ENSO induced harmonic oscillations of marine survival (HOMS) in southern British Columbia sockeye salmon populations: Adult sockeye returns "in HOMS way"!

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Observation Type:
[X] acoustics and trawl, [X] spawning ground, [X] other. Comparisons of time series data sets of smolt-to-adult survival indices for “indicator stocks” of Fraser (Sue Grant, unpublished data) and non-Fraser sockeye (Dr. Kim Hyatt, unpublished data) salmon originating from Central and South Coast areas of British Columbia.

Rationale:

The terms of reference of the Commission of Enquiry into the Decline of Sockeye Salmon in the Fraser River (*i.e.* the Cohen Commission) directs the Commission, in part, to “investigate and make independent findings of fact regarding the causes for the decline of Fraser River sockeye salmon including, but not limited to, the impact of environmental changes along the Fraser River, marine environmental conditions, aquaculture, predators, diseases, water temperature and other factors that may have affected the ability of sockeye salmon to reach traditional spawning grounds or reach the ocean”. In short, one key objective of the Cohen Commission is to examine information about relationships between dependent variables serving as indices of salmon survival (i.e. total returns, returns-per-spawner, smolts-per-spawner, returns-per smolt) and a variety of independent variables (biophysical factors such as water temperature, competitors, predators, pathogens etc…) that may influence salmon survival in either freshwater or marine ecosystems.

Total return and return-per-spawner observations are the most commonly available time series used to characterize variations in production of sockeye salmon populations throughout their geographic range (Muetter *et al.* 2002a). However, both of these dependent variable series confound freshwater and marine events (Muetter *et al.* 2002a, 2002b) and so are of equivocal value in resolving the separate influences of freshwater versus marine factors on year-specific or time series production trends exhibited by sockeye salmon (Pyper *et al.* 2005). Observational data sets that partition freshwater and "marine" survival rates are available for few BC salmon stocks in general and sockeye in particular. Regardless, partitioned survival series have considerable value in establishing the location (freshwater versus marine ecosystem), time (single to multiyear interval) and potential identity of independent variables influencing the survival(s) of a given sockeye stock. Personnel associated with the Department of Fisheries and Oceans (DFO) Salmon in Regional Ecosystems (SIRE) Program and its predecessor (the Lake Enrichment Program) have collaborated in development and maintenance of a limited number of partitioned survival data sets consisting of annual observations covering intervals from 15-30 years before present for several indicator stocks of non-Fraser sockeye. These largely unpublished observations (Hyatt *et al.* unpublished data) are compared and contrasted here with a similar published series of marine survival estimates for Chilko sockeye salmon originating from the Fraser River (Grant *et al.* 2010) in order to better characterize what we do and do not know about the generality or uniqueness of regional factors controlling recent production variations exhibited by Fraser River sockeye salmon.

<u>General Origins and Status of Sockeye Salmon Survival Observations</u>:

Determinations of marine survival (*i.e.* a smolt-to-adult return rate or SAR) are conceptually simple requiring only that one estimate the number of adult returns as a proportion of the number of seaward migrating smolts where both are derived from the same parental spawning year (*i.e.* the brood-year of origin). Although deceptively simple in theory, SAR estimation is not simple in practice. This is because marine survival indices are estimated from combinations of traits belonging to both individual fish (age of smolts and adults) and populations (abundance of smolts and returning adults). Sockeye salmon smolts originating from a single brood-year of origin may migrate seaward following 1-3 years of rearing in freshwater and subsequently return as adults following 1-4 years of rearing in the ocean. Thus, assessment of marine survival for the progeny of a single brood-year could theoretically require completion of year-specific abundance estimates and sampling for biological traits over intervals spanning up to 8 consecutive years. Because most adult salmon in the populations of interest here generally mature at or before their 5^{th} year of age a marine survival estimate associated with a given brood or sea-entry year may be derived from sampling routines executed over as few as four subsequent years. However, the requirement to maintain consecutive years of sampling still results in a "string" of no less than 15, and upwards of dozens of separate salmon abundance and biological trait estimates used to calculate a single SAR for the sockeye populations considered here (Table 1 and Appendix 1).

The accuracy and precision of "compound" survival indices depends on the accuracy and precision of their component observations. Historic to current survey, sample processing and data analysis methods are reviewed by DFO personnel on an annual basis. However, rigorous standardization of multi-year assessment procedures and maintenance of constant data quality pose an ongoing challenge when time series SARs are assembled over several decades because of potential changes in the populations of interest (*e.g.* abundance variations and age structure), the field context for sampling (*e.g.* changes to the subject population's inclusion in mixed stock fisheries), the gear, procedures or levels of effort used to obtain samples or estimates (*e.g.* from pre-smolts or smolts, adults in catch, adults in escapement) along with changes to personnel executing the multitude of survey and sample processing tasks. Although commentaries on factors likely to influence the reliability of observations contributing to a given SAR are often embedded in field data logs or spreadsheet records, metadata such as these spanning decades of time are often lost or become separated from the raw data during analysis and subsequent use. Thus, survival index time series (*e.g.* recruits per spawner or SARs) are frequently used, even in the primary literature, absent any systematic documentation or substantive review of their observational origins. Given the complex origins of observational data contributing to survival estimates, generation of sufficient documentation to enable serious peer review would require major increases in resources currently allocated by DFO or others to the standardization, analysis and management of the source data and metadata. However, in the absence of such documentation, time series survival estimates presented here and elsewhere (Bradford 19??) should be considered preliminary in nature and subject to both challenge and further clarification.

Origins and Status of Survival Observations Reported Here:

Time series allowing partitioning of freshwater and ”marine” survival rates over at least a decade are available for fewer than 7 sockeye salmon indicator stocks of the more than 200 sockeye Conservation Units “managed” by DFO within Canada’s Pacific Region (Holtby and Cirunna 2007). Although survival could in theory be partitioned among several life history stages (egg-to-fry, fry-to-smolt, smolt-to-age-one, age-one to age-two etc…) practical considerations to date have generally limited partitioned data sets to dealing with just single indices of freshwater and then marine survival. When partitioned, sockeye survival series generally index freshwater survival in terms of smolt numbers produced per female spawner at or near the time of exit from a given nursery lake. By contrast, “marine” survival is indexed as adult returns per smolt but these estimates include the survival rates of smolts during their downstream migration as well as their survival in the marine environment. Marine survival series (SARs) for four geographic areas and five B.C. sockeye indicator stocks are considered here including: Fraser R. (Chilko), Upper Columbia R. (principally Okanagan), WCVI-Somass R. (Great Central L., Sproat L.) and the Central Coast-Docee R. (Long L.) because of their potential to characterize the extent to which common or separate marine survival factors may be involved in controlling production trends observed for Fraser and non-Fraser sockeye. SIRE Program personnel participate in many annual field surveys and, in collaboration with DFO Area staff, have assembled unpublished multi-year data sets on the stocks considered here as a basis for analysis and publication of future reports on factors that are likely involved in controlling sockeye salmon production variations in freshwater and marine ecosystems in various geographic areas. As noted above, documentation of the raw data and accompanying metadata used to generate SAR series for the subject stocks is only partially complete so a summary of their general origins (Table 1) has been provided as a guide to help qualify whether SAR series may be fairly compared within or among stocks either with respect to differences in year-specific values or just for temporal trends. Additional analysis and reporting will be completed as time and resources permit.

Table 1. A brief summary of indicator stocks and associated sampling required to provide observations to estimate annual SARs for selected Fraser and non-Fraser sockeye salmon.

Area-Stock	**Distance to Sea (km)**	**Smolt Assessment**[12]	**Catch Assessment**[12]	**Escapement Assessment**[12]	**Comment**
Fraser-Chilko	450 km	Diel photographic sub-sampling[1] over full period of smolt migration.	Use of unique scale or genetic markers to assess Chilko fish in large, mixed-stock, fisheries[2] from Haida Gwaii to Fraser R.	Mark-recapture of adults in two main spawning areas[3].	1, 2, 3.
Columbia – Okanagan (and Wenatchee[4])	800 km	Pit-tagging and maximum likelihood estimates of daily smolt migration[4] at McNary Dam.	Annual exploitation rates <10% in interval considered here[5]. Catch comprised of principally Okanagan and some Wenatchee returns[6]. Redfish L. sockeye have been numerically insignificant from 1995-2009.	Diel, visual counts of adult sockeye migrating through fishways[6] at Bonneville Dam.	4, 5, 6.
WCVI- Great Central, Sproat	10-20 km	In-lake, acoustic-and-trawl based estimates[7] in late winter.	Stock reconstructions or unique markers used in terminal Barkley Sound fishery[8].	Continuous, electronic counts (calibrated) of adults at fish-ways[9] just prior to lake entry.	7, 8, 9.
Central Coast-Long L.	1 km	In-lake, acoustic-and-trawl based estimates[7] in late winter.	Terminal fishery for single stock in Smith Inlet[10].	Visual counts of adult salmon[11] passing the Docee R. fence each day.	7, 10, 11.

Numbered comments associated with Table 1 above.

1. Photographic sub-sampling has been executed at the outlet of Chilko L. for decades accompanied by subtle changes in effort (seasonal timing, sub-sample volume, photographic analysis) and equipment (recent shift from optical to digital cameras). Although field logbooks and metadata in spreadsheets provide some indication of these variations they are not well documented in peer reviewed reports. Given the sampling techniques used to estimate Chilko smolt abundance, estimates of statistical precision associated with annual smolt values could be calculated but have not been routinely provided.

2. Several mixed stock fisheries intercept Chilko sockeye at variable levels off Haida Gwaii, in Johnstone Strait, off the WCVI, in the Strait of Juan de Fuca, in the Lower Fraser and the Upper Fraser. In each instance biological samples of scales or tissue must be used to derive estimates of Chilko abundance in mixed stock catches. In years when Chilko sockeye dominate total returns, assignment errors are likely small. However, in years when Chilko sockeye make up smaller proportions of total returns, assignment errors are certain to be larger. Current practice does not provide any estimate of precision for the proportion of Chilko fish present in mixed stock returns.

3. Estimates of precision are available for annual mark recapture estimates but in the absence of estimates of precision for other observational components contributing to SARs, no combined precision estimate is available for Chilko SARs.

4. Although Upper Columbia SARs presented here include smolt production and adult returns originating from both Okanagan and Wenatchee sockeye stocks, Okanagan fish have accounted for most juvenile and adult production (average >70% of total) so SARs reported here are principally attributable to Okanagan sockeye. Work currently underway (Hyatt *et al*. unpublished data) will soon allow an explicit time series of SARs for just Okanagan sockeye, although this is not expected to alter the general trends observed in the SAR series reported here.

5. Three sockeye populations make contributions to total returns to the Columbia. These are Redfish Lake sockeye (a remnant stock that is listed under the U. S. Endangered Species Act), Wenatchee sockeye that return to Wenatchee Lake in Washington State and Okanagan sockeye that return to spawn in the Okanagan River in Canada and rear in the north basin of Osoyoos Lake, also in Canada. Exploitation rates on Columbia sockeye aggregate returns reached values as high as 65% in the mid-1980s. Constraints on commercial fisheries in the Lower Columbia to protect ESA listed, Redfish Lake sockeye have reduced aggregate exploitation rates to <15% since the 1990s. Consequently, escapement to terminal spawning areas currently account for very high proportions of annual returns to all three Columbia sockeye stocks.

6. Standard procedures have been developed and maintained for estimating salmon abundance passing each of several dams on the main-stem of the Columbia River. Although counts at Bonneville Dam include returns of both Redfish Lake and Wenatchee Lake sockeye, Okanagan sockeye salmon have accounted for the majority of returns in all years considered here (*i.e.* adults passing Wells Dam to return to the Okanagan in Canada comprised 71 % of all sockeye returning to the Upper Columbia between 1995 and 2009 and 80 % of returns between 2005 and 2009) so SARs identified here, and reported by NOAA Fisheries (NOAA 2009), primarily reflect Okanagan sockeye survival trends. SIRE Program personnel are currently developing data sets (late winter ATS estimates of pre-smolts in Osoyoos Lake, escapement past Wells and catch allocated to stock of origin) that will provide a refined estimate of SARs associated with Okanagan sockeye alone in place of the current index series for the Upper Columbia stock aggregate.

7. Acoustic-and-trawl based surveys adhere to highly standardized methods (Hyatt *et al.* 1984, Hyatt *et al.* 2000) that provide known precision estimates of pre-smolt abundance in the late winter of each year.

8. Allocation of mixed stock catches (Great Central, Sproat and Henderson sockeye) based on stock reconstruction techniques (Steer *et al.* 1988; LaBelle *et al.* 2009) and/or stock-specific biological markers produce catch estimates of variable reliability (Henderson low, Sproat moderate, Great Central highest) among years. However, because greater than 90% of returns to Barkley Sound originate from Great Central and Sproat stocks (Dobson *et al.* 2005), annual catch estimates for Henderson are likely of limited reliability for SAR estimation. Moreover, because stock reconstruction techniques have been used in many years to assign catch to Great Central and Sproat, both SAR time series should be viewed as interdependent rather than statistically independent. A simpler, reliable time series would estimate annual SARs for both stocks as an aggregate, although this work has yet to be completed.

9. Use of Pulsar Electronic Counters at both Sproat Falls and Great Central fish-ways provide continuous estimates of sockeye passage by hour through virtually the entire migration period. Records of weekly calibration of counter accuracy and species composition are used in combination with daily totals of fish passage to estimate adult sockeye escapement. Although field logbooks, metadata and daily count observations are well represented in spreadsheets or databases they are not sufficiently documented in formal reports to verify their year-specific level of reliability.

10. The Smith Inlet fishery is comprised virtually entirely of sockeye salmon returning to the Docee River and Long Lake, so annual estimates of catch across the period of record considered here are highly reliable. The dominance of age 1.0 smolts and absence of a mixed stock fishery reduces the number of component observations required to estimate a SAR for this stock to a minimum of 14 samples taken over 3 consecutive years.

11. Sockeye, Chinook and coho salmon adult returns are visually enumerated at the Docee fence. Mixed species returns were dominated by sockeye salmon (>80%) throughout the interval prior to the mid-1990s. However, after the mid-1990s sockeye returns were so low in a few years that adult coho salmon outnumbered sockeye adults. This may have biased some SAR estimates for sockeye although the exact nature of the bias (higher or lower than actual) is not immediately obvious.

12. At each location and interval of abundance estimation, samples of sockeye pre-smolts, smolts, adults in catch, and adults in escapement are required to estimate sockeye age composition for the purpose of assigning smolts and adult returns to their correct brood-year and/or sea-entry-year(s) of origin. Although sampling conditions and sample sizes supporting these age assignments are generally known for each SAR component, systematic assembly, review and documentation of annual records involving multi-decadal intervals is incomplete and likely warranted before time series SARs may be viewed as authoritative. For example, age composition of either juvenile or adult sockeye is known to have been estimated on the basis of all-year mean values in some instances due to either missing samples or small sample size. Errors in age composition may propagate errors in assignment of either seaward migrating smolts or, more commonly, adult sockeye in returns to an adjacent brood-year of origin thus skewing SAR values in consecutive years.

Notes Regarding Statistical Limitations on SAR Comparisons:

For the sockeye indicator stocks considered here, time series SARs cover intervals ranging from 13 (Okanagan) to 38 (Chilko) sea-entry years (Figure 1). However, some obvious statistical limitations need to be considered before attempting any interpretation of their biological significance. First, each SAR estimate depends on the systematic assembly of a minimum of more than a dozen sample observations derived from consecutive years of field programs (Appendix 1). Although some of these observations are generated with known precision (*e.g.* ATS estimates of "smolts", mark recapture estimates of adult spawners), many are not, due to the excessive cost that replication of surveys would entail to obtain such measures. Consequently, SAR estimates are generally of unknown precision and virtually always of unknown accuracy. Second, sampling methods used to assess adult and juvenile salmon abundance may vary among indicator stocks and sometimes even within stocks between intervals (Table 1 and associated notes). Although SARs are always expressed as a return rate (*i.e.* the proportion of smolts from a given sea entry year that subsequently return as adults), differences in assessment methodologies may result in the creation of SARs involving inherently different metrics (*i.e.* SARs that are no more similar than "apples are to oranges"). Thus, differences in SARs should not be automatically interpreted as providing reliable information about the absolute magnitude of survival differences between stocks or intervals prior to consideration of their methodological origins (*e.g.* Table 1). Face value comparisons among SARs require either that they be derived from component samples acquired through identical sampling methods or that methodological differences affecting component samples of SARs have been cross-calibrated to account for such differences.

To balance the several caveats that apply when interpreting the possible biological significance of SARs presented here, consideration should be given to approaches that offer greater certainty in the use of a given SAR series. First, as long as methodological consistency is maintained in generating SAR observations, the resultant series should be useful for identifying temporal trends of marine survival by a given indicator stock. In addition, persistence of either low or high survival for a decade or more does provide a form of repeated measures observations revealing survival patterns that are unlikely to occur due to any statistical artifact. SAR series lacking such persistence are more problematic given the absence of estimates of precision on annual estimates. However, personal experience with estimating precision levels associated with many of the "types" of component estimates that form the foundation for SARs suggests that SAR estimates differing by a factor of two or more within a series are unlikely to be attributable to statistical artifact(s) and so may be considered as biologically significant. The minimum difference between the highest and lowest SAR estimates for each of the sockeye indicator stocks considered here is more than a factor of 12 (for Okanagan sockeye salmon) and the maximum difference is greater than a factor of 200 (for Smith Inlet-Long L. sockeye) so each series provided here is likely a useful source of information about temporal patterns of marine survival affecting sockeye stocks in southern B.C.

Marine Survival Comparisons and Conclusions:

Given the qualifiers noted above, the SARs presented here provide a reliable basis for several generalizations about marine survival trends for sockeye salmon in the southern half of British Columbia. First, it's clear that all of the subject stocks display a pattern of large magnitude oscillations that encompass a wide enough range of SAR values to be considered highly significant from a biological perspective. Hyatt and Steer (1988) and Hyatt *et al*. (in DFO 2005, 2007, 2009) have attributed observations of SAR fluctuations exhibited by Barkley Sound sockeye (Panel-3, Figure 1) as evidence of the influence of alternating La Nina-like and El Nino-like conditions on the structure of coastal marine ecosystems that favor relatively high marine survival in cool sea-entry years (1971-72, 1979-80, 1985, 1988-89, 1995, 1999-01, 2006-08) and then lower marine survival in warm sea-entry years (1982-83, 1986-87, 1992-93, 1997-98, 2003-05).

The hypothesis that changes in ENSO variations induce harmonic oscillations in sockeye marine survival (*i.e.* the harmonic oscillating marine survival hypothesis or **HOMS**) has served as the conceptual basis (Figure 2) for a highly successful pre-season forecasting method (the survival stanza method or SStM) that has been used to predict large variations in annual returns of Barkley Sound sockeye for more than twenty years (Hyatt and Steer 1988, Hyatt and Luedke 1999, Dobson *et al.* 2005). Agreement among SAR data sets and, as noted above, the data themselves, are less than perfect. However, examination of these same years of warm versus cool sea-entry by juvenile sockeye salmon originating from the Fraser, Smith Inlet and even the Columbia indicates that varying ENSO-like conditions, anticipated by sea surface temperature changes, appear to induce predictable oscillations from higher to lower marine survival for all stocks. Thus, for the 5 indicator stocks considered here, 24 of 27 possible La Nina cases are accompanied by elevated marine survivals relative to proximal values observed in non-La Nina years. Conversely, roughly 18 of 22 possible sea-entry year cases exhibiting El Nino conditions are accompanied by depressed marine survivals relative to proximal values observed in non-El Nino years (Figure 1). This knowledge alone should have value in improving future forecasts of marine survival and total return variations for these stocks and, at this writing, we anticipate that the 2008 through 2009 sea entry years (2010-2011 return years) will be accompanied by relatively high marine survival for sockeye stocks from the BC Central and South Coast areas.

The magnitude of the marine survival oscillations around the all-year mean of SARs displays no strong trend in the case of Barkley Sound sockeye suggesting that ENSO-like variations alone provide a sufficient condition to account for most of the variation in marine survival exhibited by this stock over the period of record. However, this conclusion does not apply equally well to stocks in other areas of the coast. For example, although Smith Inlet sockeye do exhibit an oscillating pattern of marine survival, this stock also displays an interval of relatively high marine survival (1978-1991 sea entry years) followed by an interval of much lower, although still oscillating, marine survival (1992-2005). The sudden transition in 1991 and 1992 from relatively high to much lower marine survivals exhibited by Smith Inlet sockeye salmon suggests an ocean-production, regime-shift (Polovina 2005) of as yet unknown origins. Of interest here, the 2006 sea-entry year shift to ENSO neutral and then to powerful La Nina conditions along the BC coast in sea-entry years 2007 and 2008 appear accompanied by the first evidence that marine survival of Smith Inlet sockeye may finally be emerging from a long interval of persistently low values.

The marine survival pattern for Chilko sockeye (Fraser) is more similar to the Barkley Sound than Smith Inlet pattern (Panels 1-3, Figure 1) but there are notable differences between the latter stocks in both trends and especially single-year events. Within the context of an oscillating marine survival (OMS) pattern, there appears to be a trend for a dampening and declining marine survival of both Chilko and Barkley Sound sockeye from the 1990s to present. Thus, although Smith Inlet, Chilko and Barkley Sound sockeye stocks exhibit a common shift from a higher to a lower mean marine survival during the intervals prior to and then following the 1990 sea-entry year, the precise trajectories of these declines differ among stocks suggesting the interaction of additional mechanisms superimposed on a common OMS pattern. This should not be surprising given that the "marine" survival series (*i.e.* dependent variable series) for all stocks are determined during seaward migration through some areas that are shared in common and some that are not. Thus, Chilko and Columbia sockeye SARs reflect responses, in part, to factors operating during hundreds of km of migration through the Fraser and Columbia rivers respectively while Chilko sockeye alone, of the stocks considered here, spend periods of several weeks of time in Georgia Basin. By contrast, all stocks considered here, share common areas during migrations that take them through continental shelf waters along the coasts of Central BC and Southeast Alaska (Tucker *et al.*. 2009). These differences are undoubtedly responsible for subtle differences in multi-year trends and especially for single year events that may be shared among stocks or associated with just one stock. For example, the 2005 sea-entry year was associated with strongly sub-average "marine" survivals for sockeye stocks returning throughout the BC south-to-central coast in 2007 (Figure 1), suggesting the action of a common mechanism operating over large spatial and temporal intervals (*e.g.* possibly food production and/or predation mechanisms associated with coastal areas under the influence of the Northern California Current System, Hyatt *et al.* in DFO 2009). However, these same stocks exhibited widely divergent marine survival values in association with the 2007 sea-entry and 2009 return years accompanied by: strongly sub-average survival (and returns) of Chilko sockeye (Fraser), far above average survival for Okanagan sockeye (Columbia R.), near average survival of Barkley Sound (WCVI) and Smith Inlet (Central Coast) sockeye (Hyatt *et al.* this report). Thus, the factor(s) controlling the surprisingly poor returns to the Fraser R. in 2009 had little to no influence on many non-Fraser sockeye stocks suggesting the operation of mechanisms in areas uniquely occupied by juvenile Fraser sockeye in 2007 (*e.g.* Fraser River migration corridor or Georgia Strait).

The value of partitioned freshwater and marine survival observations to guide DFO in making important decisions or investments in assessment programs has been demonstrated previously with respect to the collapse of the Rivers and Smith Inlet sockeye stocks and fisheries in the early 1990s. At that time, various fisheries interest groups adopted adversarial positions suggesting that logging activities, an absence of due diligence in habitat protection by DFO, and subsequent freshwater survival declines were the causal agents for the collapse. Analysis of the partitioned survival series for Smith Inlet sockeye provided critical evidence that the Rivers and Smith Inlet sockeye collapses were due to marine rather than freshwater events in the early 1990s (McKinnell *et al.* 2001) and subsequently that survival compensation in freshwater was contributing to an acceleration of stock recovery (Hyatt *et al.* in DFO 2009). The ability to make these determinations has undoubtedly saved the Department from needless expenditures of effort and budget on assessment programs focused in the wrong areas.

In the current case concerning declines of Fraser River sockeye, the degree of covariance of freshwater or "marine" survival observations between and among sockeye stocks that exhibit either similarities or differences in: time of sea entry, area of sea entry, and co-occurrence in coastal marine zones provide a vital source of evidence for testing or at least qualifying hypotheses about the time, place and potential identity of mechanisms controlling survival and subsequent adult return variations. To site a relevant example, the match-mismatch predation hypothesis invokes the degree of overlap between seaward migrating salmon and either their customary predators (*e.g.* fish-eating birds, piscivorous fish) or novel ones (*e.g.* Humboldt squid) as a potential explanation for marine survival variations of salmon. The relatively recent occurrence of large numbers of Humboldt squid migrating from more southerly waters into areas along the BC continental shelf has been suggested as a possible cause for the increased frequency of exceptionally low SARs of juvenile sockeye salmon originating from the Fraser River. However, this hypothesis is virtually impossible to reconcile with the spatial and temporal patterns of SARs provided here! The mean SAR for Columbia River sockeye entering the ocean closest to the southern water "source" of Humboldt squid has increased in recent years while for Smith Inlet sockeye, exhibiting a sea entry point the furthest away from the leading edge of seasonal migrations by this predator, reductions in mean SAR have been greater than for other stocks. Thus, although Humboldt squid may turn out to be an important salmon predator, it is very unlikely that they are the causal agent of the sockeye stock declines at issue here. Taken together, the time series SARs presented here constitute a valuable observational framework of marine survival variations (*i.e.* dependent variables) against which information on any independent variables (*e.g.* sea lice, pathogens, predators, competitors), proposed as potential causal mechanisms (*e.g.* Beamish *et al.* 2010), may be reconciled or rejected as having explanatory power.

<u>Preliminary Conclusions:</u>

(1) Total return and return-per-spawner time series confound freshwater and marine events and so are of equivocal value in resolving the identity of mechanisms controlling production events or trends exhibited by sockeye salmon.

(2) Time series that partition freshwater and "marine" survival rates are available for only a few BC sockeye stocks but have demonstrable value in establishing the location (freshwater versus marine ecosystem), time (single to multiyear interval) and potential identity of independent variables affecting survival(s) of a given sockeye stock.

(3) Determinations of marine survival (*i.e.* a smolt-to-adult return rate or SAR) are conceptually simple but practically challenging due to requirements for the maintenance of highly standardized sampling procedures and rigorous quality control over more than a dozen component samples associated with each SAR estimate.

(4) Given the usually incomplete state of documentation of methods, raw data and metadata used in their estimation, most SAR time series should be treated as preliminary in nature, warranting caution during analysis or interpretation especially by those lacking a high degree of familiarity with associated metadata and the specific assessment methods used on each subject stock.

(5) In spite of many statistical uncertainties, differences and trends exhibited by SARs presented here, have been carefully assembled and provide sufficient contrast to warrant their use in drawing inferences about SAR variations as biologically meaningful events.

(6) The SAR time series for Fraser and non-Fraser sockeye stocks examined here show evidence of marine survivals that oscillate between relatively high and then relatively low values in association with respectively cool La Nina-like and warm, El Nino-like, conditions, during the late winter and spring of juvenile salmon sea-entry.

(7) Four out of five indicator stocks exhibit declines in the all-year average marine survival during the interval following the 1990 to 1991 sea-entry years by comparison with pre-1990 sea-entry years, although the temporal trajectories for the general decrease in marine survival after 1991 differs among stocks.

(8) In terms of notable single year events, the 2005 sea-entry year was associated with exceptionally low marine survival of all five sockeye indicator stocks while the 2007 sea-entry year was associated with a record low marine survival restricted to Chilko sockeye alone.

(9) Taken together, the time series SARs presented here constitute a vital observational framework of marine survival patterns against which information on independent variables (*e.g.* sea lice, pathogens, predators, competitors), proposed as potential causal mechanisms, may be reconciled or rejected as having explanatory power.

<u>Recommendations:</u>

(1) The dependent variable data sets assembled here to document specific marine survival events and trends affecting stocks of Fraser and non-Fraser sockeye salmon should be part of the foundation for any systematic consideration of causal agents or mechanisms controlling sockeye salmon production variations. Consequently, these observations should be provided to the Cohen Commission in support of its mandate while respecting the proprietary interests of the authors of the current report in protecting their right to first publication of these observations in peer reviewed literature.

(2) Various branches of DFO are frequently challenged to identify and explain the causes of salmon production variations that originate from complex mechanisms operating in both freshwater and marine ecosystems. Time series observations partitioned into freshwater and marine components are highly valuable in determining the location, time and potential identity of such mechanisms but efforts to maintain or supplement these series

have declined in DFOs Pacific region during the recent decade. Expenditures on new research on a wide range of biophysical factors (parasites, disease, predators, competitors, climate indices) serving as independent or explanatory variables should not be initiated in the absence of sound maintenance of the dependent variable, SAR series. Consequently, DFO should renew its efforts to create and maintain an effective network of sockeye indicator stocks representing major eco-zones throughout the B.C. coast for the reasons noted above and to help implement the type of ecosystem based management envisaged in its Wild Salmon Policy (DFO 2005).

(3) The source methods, data and metadata supporting existing SAR series are incompletely documented and have inevitably been subjected to variable levels of quality control over decades of time. Therefore, DFO should increase support for the completion of data and metadata assembly, review, analysis and documentation required to ensure valuable time series of partitioned survival observations for salmon indicator stocks are peer reviewed and authoritative.

(4) Methodological and data issues noted in 3 above are dealt with for Chinook and coho salmon by Pacific Salmon Treaty technical committees that promote a standardized approach to salmon assessments supporting shared fisheries in Canadian and U.S. waters. The terminal nature of sockeye salmon fisheries has resulted in the creation of more localized technical committees which lack a mandate to develop and implement broadly applicable assessment standards for sockeye salmon indicator stocks. DFO should consider creation of a sockeye technical committee (STC) to promote greater standardization of indicator stock assessments in Canadian and U.S. waters to improve the availability and quality of survival series data sets and explanatory information for agencies in both countries.

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Completed By: K. Hyatt **Date:** July 26, 2010.

Distribution Requested by: Arlene Tompkins

Title: Head, Salmon Assessment Section, SAFE Division.

Distribution Approved By:...
Title:... **Date:**.....................................

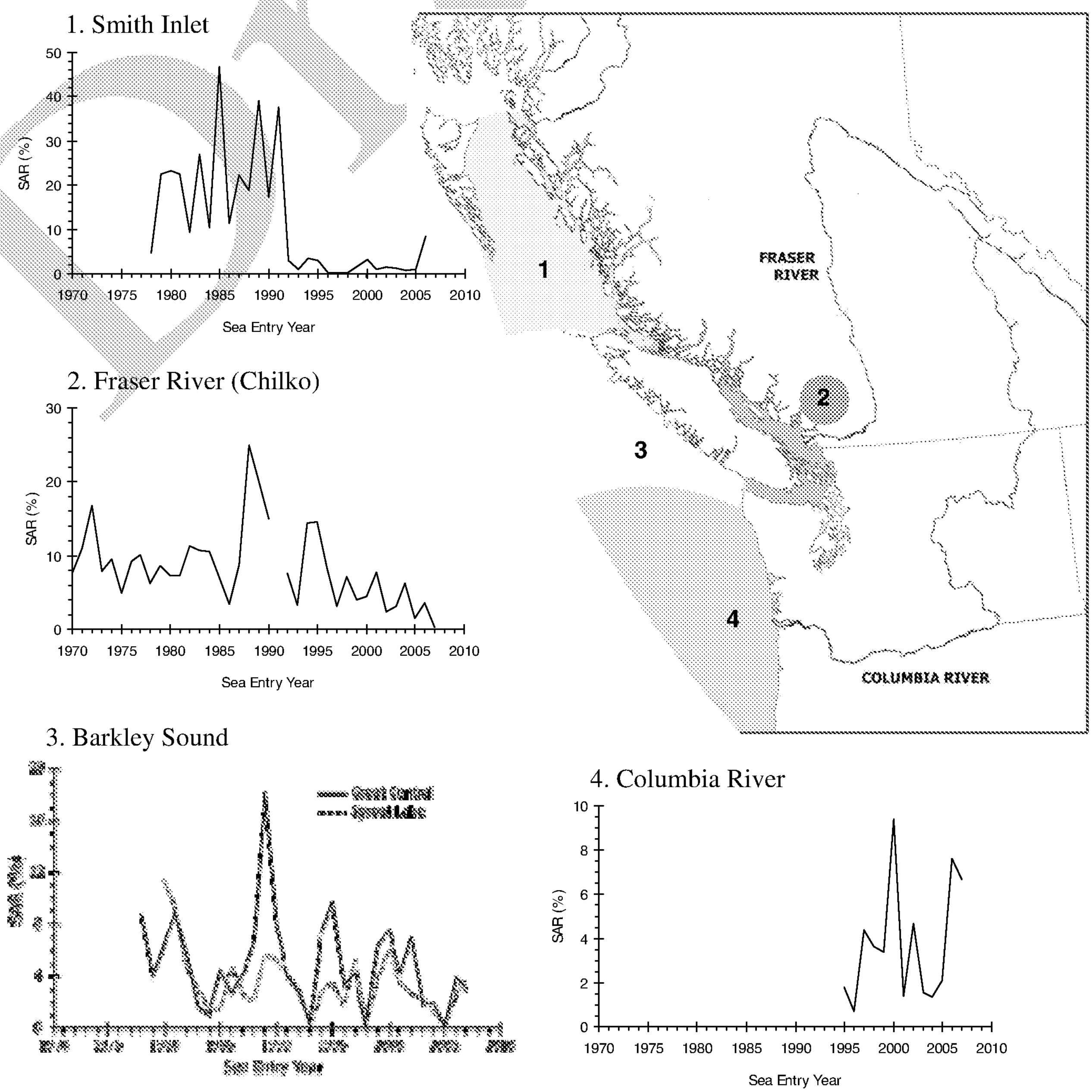

Figure 1. Marine survival variations (SARs) exhibited by sea-entry year, for five indicator stocks of sockeye salmon, originating from freshwater ecosystems tributary to: 1. Smith Inlet on the B.C. Central Coast (Long Lake), 2. The Fraser River and Georgia Basin (Chilko Lake), 3. Barkley Sound on West Coast Vancouver Island (Great Central and Sproat lakes) and 4. Upper Columbia River (Okanagan River-Osoyoos Lake).

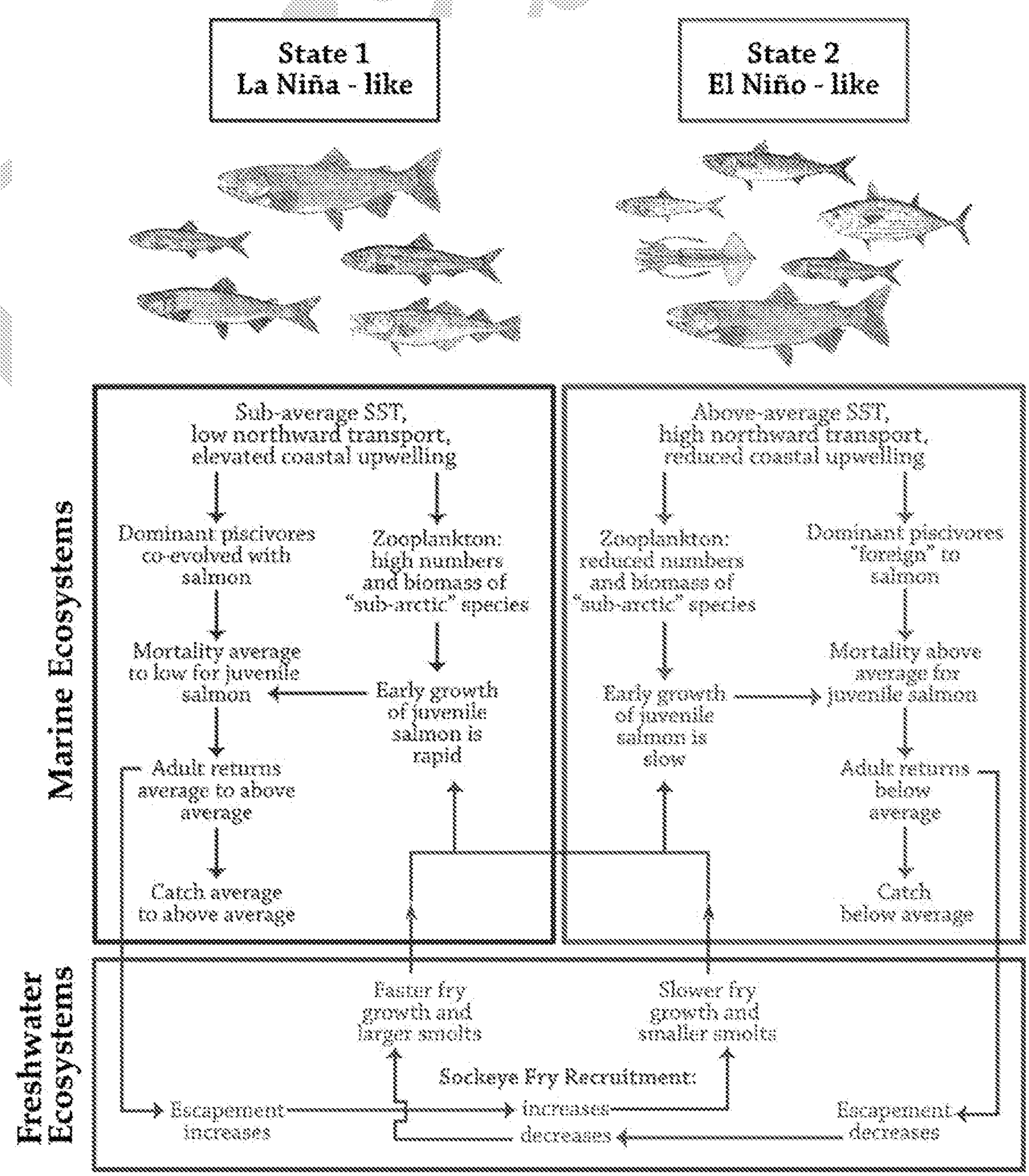

Figure 2. General conceptual model summarizing biophysical mechanism interactions proposed (Hyatt and Steer 1988) as the basis for ENSO induction of harmonic oscillations of marine survival (HOMS) exhibited by sockeye indicator stocks.

Appendix 1. Sockeye life history events and field assessment sequence required to produce observations Contributing to a smolt-to-adult return (SAR) estimate for a single brood-year.

Time	Activity	Assessment Sequence Leading to a Year-specific SAR Estimate
Fall-2005	adults spawn	(B-1) assess adult numbers (*i.e.* escapement) on spawning grounds,
Spring-2007	smolts migrate seaward	(B-2) assess smolt numbers at or just prior to sea entry,
		(B-3) sample smolts for age composition,
		(C-1) use observations from 2 & 3 to determine production of
		age 1.0 smolts originating from fall-2005 escapement,
Spring-2008	smolts migrate seaward	(B-4) assess smolt numbers at or just prior to sea entry,
		(B-5) sample smolts for age composition,
		(C-2) use observations from 2 & 3 to determine production of
		age 2.0 smolts originating from fall-2005 escapement,
Summer-fall	1.1 adults derived from fall 2005	(B-6) assess numbers of sockeye caught in 2008 fishery,
2008	spawners return and are captured	(B-7) if a mixed stock fishery, take scale or tissue samples from
	in coastal fisheries or escape to	adults and assess for markers to identify catch stock composition.
	spawn in their systems of origin	(B-8) sample catch to determine its age composition,
		(B-9) assess escapement of adults to terminal spawning area,
		(B-10) sample escapement to determine its age composition,
		(C-3) use observations from 4-8 above to determine total numbers
		of 1.1 adults in catch and escapement originating from fall-2005
		brood-year of the population of interest,

Summer-fall	1.2 & 2.1 adults derived from 2005	(B-11) assess numbers of sockeye caught in 2009 fishery,
,2009	spawners return and are captured	(B-12) if a mixed stock fishery, take scale or tissue samples from
	in coastal fisheries or escape to	adults and assess for markers to identify catch stock composition.
	spawn in their systems of origin.	(B-13) sample catch to determine its age composition,
		(B-14) assess escapement of adults to terminal spawning area,
		(B-15) sample escapement to determine its age composition,
		(C-4) use observations from 4-8 above to determine total numbers
		of 1.2 & 2.1 adults in catch & escapement originating from fall-2005
		Brood-year of the population of interest,
Summer-fall	1.3 & 2.2 adults derived from 2005	(B-16) assess numbers of sockeye caught in 2010 fishery,
,2010	spawners return and are captured	(B-17) if a mixed stock fishery, take scale or tissue samples from
	in coastal fisheries or escape to	adults and assess for markers to identify catch stock composition.
	spawn in their systems of origin.	(B-18) sample catch to determine its age composition,
		(B-19) assess escapement of adults to terminal spawning area,
		(B-20) sample escapement to determine its age composition,
		(C-5) use observations from 4-8 above to determine total numbers
		of 1.3 & 2.2 adults in catch & escapement originating from fall-2005
		Brood-year of the population of interest,
Summer-fall	1.4 & 2.3 adults derived from 2005	(B-21) assess numbers of sockeye caught in 2011 fishery,
,2011	spawners return and are captured	(B-22) if a mixed stock fishery, take scale or tissue samples from
	in coastal fisheries or escape to	adults and assess for markers to identify catch stock composition.
	spawn in their systems of origin.	(B-23) sample catch to determine its age composition,
		(B-24) assess escapement of adults to terminal spawning area,
		(B-25) sample escapement to determine its age composition,
		(C-6) use observations from 4-8 above to determine total numbers

	of 1.4 & 2.3 adults in catch & escapement originating from fall-2005
	Brood-year of the population of interest,
	(C-7) SAR (as%) = (SumAR @steps C3-C6/ SumS @steps C1-C2)(100)