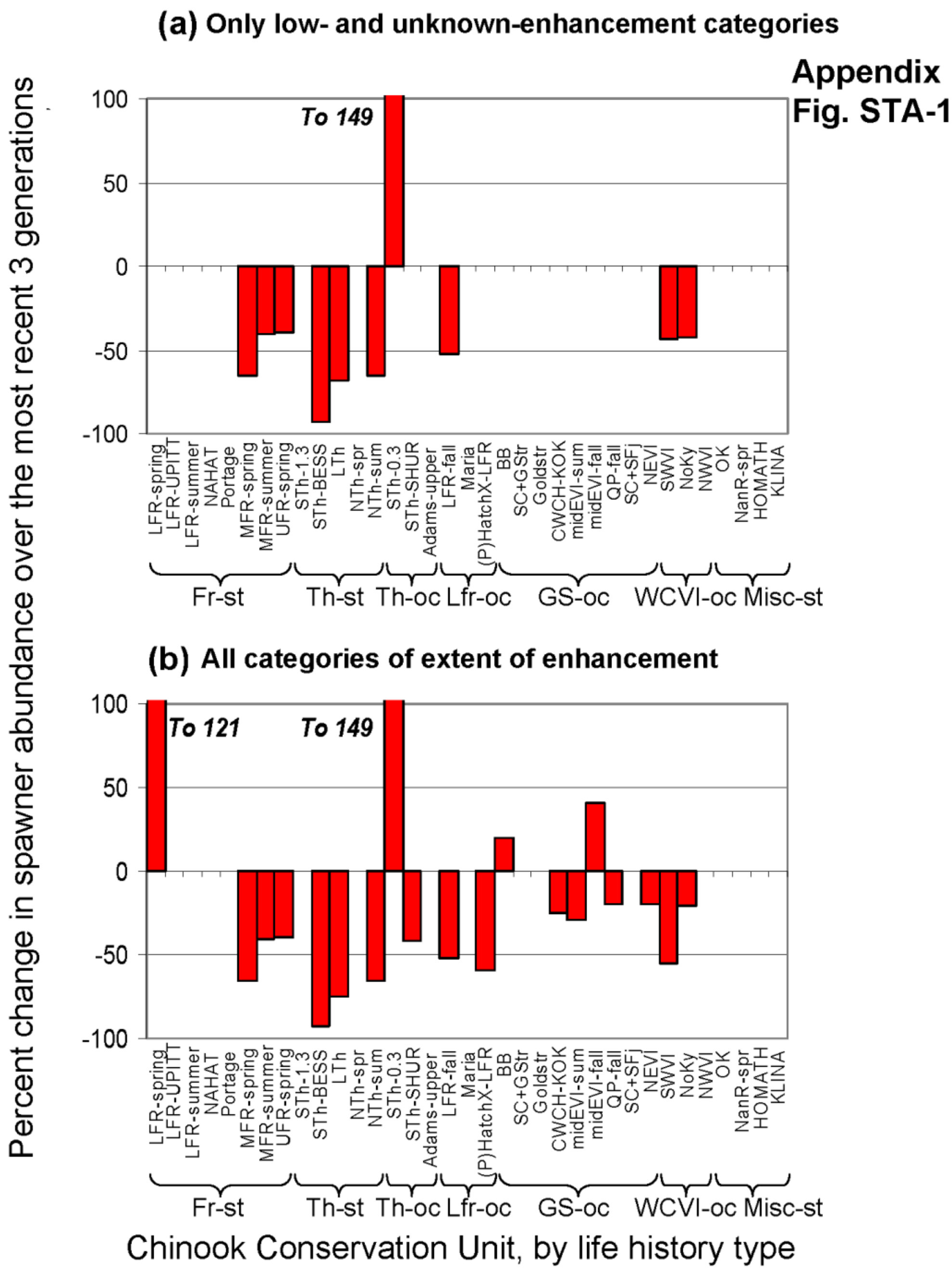


Figure STA-1. The percent change in spawners over 3 generations was based only on 3-generational spans with no missing values, and a linear model fit to $\log_e$-transformed generational average escapement estimates. Results are shown for 35 Conservation Units (CUs) for Southern British Columbia Chinook salmon, arranged by CU and type of life history. Depending on the particular CU, the generation time is either 3, 4, or 5 years; see "Avg. gen. (years)" column of **Table ST-1**. Data for spawning sites that were categorized as having a "low or unknown" extent of enhancement activity are shown in panel (a), organized by CU. Here, "unknown" most likely means little or no enhancement. In contrast, panel (b) is based on data for spawning sites across all levels of enhancement, including "moderate" and "high" categories. Data source: Gayle Brown, DFO.

Appendix STA-3: Life-cycle Productivity for Chinook Salmon Stocks outside of Southern B.C.

Time series of measures of life-cycle productivity for the 28 stock aggregates other than the 5 Southern B.C. stocks.

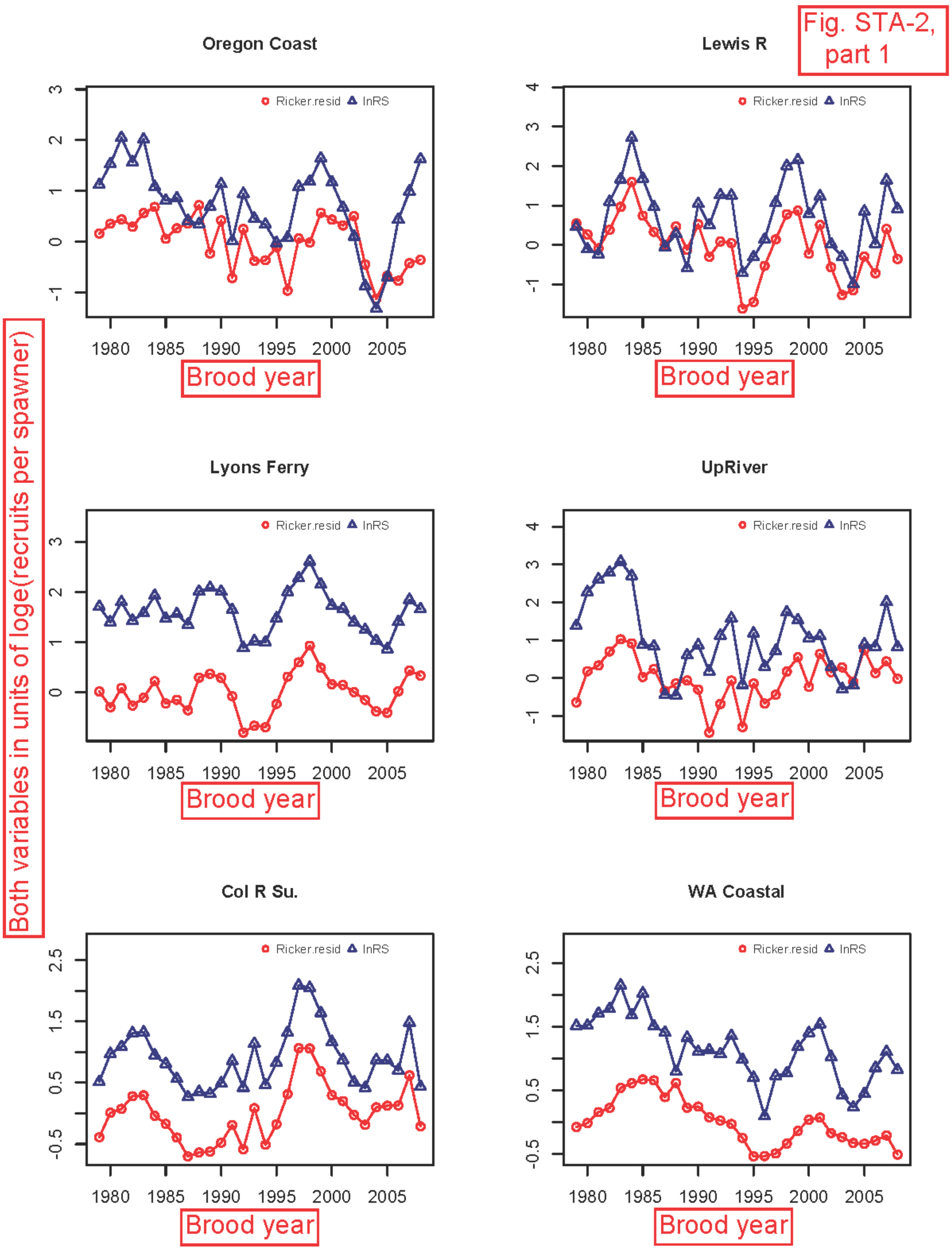
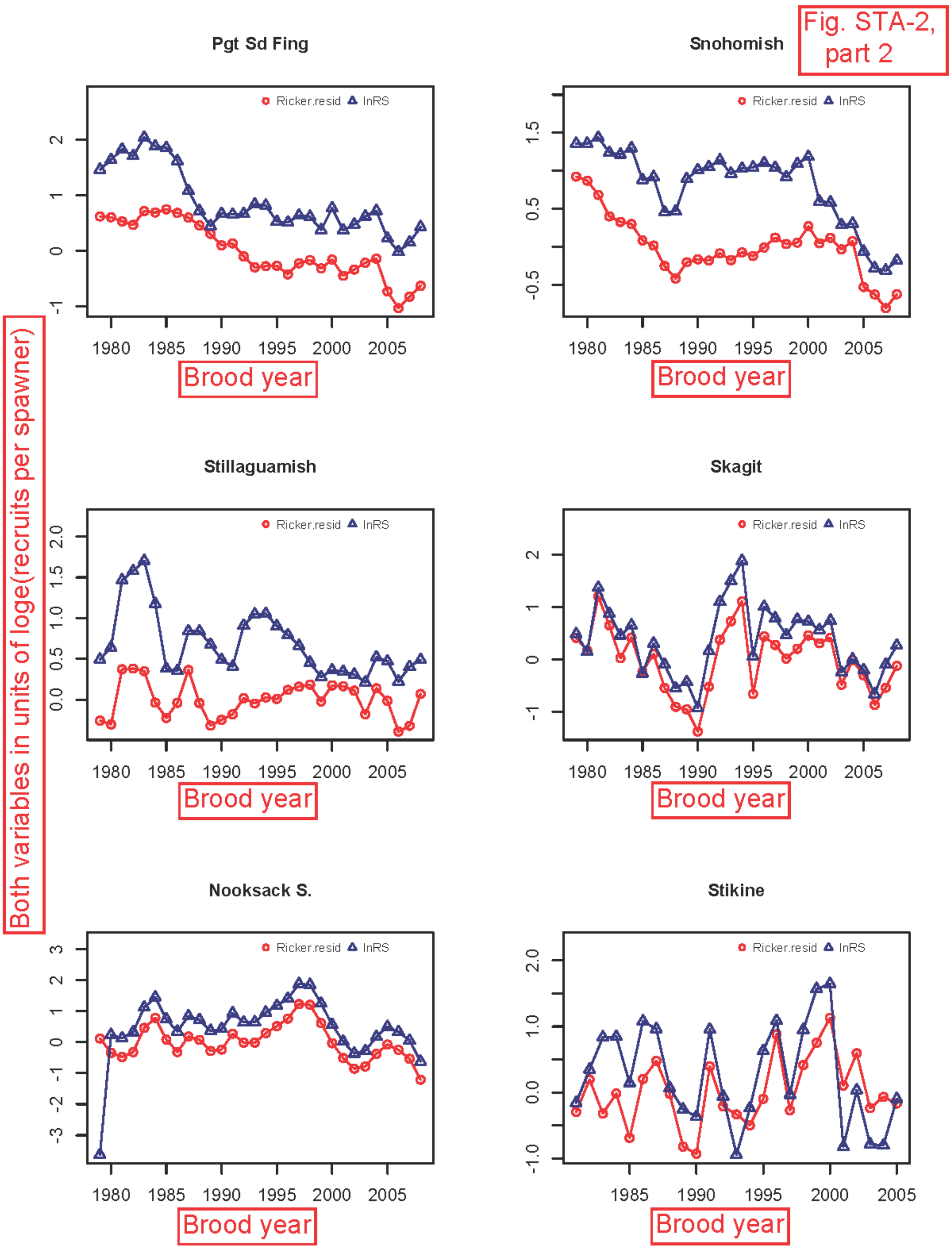


Figure STA-2. Part 1. Full caption at bottom of figure.



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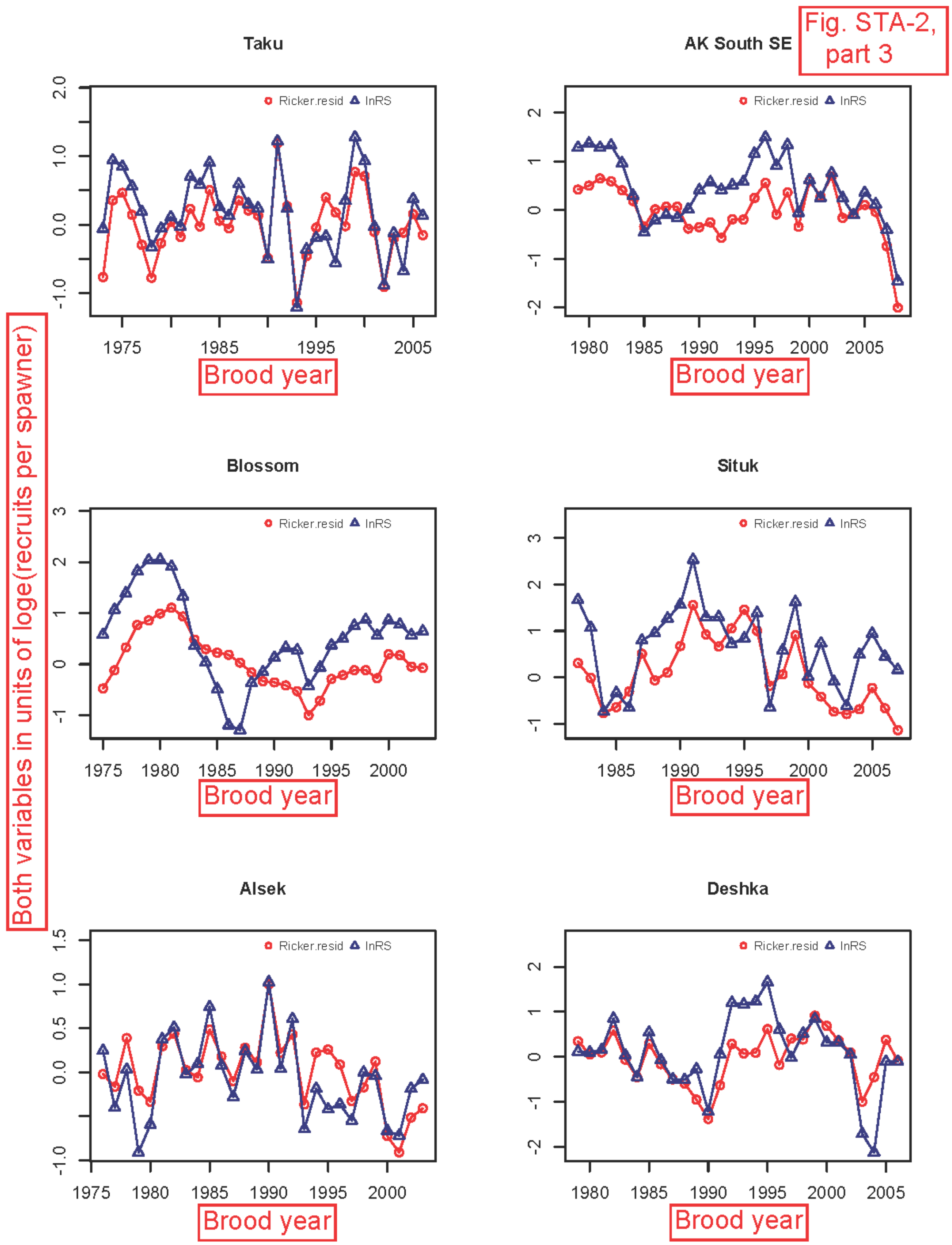

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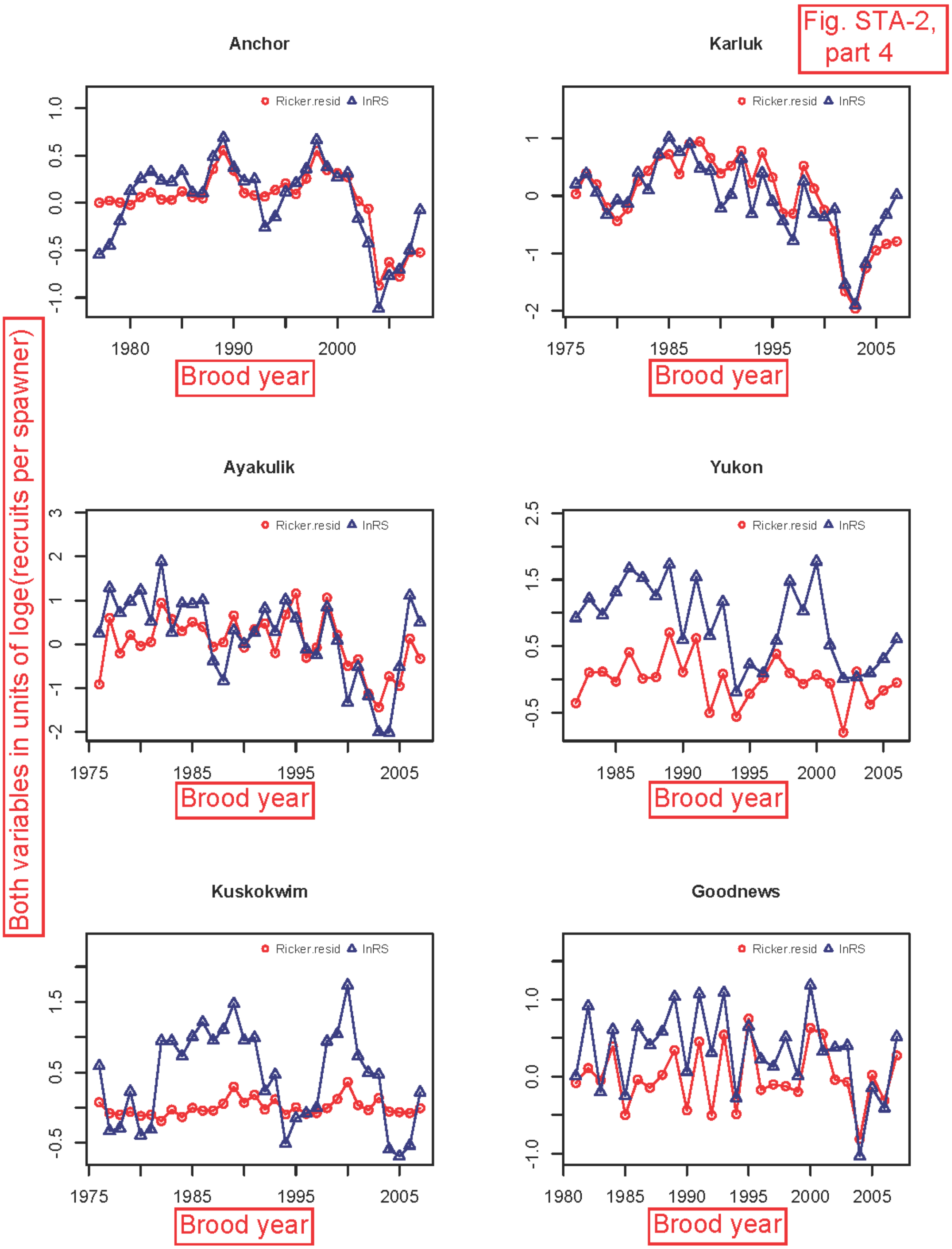

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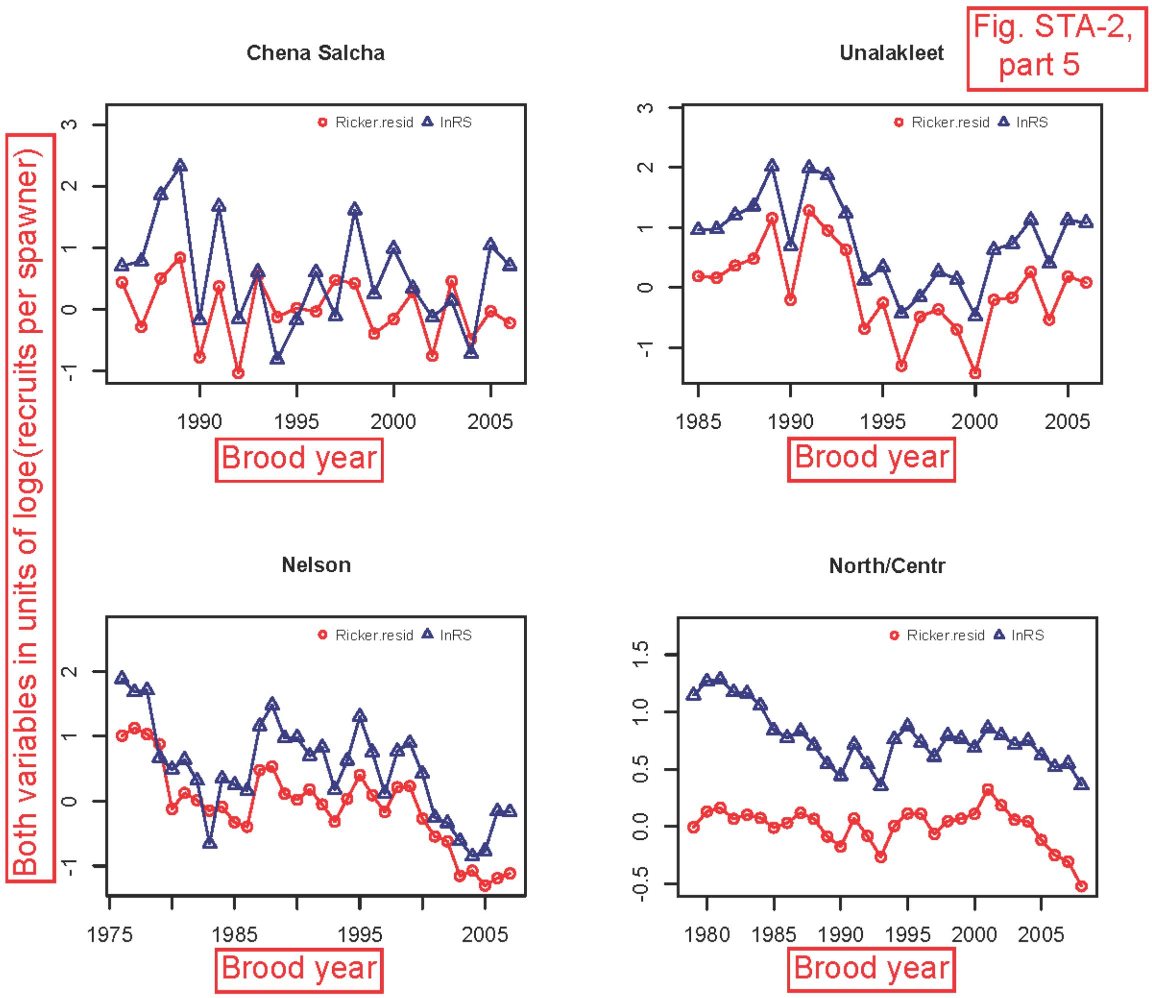
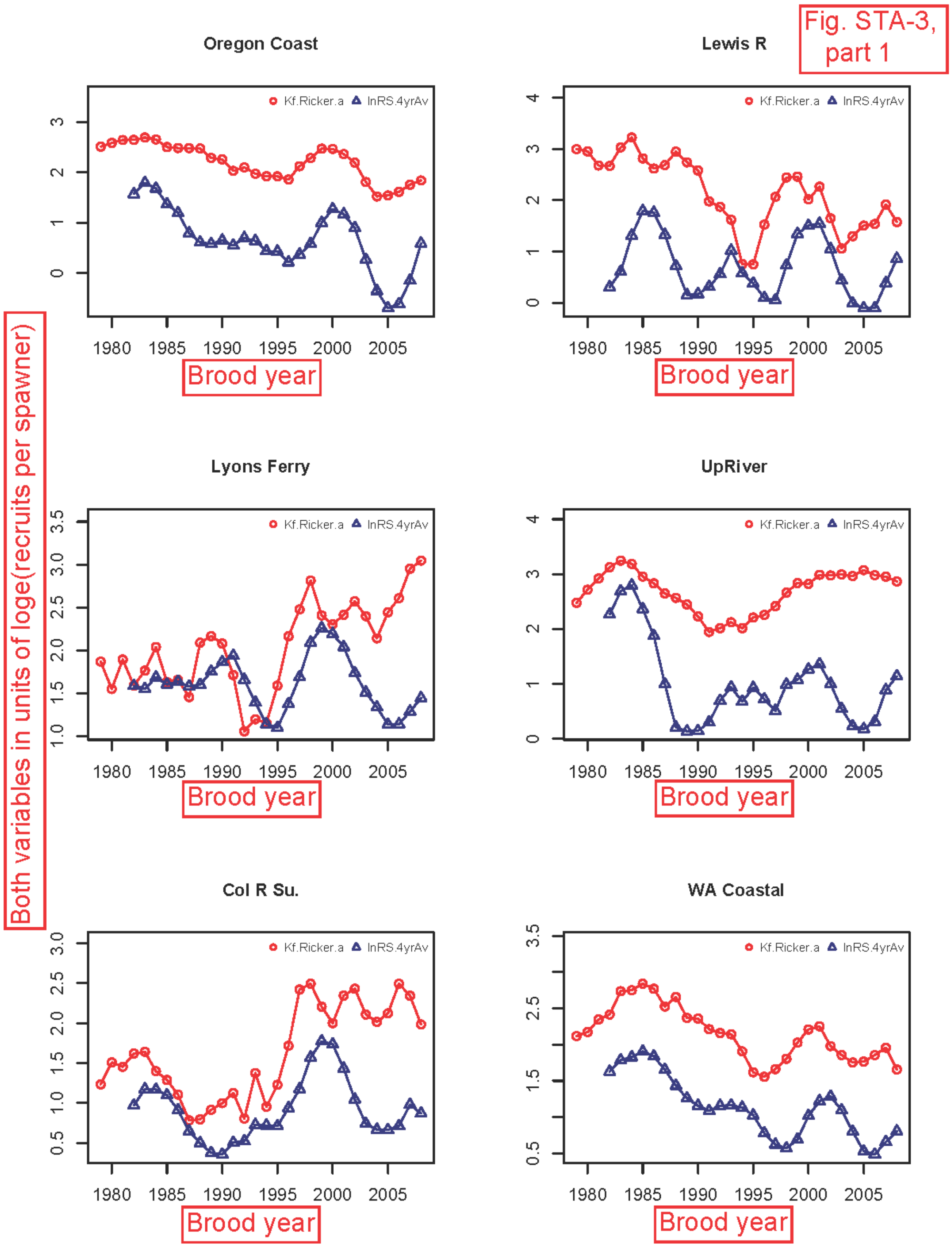


Figure STA-2. Same as **Figure ST-6** except here are shown two measures of life-cycle productivity derived from abundance of spawners (S) and their resulting adult recruits (R): annual $\log_e$(recruits per spawner) and residuals from the best-fit, stock-specific Ricker stock-recruitment model ("Ricker residuals"), plotted by brood year. For the $\log_e$(R/S) series only (blue triangles), a value of 0 means that adult recruits are just replacing the number of parental spawners; positive values indicate an increasing population, and negative values a decreasing one. Plots are for 28 stock aggregates <u>other than</u> the 5 Southern B.C. stocks shown in **Figure ST-6**. North/Central B.C. is shown in the last graph. Data on spawners and recruits for 13 Chinook stocks in Alaska (from Blossom through Nelson) were obtained from the Alaska Department of Fish and Game via Matt Catalano, Auburn University. Time series of spawner and recruit abundance for the remaining stocks were reconstructed using the Pacific Salmon Commission's coast-wide model. Source: Gayle Brown, DFO.



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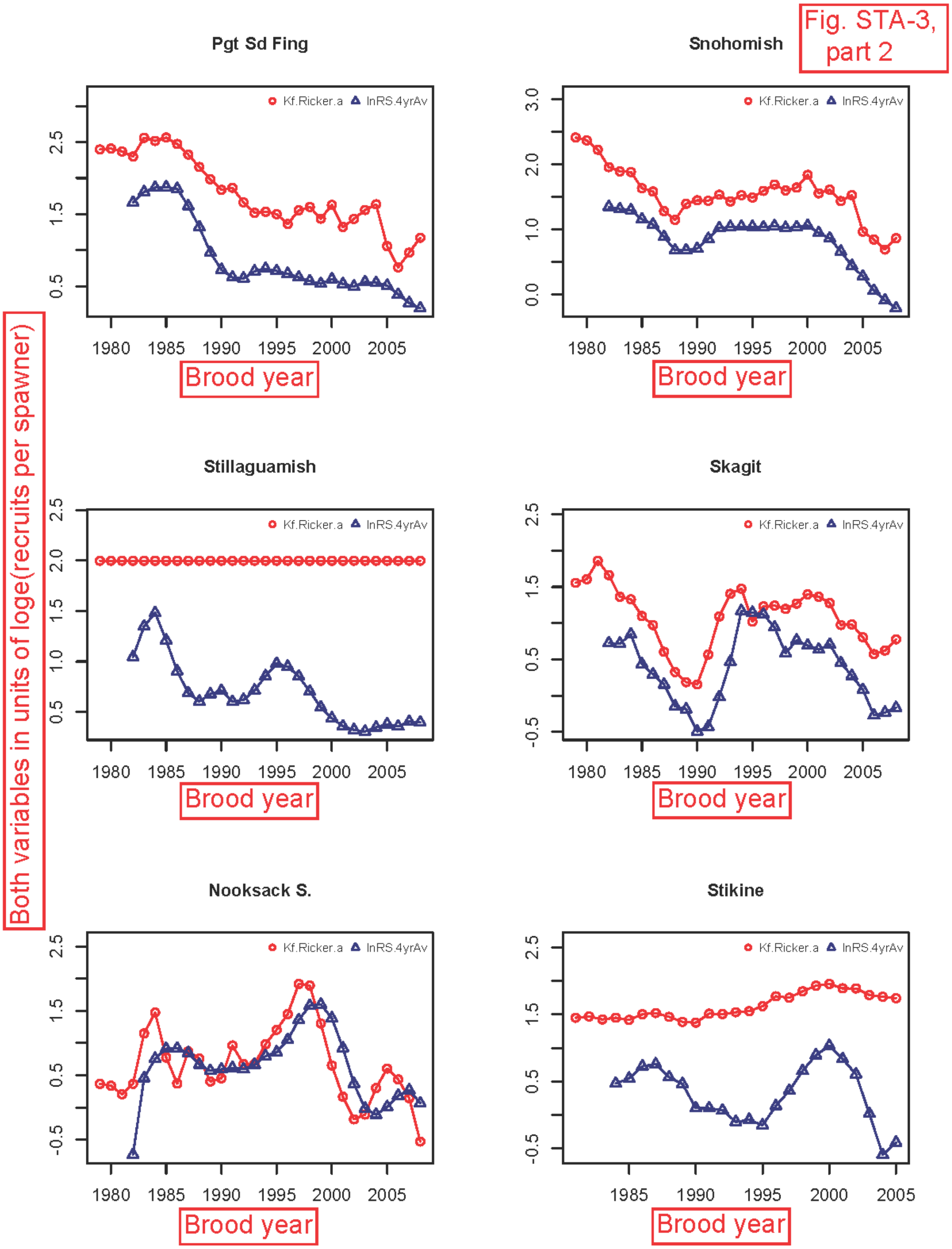

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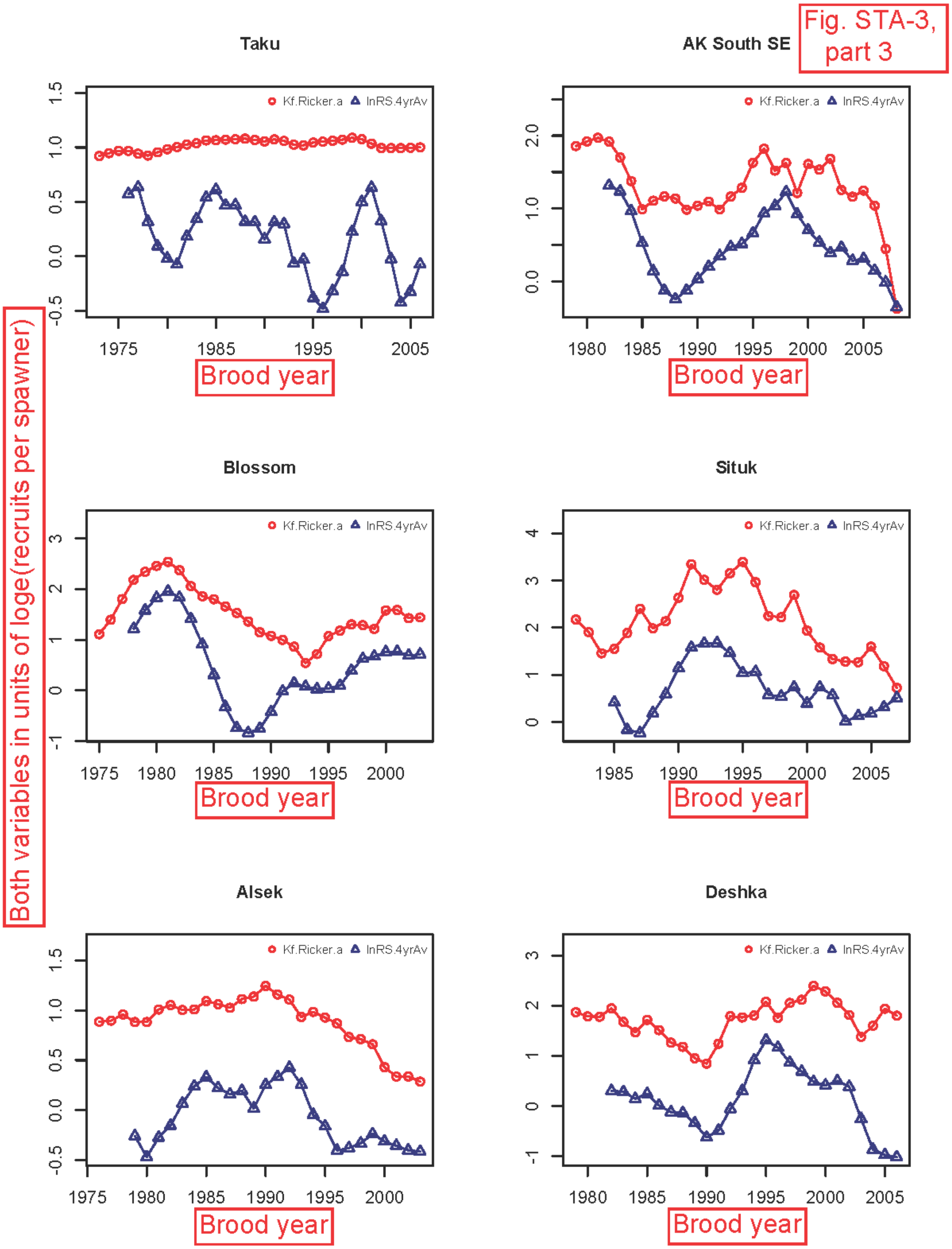

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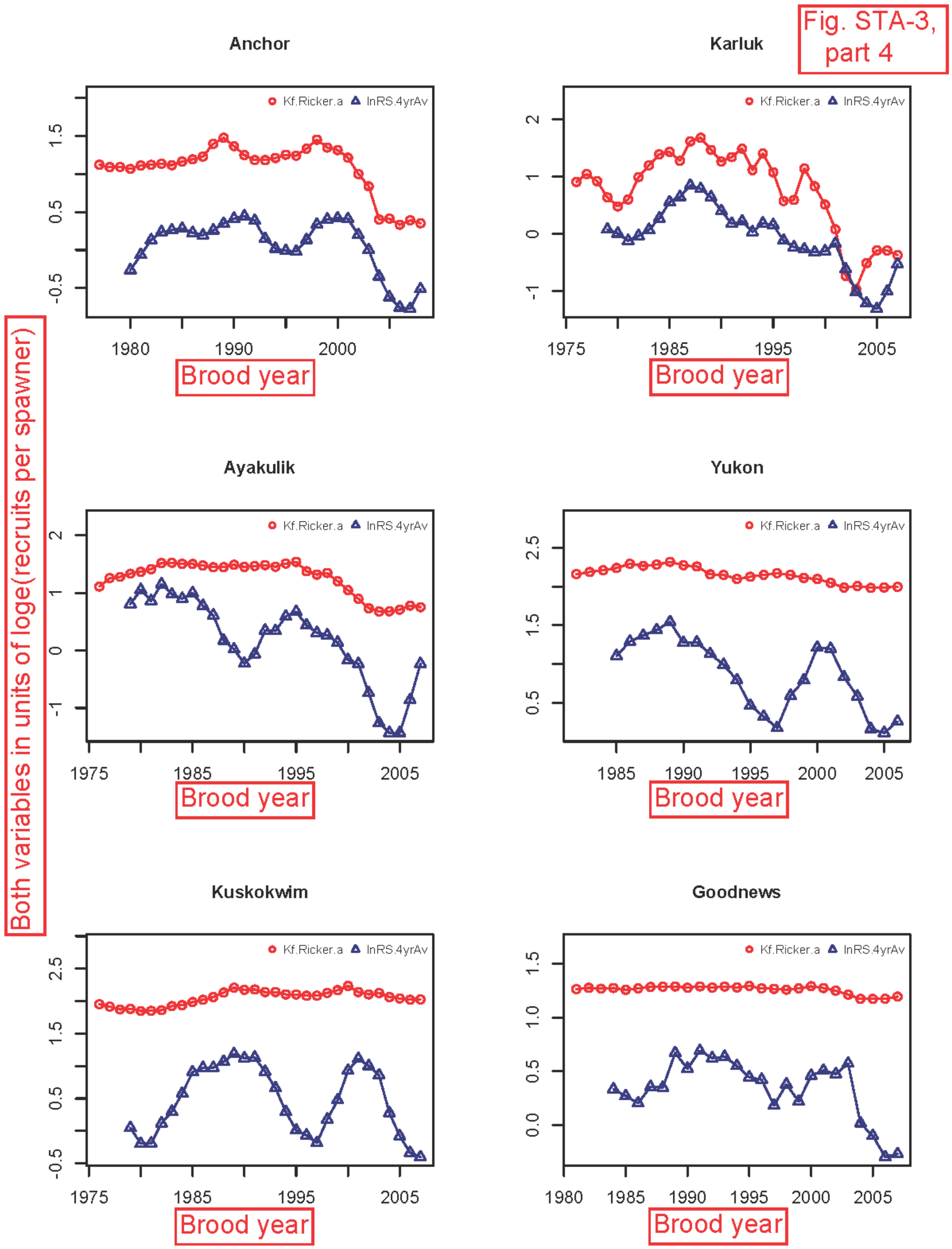

Figure STA-3. Part 4. Full caption at bottom of figure.

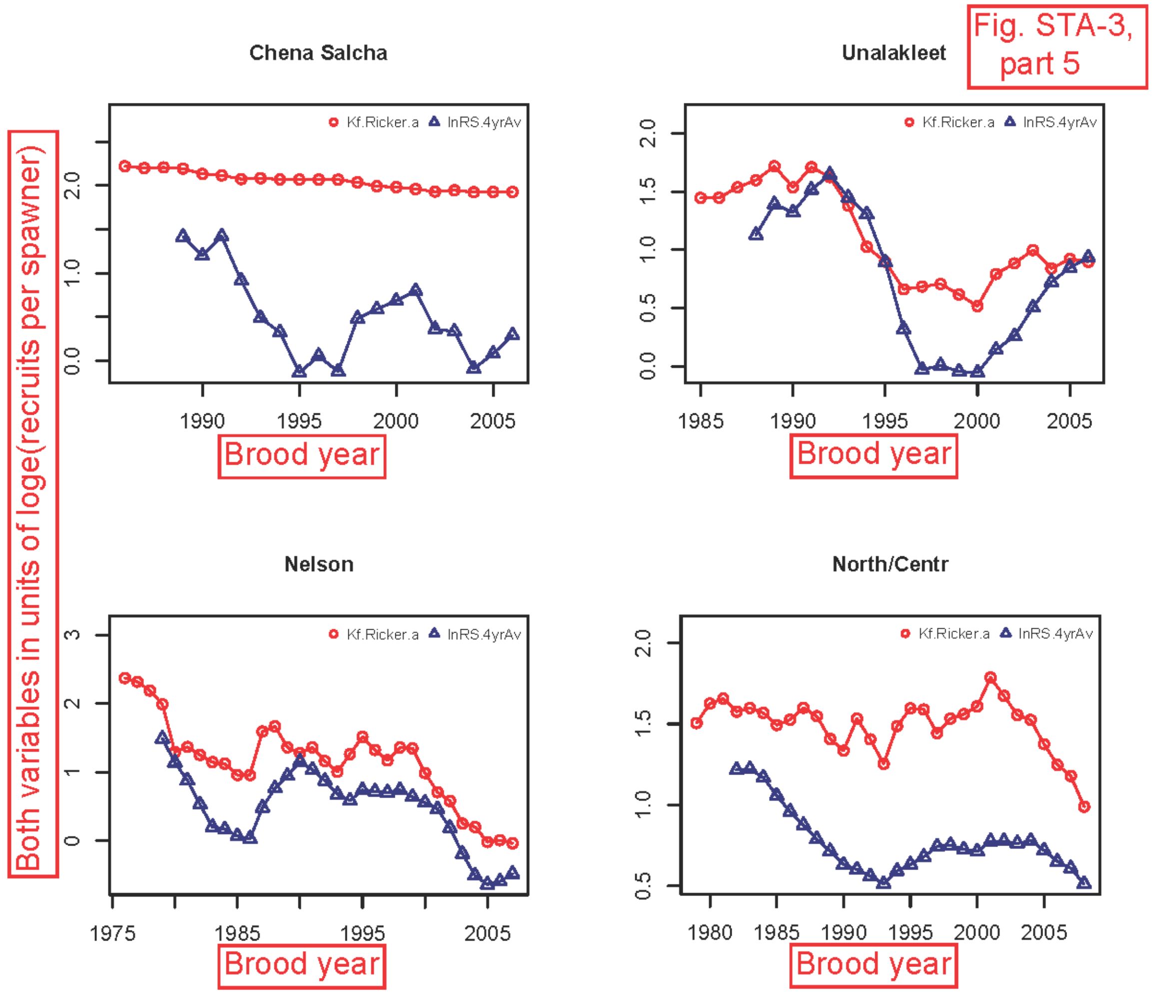

Figure STA-3. Same as **Figure ST-7** except here are shown two measures of life-cycle productivity derived from abundance of spawners (S) and their resulting adult recruits (R) for 28 stock aggregates <u>other than</u> the 5 Southern B.C. stocks shown in **Figure ST-7**, plotted by brood year. Those two measures are the 4-year moving average of $\log_e$(recruits per spawner) and the Kalman filter estimates of the Ricker 'a' parameter. For the $\log_e$(R/S) series only (blue triangles), a value of 0 means that adult recruits are just replacing the number of parental spawners; positive values indicate an increasing population, and negative values a decreasing one. North/Central B.C. is shown in the last graph. Data on spawners and recruits for 13 Chinook stocks in Alaska (from Blossom through Nelson) were obtained from the Alaska Department of Fish and Game via Matt Catalano, Auburn University. Time series of spawner and recruit abundance for the remaining stocks were reconstructed using the Pacific Salmon Commission's coast-wide model were obtained from Gayle Brown, DFO.

APPENDIX STA-4: SENSITIVITY ANALYSES

Longer data series (1981-2009)

To determine whether our baseline results for the 1995-2009 ocean entry years reflect longer-term trends, we repeated our analyses of survival rate and productivity with a longer data set. In this sensitivity analysis, we used ocean entry years 1981-2009 because that was the earliest period for which spawner and recruit data were available from stock reconstructions using PSC's coast-wide model, and we wanted the periods for survival rate and productivity analyses to be the same.

Log_e(CWT surv. rate) results

The correlation matrix for ocean entry years 1981-2009 for the 4-year moving average of log_e(cohort survival rate) shows slightly more and stronger positive correlations among just the SBC stocks than in the 1995-2009 period (**Figure STA-4**). The same is true, but to a lesser extent, for correlations between SBC and transboundary and Southeast Alaska stocks. However, there is little noticeable difference between the two periods for SBC correlations with Washington and Oregon stocks. Across the entire set of correlations from Oregon up to Southeast Alaska, there are slightly more positive correlations in the 1981-2009 analysis than 1995-2009 (**Figures STA-4, 5**).

Unfortunately, no results from the Dynamic Factor Analysis are available for this longer survival-rate data set because of convergence problems with the algorithm. DFA works well with up to 30 different time series, but here we had 53, which led to instability in the fitting procedure.

Productivity results

The detailed KF a_t correlation matrix for 1981-2009 shows a larger number of negative correlations (6 of 10) among Southern B.C. stocks alone than in the 1995-2009 results (3 of 10) (**Figure STA-6**). The correlations between SBC and more northern stocks have fewer positive values in 1981-2009 than 1995-2009. Over all the regions, positive between-stock correlations of KF a_t in 1981-2009 are weaker and more negative values appear than in 1995-2009, as is most evident in the regional average matrix (**Figure STA-7**).

Again, no results are available from the Dynamic Factor Analysis for the 1981-2009 analysis of Ricker residuals because of convergence problems with the 33 data series.

Few incomplete cohorts

In the baseline analyses of the age-2-cohort survival rates reported above for ocean-entry years 1995-2009, there were either 1 or 2 missing adult age classes in each stock that had not yet returned, with the exception of Northeast Vancouver Island, which was missing 3 ages. To extend the time series of age-2-cohort survival rates as far as possible, DFO filled in these incomplete cohorts with estimates based on historical adult age structure and indications of cohort strength from earlier ages that had already returned. However, given these missing values and the possibility that age distributions might be changing from the long-term average, the most recent few years of estimates from baseline analysis might be considered less certain than estimates for earlier years.

For this reason, we determined how robust our conclusions above were by repeating the among-stock correlations by only using data up through ocean-entry year 2007, instead of 2009 as for the analyses described above. This shorter data set meant that all except two of the 33 stocks (Kitsumkalum and Northeast Vancouver Island) had CWT-derived marine survival rates that were based on estimates of all adult age classes; those two exceptions were only missing data for the last age class to mature. Thus, for most stocks in this sensitivity analysis, there were no incomplete cohorts that required assumptions about age structure to calculate cohort survival rates.

Our sensitivity analysis of this shorter data set produced correlation matrices for that were very similar to the original ones. We therefore are confident that the general patterns of shared variation among Chinook salmon stocks in the survival rates and productivity are valid.

Alignment by brood year

The correlation matrices above were calculated by aligning all time series of survival rate and productivity so that all stocks shared the ocean entry year. This alignment was based on the fact that numerous Chinook salmon stocks in our data set have large contributions of juveniles from hatcheries, which obviously do not have a freshwater life stage. Nevertheless, to reflect the fact that the other stocks with different ages of juveniles entering the ocean could share important freshwater influences on productivity, we repeated the correlation analyses and aligned the stocks by brood year instead of ocean-entry year. The resulting correlation matrices for survival rate and productivity were similar to the original analyses, so there were no changes in overall patterns or conclusions. This similarity in results is in part because the 4-year moving average survival rate and the Kalman filter a_t values are strongly autocorrelated, so offsetting some time series by only one year will make very little difference.

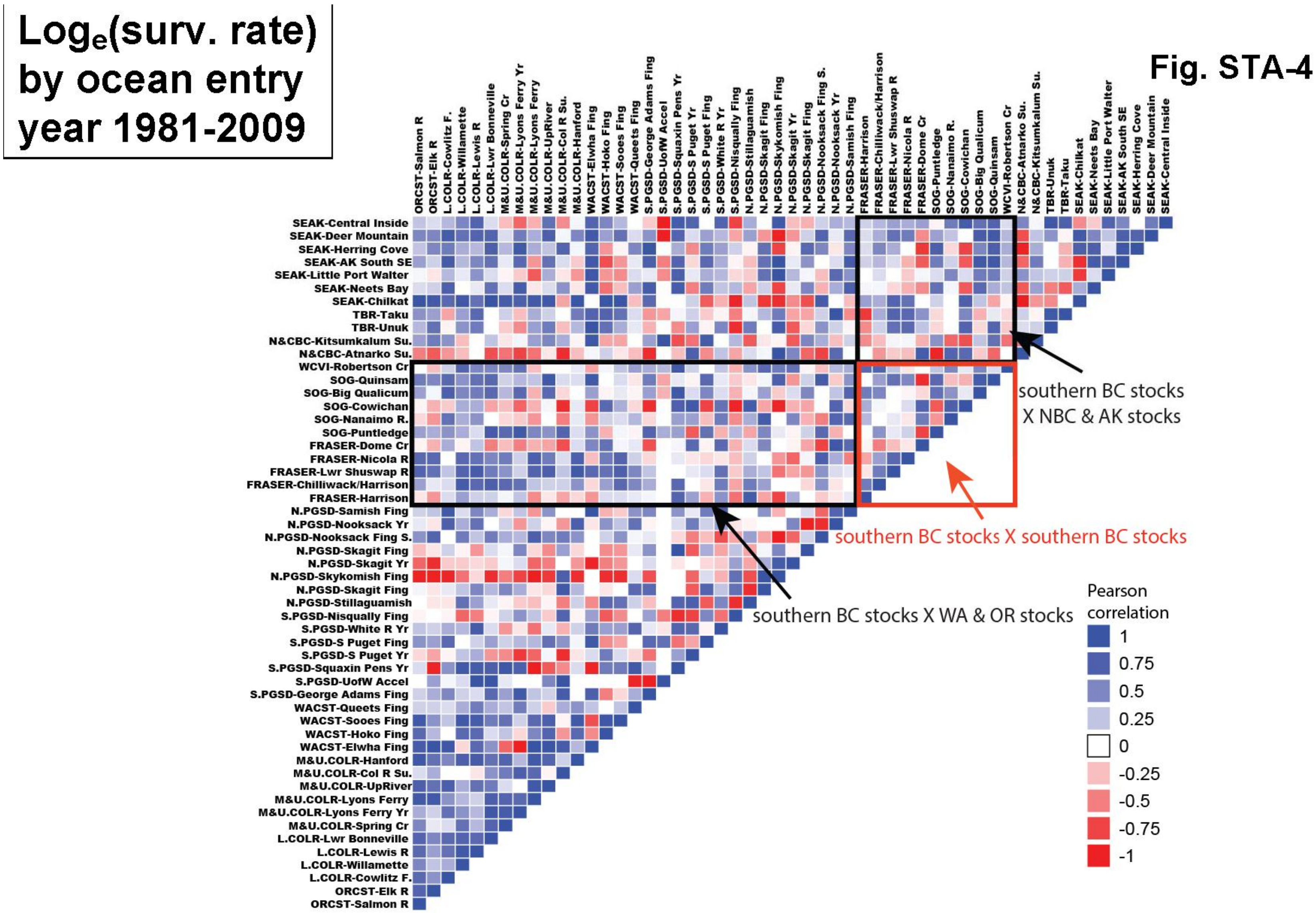

Figure STA-4. Pearson correlations between each pair of stocks that had time series for the CTC's CWT-based juvenile-to-age-2-cohort survival rate, for stocks from Washington up through Southeast Alaska. Results are for ocean-entry years 1981-2009 and with data series aligned to have the same ocean entry year for each stock, regardless of juvenile life-history type. Strength and magnitude of correlations are denoted by color. Note that by definition, diagonal elements have a correlation of 1.0 (the time series is correlated with itself).

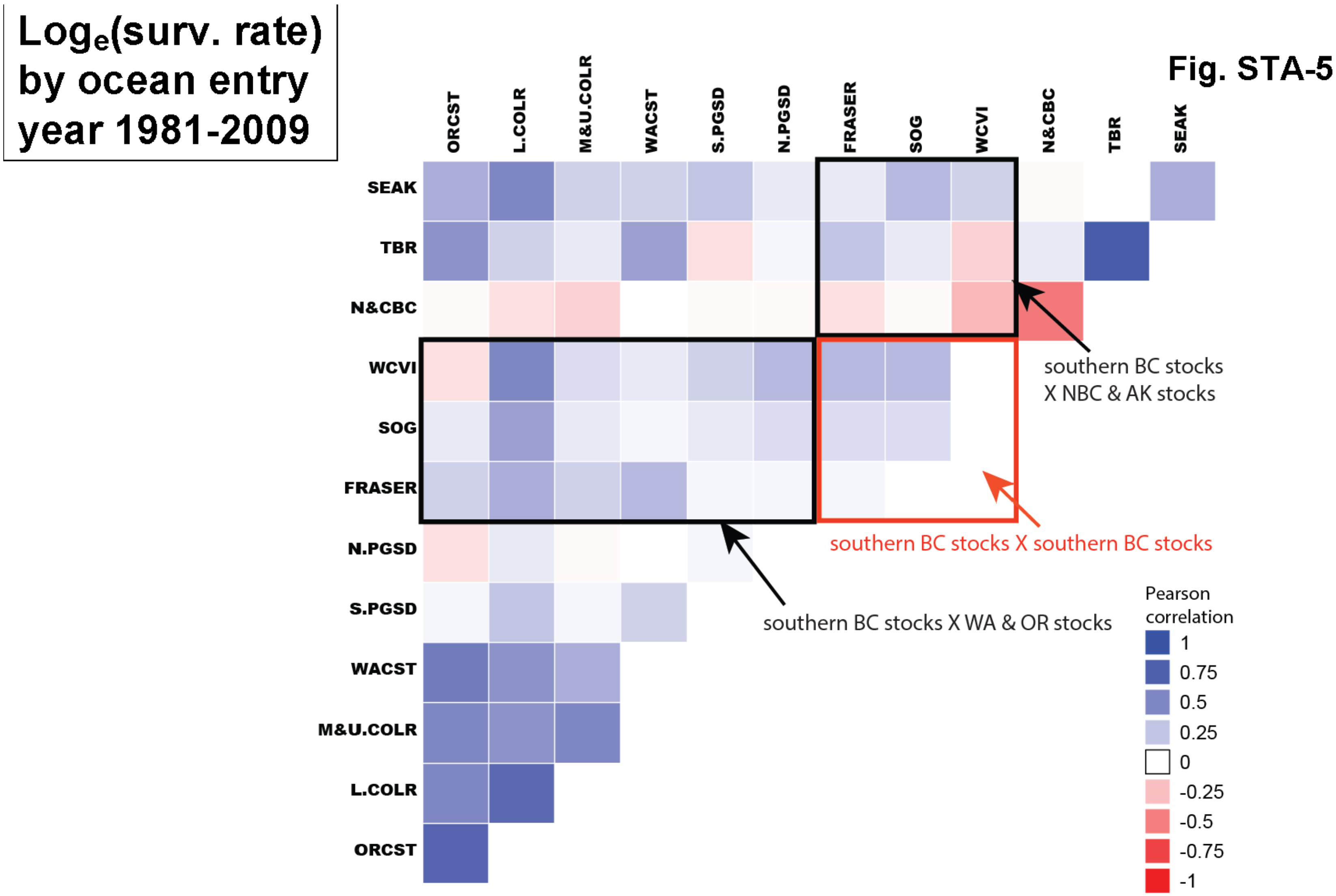

Figure STA-5. Summary of average correlations in juvenile-to-age-2-cohort survival rate within regions, based on the detailed pairwise correlation matrix in **Figure ST-9**, for ocean-entry years 1981-2009. Diagonal cells from that figure were omitted for calculating average pairwise correlations here within each region. No cell is shown here if there was only one stock in the region (which would result in a correlation of 1.0, thereby overestimating the average correlation among stocks within the three Southern B.C. areas, for example).

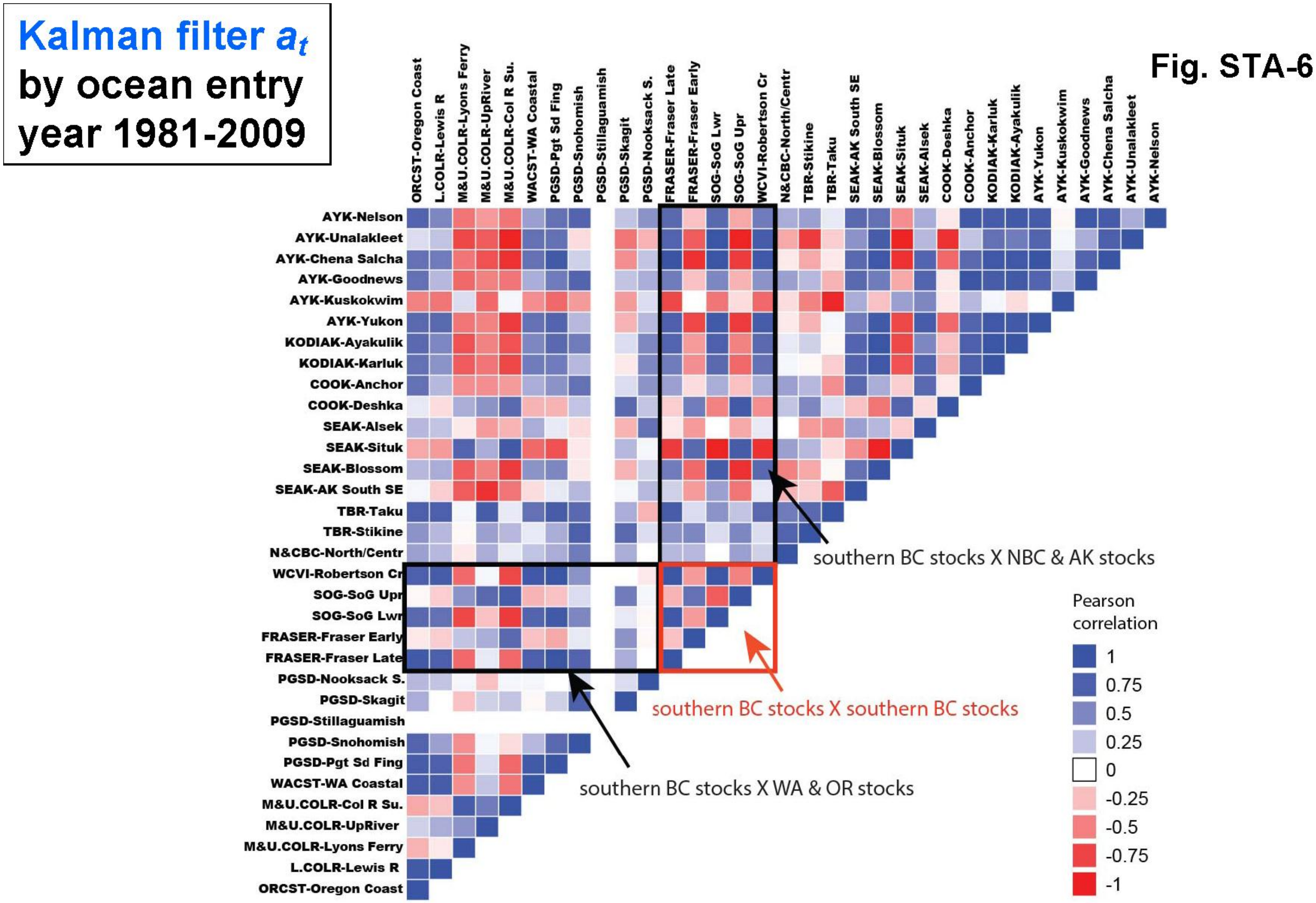

Figure STA-6. Pairwise correlations for the Kalman-filter-estimated time-varying Ricker a_t parameter between each pair of stocks that had time series for the CTC's CWT-based juvenile-to-age-2-cohort survival rate, for stocks from Washington up through Southeast Alaska. Results are for ocean-entry years 1981-2009 and with data series aligned to have the same ocean entry year for each stock, regardless of juvenile life-history type. Strength and magnitude of correlations are denoted by color. Note that by definition, diagonal elements have a correlation of 1.0 (the time series is correlated with itself).

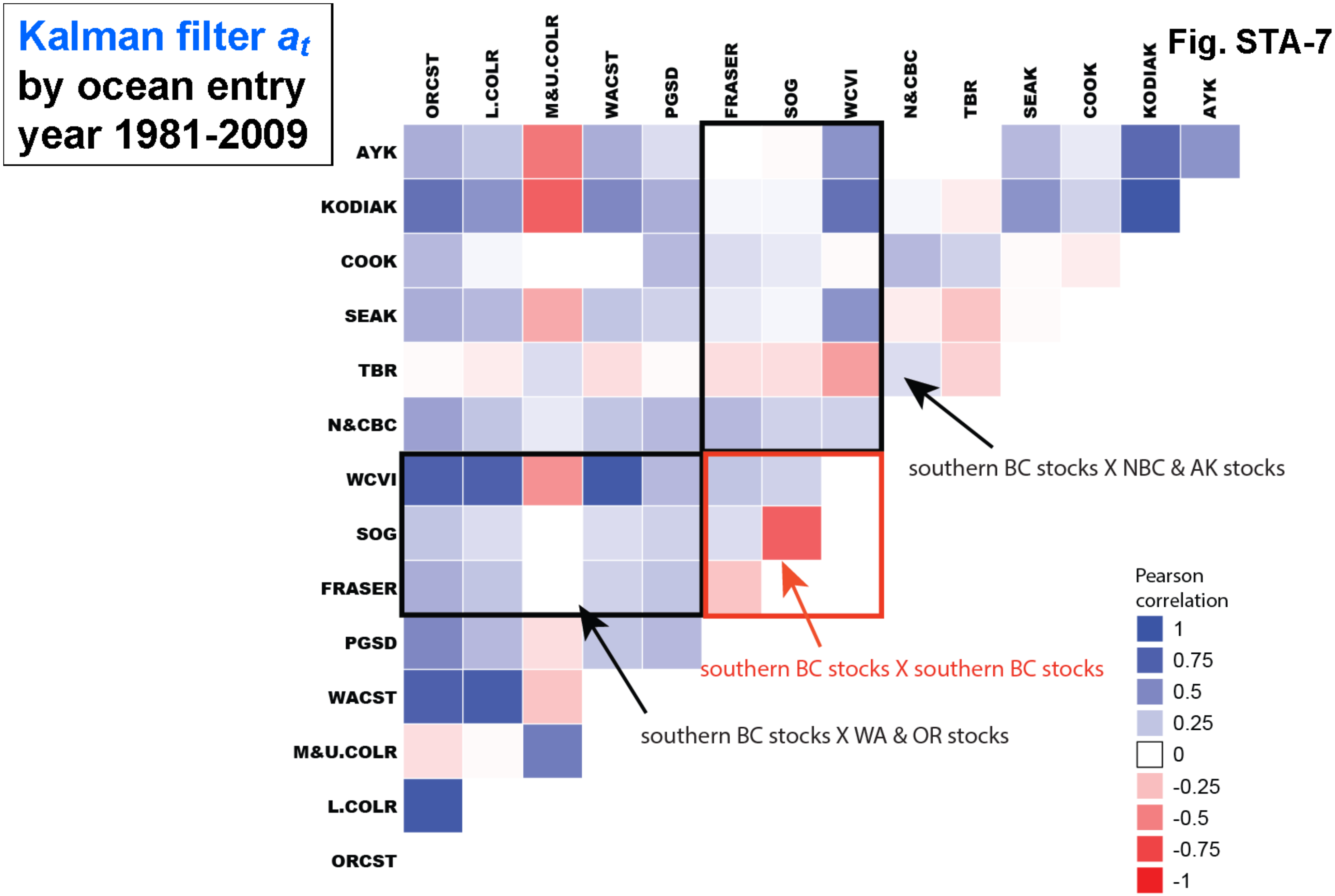

Figure STA-7. Summary of average correlations in juvenile-to-age-2-cohort survival rate within regions, based on the Kalman-filter-estimated time-varying Ricker a_t parameter correlation matrix in **Figure ST-13**, for ocean-entry years 1981-2009. Diagonal cells from that figure were omitted for calculating average pairwise correlations here within each region. No cell is shown here if there was only one stock in the region (which would result in a correlation of 1.0, thereby overestimating the average correlation among stocks within the three Southern B.C. areas, for example).

APPENDIX HATA-1: CALCULATION OF FIGURE HAT-9

Explanation of Calculations made to produce Figure H-9, figure prepared by Dr. David Hankin.

The graphed results are based on a "two generation" setup and assumed differential reproduction success of natural spawners. The logic of the calculations is as follows:

In generation "1", pHOS gives the proportion of 1st generation hatchery fish on the spawning grounds. These are returns to natural spawning grounds of fish released from a hatchery. (1-pHOS) therefore gives the proportion of fish on natural spawning grounds, in generation 1, that resulted from natural spawning (origin unspecified).

Assume that 1st generation hatchery fish (H) and natural-origin spawners (N) randomly mate with one another on a 1:1 basis (i.e., ignore complications of multiple males/female, etc.). In that case, the expected proportions of matings would be:

pHOS^2 = % of matings that are 1st gen H x 1st gen H

2 pHOS (1-pHOS) = % of matings that are "hybrids" (1st gen H x N)

(1-pHOS)^2 = % of matings that are N x N

Note that only returns in the next generation that result from the last category would be considered "wild salmon" under the WSP. However, all of these three groups will contribute to the naturally produced fish spawning in generation 2 (ignoring complexities of age structure, etc.)

We then assumed that the relative reproductive success of the three types of matings differ from one another. Specifically, for every one (1) returning spawner is produced by 1st gen H x 1st gen H matings, 1.5 are assumed produced by "hybrid" matings, and 2.0 are assumed produced by N x N matings.

Assuming that pHOS will be the same value in generation 2 as in generation 1, the remaining fraction of fish present, (1-pHOS), will have originated from natural spawning of the three types of matings above. Given the relative reproductive performance values assumed above, the expected proportions of spawners (in (1-pHOS)) from the three types of natural spawning would be:

[pHOS^2]/(Total Performance) = proportion of (naturally produced) returns originating from 1st gen H x 1st gen H matings

[1.5 x 2 pHOS (1-pHOS)]/(Total Performance) = proportion of (naturally produced) returns originating from hybrid matings

[2 x (1-pHOS)^2]/(Total Performance) = proportion of (naturally produced) returns originating from N by N matings (= proportion of (1-pHOS) that would be considered "wild salmon" under the WSP)

where Total Performance = (pHOS^2) + (1.5 x 2 pHOS (1-pHOS)) + (2 x (1-pHOS)^2)

The above proportions need to be multiplied by (1-pHOS) to give the actual proportions on the spawning grounds as pHOS is assumed to be constant across generations.

The relative reproductive success values in the above calculations are "arbitrary", but they are roughly consistent with recent studies. If one instead assumed equal reproductive performance of all mating types, then the proportion of "wild salmon" would be even less than the above calculations generate.