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Location & Timing Of Poor Marine Survival Causing The 2009 Fraser Sockeye Failure: Elevated Smolt Mortality After Migration Through Discovery Passage & Queen Charlotte Strait.

Submission To The Cohen Commission

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Summary

This document has been prepared for the Cohen Commission's use. It has two major components: (1) an analysis of where the 2009 Fraser River run failure likely occurred and (2) a commentary on the most likely reasons why fisheries management has failed to successfully deal with the on-going major declines in British Columbia salmon populations due to worsening marine survival over the past two decades.

(1) Analysis localizes the region of high juvenile mortality as occurring after the 2007 out-migrant sockeye smolts passed the Discovery Passage/Broughton Archipelago and before they reached Hecate Strait. This indicates that the migrating smolts likely did not die in the region containing the fish farms (Discovery Passage to Queen Charlotte Strait). However, additional data indicate that the 2007 Fraser River sockeye migration had likely failed by the time the smolts reached Hecate Strait. Calculations suggest a rough upper bound on the time for the run failure to develop would be 20-30 days after exiting Queen Charlotte Strait at the north end of Vancouver Island. This time line is consistent with either a direct effect of environmental conditions occurring in Queen Charlotte Sound in spring 2007 or a

delayed effect due to disease transfer from fish farms in the Discovery Passage/Broughton Archipelago region.

(2) Although in my view it is not yet possible to confidently attribute the salmon decline to one single cause, the concurrent and increasing influences of climate change, global warming, harvest pressures, and aquaculture are almost certain to have profound impacts on British Columbia's salmon populations and the province at-large. Unless government acts much more pro-actively to ascertain the reason for salmon failures, British Columbians will be ill-served by the result: more fisheries closures, an increasingly fractious debate amongst the citizenry, and further isolation and marginalization of the Department of Fisheries and Oceans as a respected custodian of the Province's salmon resources. Unless addressed, both private sector (fisheries, aquaculture) and public sector costs will increase substantially as public policy decisions are made that are both ineffective and possibly harmful—and we may completely lose the salmon resources that are supposedly an integral part of the fabric of this province. Lest this final statement sound too extreme, then we need only look at the devastation wrought in just 20 years by the declining marine survival of salmon and the loss of most of the commercial salmon fishery in British Columbia, and along with it close to 20,000 jobs. As we are no farther ahead now than 20 years ago in understanding what the problem is and thus how to deal with it, it seems entirely plausible that in another 20 years marine survival will be only 1/10th the current level—0.1%. Should this prediction seem outlandish, one need only look at Sakinaw Lake sockeye, which now has an average marine survival rate of only 0.2% (see below)—1/5th the level precipitating the 2009 Fraser River calamity and the reason for the Cohen Commission.

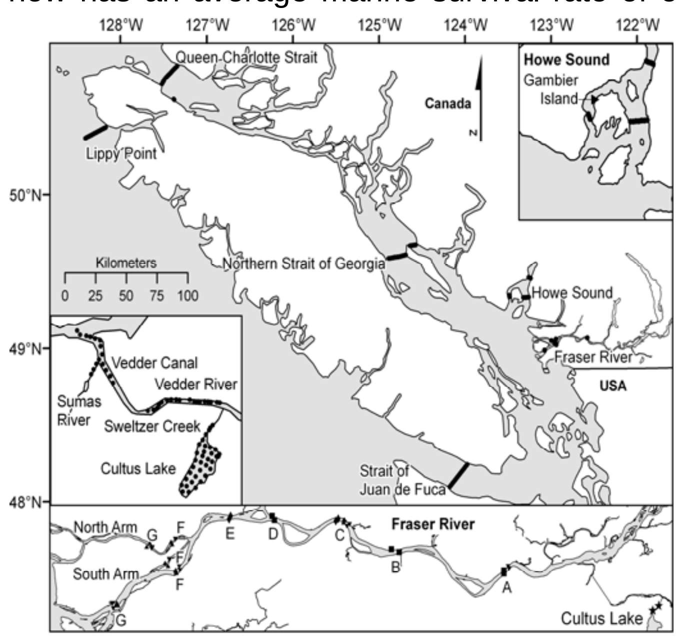

Fig. 1. Layout of the prototype acoustic array (Pacific Ocean Shelf Tracking array, POST), with location of the southern British Columbia sub-arrays used to estimate survival.

I. Probable Location of the 2009 Fraser River Sockeye Run Failure

1. Survival to adult return ("marine survival") of Cultus Lake sockeye dropped sharply to around 1% beginning in the 1990s and has now continued at this level for almost two decades, prompting a listing of this

stock as endangered by COSEWIC[1]. The cause of the poor marine survival cited as part of the problem leading to the endangered listing has to date not been established, nor has the relative influence of marine survival and the other factors listed by COSEWIC as possible contributors. However, a recent survey[2] has identified decreased marine survival as the common factor driving population decline for many south-central BC salmon stocks, suggesting that its role is both pervasive and dominant.

2. Other stocks of Fraser River sockeye have also shown a long-term decline over the past two decades, although (at least until recently) the marine survival decline was not as severe as for Cultus Lake sockeye. However, the 2007 smolt outmigration (resulting in the failed 2009 adult return) brought the marine survival of these other populations down to the level that Cultus Lake sockeye has now been at for many years. As the marine phase of the sockeye life history lasts for 2.5 years, it has been difficult to understand when in the life history the reduced marine survival has developed in recent decades—or why.

3. Survival of Cultus Lake sockeye smolts during their 2004-2007 outmigration was measured using a large-scale prototype acoustic telemetry array. In addition to estimating survival, this system allows direct measurement of speed and direction of the tagged smolts to be made.

i) We surgically implanted large (15-19 cm) hatchery-reared Cultus Lake sockeye smolts with acoustic transmitters, and released them at the outlet of Cultus Lake into Sweltzer Creek, which leads to the Fraser River (see Fig. 1). To accommodate the large acoustic tags used in the study, these hatchery-reared smolts were about twice the size of the wild smolts (ca. 10 cm).

ii) The lay-out of the southern British Columbia elements of the acoustic array relevant to this submission is shown in Fig. 1.

iii) As in the three prior years, 2004-2006, the majority of smolts exited from the Strait of Georgia by choosing the northern route out of Discovery Passage/Queen Charlotte Strait, with

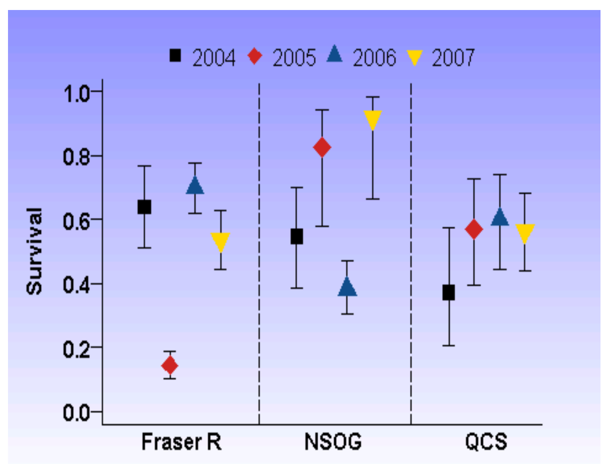

Fig. 2. Measured survival of Cultus Lake sockeye smolts, 2004-07. (Reproduced from Fig. 4 of Welch et al. (2009)). Segment-specific survival estimates for acoustically tagged Cultus Lake sockeye from release to the lower Fraser River, lower Fraser River to northern Strait of Georgia (NSOG), and NSOG to Queen Charlotte Strait (QCS), 2004–2007. Vertical bars represent 95% confidence intervals.

[1] COSEWIC 2003. COSEWIC assessment and status report on the sockeye salmon *Oncorhynchus nerka* (Cultus population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. ix + 57 pp. Available from http://www.sararegistry.gc.ca/virtual_sara/files/cosewic/sr%5Fcultus%5Fsockeye%5Fsalmon%5Fe%2Epdf

[2] English KK, Glova GJ, & Blakley AC (2008) An Upstream Battle: Declines in 10 Pacific Salmon Stocks and Solutions for Their Survival. (David Suzuki Foundation, Vancouver), p 49 pp.

only 6 of 200 smolts detected exiting via Juan de Fuca Strait. Also as in three prior years, survival during the 2007 smolt outmigration was high after release, and stable to both the Fraser River mouth[3], the northern end of Texada Island (northern Strait of Georgia; NSOG) and to the northern exit from the Strait of Georgia at Queen Charlotte Strait (QCS).

iv) There was no indication that 2007 smolt survival in any of the three measured segments of the migration was unusual or that the 2009 adult return would be worse than in earlier years (yellow triangles; Fig. 2). Overall, estimated survival to exit via either the Juan de Fuca or Queen Charlotte Straits was approximately 27.1% (SE=3.9%), from release at Cultus Lake. (This value is calculated as the product of survival in the three migration segments).

v) The 2007 smolts were implanted with specially programmed acoustic tags. The programming provided for two periods of survival measurement: (1) an initial six week period of active transmission (from 13-14 May to 27-28 June 2007), covering the early period of smolt outmigration and (2) a second period of active transmission beginning two years later, on 26-27 July 2009 and continuing until battery exhaustion (probably in November-December 2009). Between these two periods, the tags' transmitters were turned off so that only small amounts of power were used to operate the on-board clock, thus conserving battery power for the adult return migration.

vi) Our peer-reviewed paper[4], published in May 2009, reported the smolt survival data for 2007 and prior years and associated analyses summarized above. However, subsequent to the publication of that paper two tagged smolts (of 200 tagged smolts released; a 1% survival rate) returned in August 2009 as adults (unpublished data; see the animations provided on our website[5]). Both returning adults were previously detected as smolts migrating north out of the Strait of Georgia/Discovery Passage/Broughton Archipelago (Queen Charlotte Strait) region during their out-bound smolt migration in 2007 (red dots on the 2007 animation).

vii) Despite their exit as smolts via Queen Charlotte Strait, the two adults both returned via the west coast of Vancouver Island, passing over the Juan de Fuca Strait sub-array on 23 August, 2009. Both sockeye then entered and quickly moved up the Fraser River and were detected as far as Mission, the location of Kintama's last permanent acoustic receiver sub-array in the Fraser River (Fig. 1, Location A). The timing of river entry indicates that they did not delay in the Strait of Georgia for

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[3] In 2005, an extremely late release of the tagged Cultus Lake smolts occurred because a power failure just prior to the original planned release. It was necessary to repeat all surgeries approximately one month later when logistics permitted. High freshwater mortality to the Fraser River mouth was observed for the late smolt release, but subsequent marine survival was similar to other years.

[4] Welch, D.W., M.C. Melnychuk, E.L. Rechisky, A.D. Porter, M.J. Jacobs, A. Ladouceur, R.S. McKinley, G.D. Jackson (2009). "*Freshwater and marine migration and survival of endangered Cultus Lake sockeye salmon smolts using POST, a large-scale acoustic telemetry array*". Can. J. Fish. Aquat. Sci. 66(5):736-750. http://dx.doi.org/10.1139/F09-032

[5] www.kintama.com/Cohen_downloads.htm The two animations show the movement patterns of Cultus Lake sockeye smolts for the 4 years 2004-07 and 2007 only. (The latter also shows the adult return in 2009; the two 2007 out-migrant smolts that return as adults in 2009 are shown in red).

six weeks as was once the typical behaviour of late run Fraser River sockeye stocks, and instead exhibited the "early entry" behaviour[6] that has caused great problems for Fraser River fisheries management in recent years.

viii) Of particular relevance to the Cohen Commission's mandate, the 1% survival rate for our tagged hatchery-reared smolts is consistent with the 2009 smolt to adult survival of wild Cultus Lake sockeye smolts (1.5%) and the survival of untagged hatchery-reared smolts (0.54%)[7]. The similar return rate of adults suggests that surgical implantation of tags had relatively little impact on overall survival and that both hatchery smolts and the larger individuals we selected for study may provide a reasonable understanding of where mortality occurred for the overall run. Several published surgical trials show mortality and tag loss are small in the first month of life post-implantation for smolts held in hatchery tanks for observation[8,9,10], but not zero; any post-surgical mortality that does occur would result in underestimating survival during the first month of life[11].

ix) As shown in our 2009 research paper, survival from release to exit from Queen Charlotte Strait was approximately 27.1%. Survival to adult return was 1%. Therefore the ratio of survivals inside the Strait of Georgia/Queen Charlotte Strait ecosystem to that occurring outside was:

$$\frac{Survival_{\text{Outside Strait of Georgia}}}{Survival_{\text{Inside Strait of Georgia}}} = \frac{1/27.1}{27.1/100} = \frac{1}{7.3}$$

x) Thus survival after passing the Queen Charlotte Strait sub-array was only ca. 1/7th the survival to Queen Charlotte Strait, which the tagged smolts reached approximately four weeks after release at the outlet of Cultus Lake. This result

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6 Cooke, S. J., et al. (2004). "Abnormal migration timing and high en route mortality of sockeye salmon in the Fraser River, British Columbia." Fisheries 29(2): 22-33.

7 Data courtesy Dr Mike Bradford, DFO

8 Welch, D.W., Batten, S.D., and Ward, B.R. (2007) "Growth, survival, and tag retention of steelhead trout (O. mykiss) surgically implanted with dummy acoustic tags". Hydrobiologia 582:289–299 doi: 10.1007/s10750-006-0553-x

9 Chittenden, C.M., K.G. Butterworth, K.F. Cubitt, M.C. Jacobs, A. Ladouceur, D.W. Welch & R.S. McKinley (2009) Maximum tag to body size ratios for an endangered coho salmon (*O. kisutch*) stock based on physiology and performance. Environmental Biology of Fishes: 84(1):129-140. http://dx.doi.org/10.1007/s10641-008-9396-9

10 Rechisky, E.L., and Welch, D.W., 2010. "Surgical implantation of acoustic tags: Influence of tag loss and tag-induced mortality on free-ranging and hatchery-held spring Chinook (*O. tschawytscha*) smolts", in Wolf, K.S., and O'Neal, J.S., eds., PNAMP Special Publication: Tagging, Telemetry and Marking Measures for Monitoring Fish Populations—A compendium of new and recent science for use in informing technique and decision modalities: Pacific Northwest Aquatic Monitoring Partnership Special Publication 2010-002, chap. 4, p. 69-94. http://www.pnamp.org/node/2890

11 Surgical implantation is likely to increase short-term mortality somewhat relative to untagged smolts, so tagging may result in higher early marine mortality rates because of the implantation procedure. Possibly compensating for this to an unknown degree is the use of smolts larger than occur in the wild, which may have higher survival than their wild counterparts. The degree to which the survival of the 15-19 cm smolts that we tagged exceeds that of 10 cm smolts in the untagged population is currently unknown.

contradicts usual theory, which posits that most mortality occurs early in the life history of a fish.

xi) Our findings allow a partitioning of overall mortality into the first month of life in the ocean and that occurring afterwards, and are of particular importance because they demonstrate that the majority of the mortality causing the observed 1% survival to adult return occurred after passing through the Discovery Passage/Broughton Archipelago region. This raises the issue of whether the poor marine survival was caused by disease transfer from the fish farms in this region or if other factors (e.g., poor ocean conditions) were responsible, or if there was perhaps a combination of impacts.

4. Lacking a direct experimental test of the effect of fish farms, the plausibility of these possible determinants depends upon the geographic location where the high mortality was expressed. Two DFO sampling programs provide potentially relevant information.

   a. There are some DFO data from an annual juvenile salmon trawl survey operating in the northern Strait of Georgia that suggest that the run failure occurred before the Fraser River smolts reached the northern Strait of Georgia in 2007[12]. This dataset is of great potential interest as it would place the mortality problem earlier in the migration period and thus clearly exclude the possibility of an interaction with the fish farming industry as a significant cause of the sockeye return failure. However, in addition to being inconsistent with the survival pattern of the acoustically tagged smolts in 2007, the proposed timing of mortality is questionable for at least two reasons:

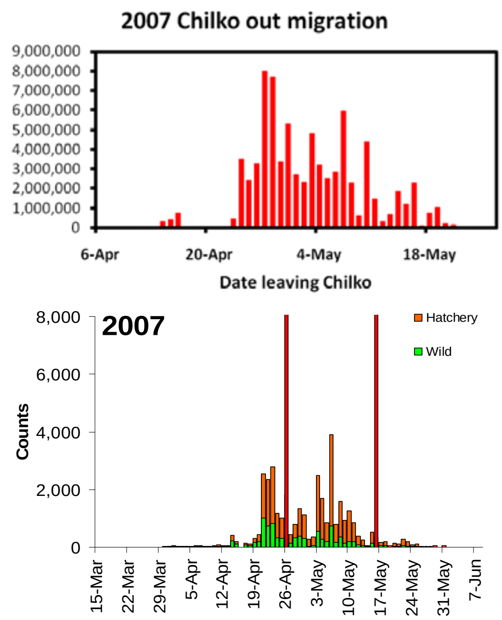

Fig. 3. Timing of sockeye smolt out-migration from Chilko Lake (top) and Cultus Lake (bottom); the latter shows the timing of both hatchery (orange) and wild (green) Cultus Lake sockeye smolts.

      i. The DFO Strait of Georgia survey takes place in July. Wild Cultus Lake smolts[13] initiated migration between 19 April-10 May, 2007, while the majority of sockeye smolts emigrated from Chilko Lake[14] between 24 April and 16 May, 2007 (Fig. 3). The speed of migration of both

[12] Brian Riddell, cited in Pacific Fishing, October 2009 article (page 9). Riddell was commenting on the fact that the location where the Fraser River sockeye run failed was unknown.
[13] Cultus Lake migration times provided by Al Stobbart, DFO.
[14] Chilko Lake migration times provided by Mr. Mike LaPointe, Pacific Salmon Commission.

wild[15] and hatchery-reared[16] sockeye smolts is approximately 1 body length per second, so a 10 cm smolt would migrate approximately 9 km/day. Excluding growth after leaving the lake, 10 cm long wild smolts migrating north through the entire length of the Strait of Georgia would reach Discovery Passage within 20 days after exiting the Fraser River. Even adding time for migration down the Fraser River (where currents assist the migration, increasing migration speeds) the July survey is incompatible with the period when most smolts would have passed through the survey area. Supporting this conclusion, Cultus Lake sockeye smolts were caught in Hecate Strait on 28 June 2008 & 24 June 2009 (none were reported for 2007), roughly 500 km north of the Strait of Georgia survey area, requiring a migration speed of 14-19 km/day[15]. DNA analysis of the sockeye catch[17] also demonstrates that by June, juvenile Fraser sockeye smolts in general are found well to the north of Vancouver Island. DFO's July Strait of Georgia survey must therefore only sample smolts forming the extreme tail end of the migration (and are thus unrepresentative of the majority), or consist of animals that have remained resident in the Strait of Georgia.

ii. Inconsistent data. Disregarding the timing issue, the conclusion that the smolts died before reaching the Northern Strait of Georgia area in 2007 critically depends upon excluding two key data points from the DFO survey:

1. The 1997 Strait of Georgia survey[18] leading to the 1999 adult return[19] found the highest juvenile sockeye numbers in the time series, yet was associated with only a mediocre adult return of <4M fish. (The 1997 survey apparently happened somewhat earlier than the norm, which would be consistent with the bulk of the smolts migrating before the standard survey took place).
2. In contrast, the 2000 July survey had a very low juvenile sockeye catch but the associated adult return in 2002 was the highest observed in the record (>15M sockeye).

[15] Trudel, M., Tucker, S., and Candy, J. 2010. Ocean Distribution Of Two Depressed Sockeye Salmon Stocks, pages 97-98 in Crawford, W.R., and J.R. Irvine (editors). 2010. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2009. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/053. viii + 137 p. http://www.dfo-mpo.gc.ca/CSAS/Csas/Publications/ResDocs-DocRech/2010/2010_053_e.pdf
[16] Welch, et al. (2009). Can. J. Fish. Aquat. Sci. 66(5):736-750.
[17] Tucker, S., M. Trudel, D.W. Welch, J.R. Candy, J.F.T. Morris, M.E. Thiess, C. Wallace, D.J. Teel, W. Crawford and T.D. Beacham (2009). "Using DNA-Based Stock Identification To Elucidate Coastal Migration Of Juvenile Sockeye Salmon (*Oncorhynchus nerka*)." Trans. Amer. Fish. Soc. 138: 1458-1480.
[18] DFO July CPUE data are from: www.pacoos.org/Presentations/May2108/Richards052208_s.pdf
[19] I am indebted to Mr Mike Lapointe, Pacific Salmon Commission, for updated Fraser River sockeye return numbers.

Excluding the juvenile sockeye surveys leading to the inconsistent 1999 (low) and 2002 (high) adult returns results in a statistical regression which accounts for about 82% of the variability in the adult returns two years later: an impressive result (Fig. 4). However, including these two years reduces the result to explaining only 2% of the variability—an amount so small as to imply that the Strait of Georgia survey results are statistically meaningless for the purpose of determining where the excess mortality occurred that led to the 2009 run failure.

This result is not surprising given that the survey likely occurred after the vast majority of the sockeye smolts had left the Strait of Georgia; only by discarding two of three data points driving the statistical relationship is there a plausible relationship to be found, probably because the bulk of the smolts have moved past the survey area and small variations in survey timing or smolt migration rates thus strongly affects the result.

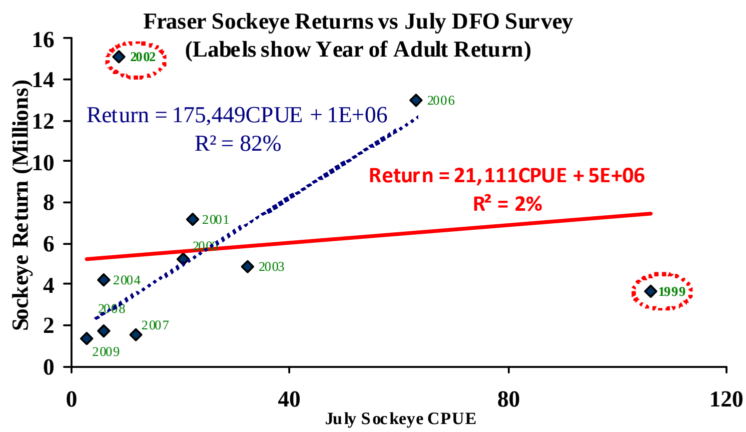

Fig. 4. Comparison of adult Fraser River sockeye returns and DFO's July survey data for the Strait of Georgia. Data points are labelled with the adult return year; juvenile catches are for two years prior. The regressions show the relationship with and without the two circled data points; R^2 is a measure of the variability explained by the relationship with 100% meaning all variability is explained and 0% none. The graphic shows that very high or very low adult returns are observed over essentially the entire range of July catches.

b. An upper bound on the timing of the unusual sockeye mortality event is provided by a second DFO survey[20] which found that the proportion of Fraser River origin sockeye smolts in the 2007 smolt catch in Hecate Strait was much lower than expected relative to other year's results. This finding suggests that much of the Fraser sockeye mortality had occurred by the time that the smolts reached Hecate Strait.

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[20] This survey is directed by Dr Marc Trudel, Pacific Biological Station. I am indebted to him for several discussions via email and telephone.

c. Our acoustic telemetry results thus indicate that the migrating smolts did not die in the region containing the fish farms (Discovery Passage to Queen Charlotte Strait) because the Queen Charlotte Strait acoustic sub-array lies just to the north of the Broughton Archipelago; however, the DFO data[21] from Hecate Strait indicate that the 2007 Fraser River sockeye migration had likely failed by the time the smolts reached the Hecate Strait region (the body of water lying between Haida Gwaii and the mainland). This constrains the geographic region where the run failure probably developed[22].

d. Hecate Strait lies some 300 km to the north of Queen Charlotte Strait. Trudel et al report[15] that Fraser River sockeye smolts achieved migratory speeds of 14-19 km/day to reach the capture locations in Hecate Strait. Thus a rough upper bound on the time for the run failure to develop would be 16-20 days after passing the Queen Charlotte Strait acoustic sub-array, as elevated mortality was not evident at this sub-array. A more refined upper bound on the time limit for the mortality event to develop would be to add (assuming that fish farm exposure is a significant contributing factor to latent smolt mortality) either 3 days (50 km/17 $km \cdot day^{-1}$; distance from the Broughton Archipelago to the Queen Charlotte Strait sub-array) or 12 days (200 km/17 $km \cdot day^{-1}$; distance from the start of Discovery Passage and the Queen Charlotte Strait sub-array).

5. Two other sources of information would also suggest that marine survival of sockeye within the Strait of Georgia appears to be better than for populations migrating to outside waters:

    i. Harrison Lake sockeye, the only Fraser River population whose marine survival appears to have remained stable in 2009, is thought to have a unique life history which involves rearing within the Fraser estuary/Strait of Georgia ecosystem, and to eventually migrate out to the west coast of Vancouver Island via Juan de Fuca Strait rather than follow the conventional migration path north. As the marine survival of this population has remained high, something about the marine life history of this sockeye population appears to be beneficial; one obvious factor is that these smolts are thought not to migrate north out of the Strait of Georgia via Discovery Passage.

    ii. Sakinaw Lake sockeye, the second (with Cultus Lake) British Columbia sockeye populations listed as Endangered by

[21] Based on unpublished DNA analysis, Fraser River juvenile sockeye formed a much smaller proportion of the research catch in Hecate Strait relative to west coast Vancouver Island sockeye populations in 2007 relative to other years. Observations of Dr Marc Trudel, Pacific Biological Station, DFO (*personal communication)* marc.trudel@dfo-mpo.gc.ca.

[22] Given the importance of establishing where sockeye survival was low, I recommend that the Commission closely examine the relevance of both DFO surveys with respect to determining their usefulness.

COSEWIC[23], has recently been found to have two distinct marine survival levels[24]. Acoustically tagged Sakinaw sockeye smolts & Kokanee that exited the Strait of Georgia while the tags were actively transmitting failed to return as adults (0% survival); sockeye smolts and Kokanee that were not observed to migrate out of the Strait of Georgia in the summer during the period the tags were actively transmitting had a 3.4% & 4.3% adult return rate, respectively[25]. Although this is not direct evidence that salmon farms and disease transfer play a role in the mortality of this population, the data strongly point to better survival for smolts remaining resident in the Strait of Georgia. This in turn suggests that the mortality problem is associated with either (i) climate-related changes in food availability or predator abundance in southern BC outside waters (west coast of Vancouver Island &/or Queen Charlotte Sound), (ii) disease transfer during smolt out-migration causing a latent mortality, or (iii) both.

6. Supporting the possibility that climate-related changes in Queen Charlotte Sound may reduce Fraser River smolt survival, Irvine et al.[26] note that satellite-derived estimates of chlorophyll concentration in Queen Charlotte Sound for spring 2007 were the lowest observed in the 12 year satellite record. There is thus some evidence that changes in marine conditions in the region that the 2007 outmigrating smolts travelled through before reaching Hecate Strait could also have caused the poor marine survival evident in the failed 2009 adult return (perhaps as a result of starvation)—although the high adult sockeye returns to the west coast of Vancouver Island and spectacular returns of sockeye to the Columbia River raise questions as to why conditions in Queen Charlotte Sound did not also affect these populations[27].

7. The relevance of the hypothesized link between fish farming and major mortality (such as occurred for the 2009 adult Fraser River runs) depends upon the degree that the mortality event can be isolated as occurring close to

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[23] COSEWIC 2003. COSEWIC Assessment And Status Report On The Sockeye Salmon *Oncorhynchus nerka* Sakinaw Population In Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. ix + 35 pp. Available from http://www.sararegistry.gc.ca/virtual_sara/files/cosewic/sr%5Fsockeye%5Fsalmon%5Fe%2Epdf

[24] Wood, C.C., D.W. Welch, L. Godbout, and J. Cameron (*In Press*). Acoustic Tagging To Compare Marine Migratory Behaviour Of Anadromous And Non-Anadromous Sockeye Salmon. American Fisheries Society. Advances in Fish Tagging and Marking Technology.

[25] Sakinaw sockeye were tagged with acoustic tags similarly programmed to those used in Cultus Lake sockeye; as previously outlined, these tags allowed tracking the migration path and survival of outbound smolts and inbound adults.

[26] Irvine, J. R., et al. (2010). Do Marine Conditions In Queen Charlotte Sound Limit The Marine Survival Of Chilko Sockeye Salmon? State Of Physical, Biological, And Selected Fishery Resources Of Pacific Canadian Marine Ecosystems In 2009. W. R. Crawford, and J.R. Irvine (eds.), DFO Can. Sci. Advis. Sec. Res. Doc. 2010/053. : viii + 137 p.

[27] http://www.cbbulletin.com/Archive/07102009/354867.aspx
http://www.cbbulletin.com/Archive/07172009/354884.aspx

the time the Fraser River sockeye smolts pass through the region containing salmon aquaculture operations; if the mortality was due to disease transfer from fish farms then a reasonable time line for the development of major mortality is that it occurred within 19-32 days after passing the aquaculture sites.

8. We emphasize that neither our own telemetry data nor the synthesis we have outlined in this submission ***prove*** a causative link between aquaculture and wild salmon survival because direct evidence is lacking. Claims (i) that the 2009 Fraser River run failure was caused by disease transmission from salmon farms to the Fraser sockeye smolts as they migrated through the area and (ii) that oceanographic changes in Queen Charlotte Sound affected smolt survival are ***both*** consistent with the available data as we understand them. However, we believe that our acoustic telemetry data set in the context of other observational data provide an important scientific advance in our understanding, as it places the timing and likely location of the high mortality in the region just *after* passing the fish farms[28]. Because Queen Charlotte Sound is also traversed by simultaneously migrating sockeye stocks from the south (Columbia River (Redfish Lake & Okanogan Lake) plus west coast of Vancouver Island stocks) that did not experience the same elevated mortality rates and had excellent survival in 2009, this may tip the balance more in favour of the disease transfer hypothesis - all of the sockeye populations experiencing high adult returns in 2009 are believed to migrate north via the west coast of Vancouver Island in 2007, and there is currently no evidence that they use Discovery Passage as a migratory pathway. Tempering this last point, however, is the basic fact that in the absence of directed telemetry studies on these populations there is no hard evidence to back up the widespread belief that Columbia River sockeye stocks migrate north around Vancouver Island and stay on the outer shelf rather than migrating through the Strait of Georgia.

   a. There are important economic and social claims on both sides of the contentious argument about the role of salmon farming and strongly held views about what is responsible for the problems of British Columbia salmon management. This rancorous debate is unlikely to be resolved without directed scientific experiments rather than anecdotal observation that both sides have needed to rely on. Our contribution has been to narrow down the likely location for the mortality, but not demonstrate the cause. However, to scientifically prove or reject theories concerning the role of fish farms requires a commitment to experimentally test causation, in this case that exposure to fish farms increases mortality relative to animals not so

[28] Given the speed with which the wild smolts are migrating (ca. one body length per second, or 14-19 km/day), it should also serve as a sobering reminder of the complexity of conducting field studies, because migrating smolts move very quickly. Field studies attempting to establish an association between fish farms and sea lice levels are faced with the difficulty that smolts collected in the vicinity of farms may have been tens of kilometers distant just a few days earlier and will be far distant from the farms within a few days of passage, making a direct association of lice levels and fish farms problematic.

exposed, **and to a level of impact sufficiently large to justify regulatory intervention. From this perspective, the potential impact of aquaculture is similar to many other situations where one economic activity (such as pollution) results in some degree of harm to another.** Rigorous experimental designs of this nature require controls and are possible to do, but DFO has failed to take the scientific lead and has instead relied on much more limited observational evidence. (The same comment applies to some—but not all—of the work done by the critics of fish farms).

b. It is pre-ordained that one side or the other in an economic dispute worth hundreds of millions of dollars a year is very likely to dispute the results unless direct experimental tests are done to a far higher standard than has been practiced to date. Showing an association between geography (presence of fish farms) and wild salmon mortality is insufficient for developing rational public policy—the level of harm must be quantified and shown to be substantial.

c. We believe that it is imperative to do so, because if the wrong policy decision is made (either to allow or prohibit open net fish farms) high economic costs will ensue and many years will pass while the successful group clings to the belief that the salmon problems will turn around if government simply maintains their preferred policy decision for long enough.

II. Why has west coast salmon management failed to deal with two decades of worsening marine survival?

a. The 2009 Fraser sockeye “collapse” should have been easily predicted by extending the nearly 20 year progressive decline in marine survival rates one year out—as the graph of declining salmon survival since 1989/90 makes clear, the 2009 crisis has more in common with a train wreck in slow motion than a “surprise”. Projecting “*next year’s marine survival*” is a trivial exercise and could have been done with fair accuracy using nothing more sophisticated than a pencil and a ruler. By implication, the fact that this was not done much earlier in the development of the poor marine survivals is an example of institutional inertia and the blind hope that next year the trend will suddenly turn around and “fix the problem” without need for institutional change.

b. The fact that marine survival has progressively worsened over such a long period of time with little systematic attempt to explicitly determine the underlying issues is indicative of a broader difficulty. Fisheries biologists have been trained (and work within a culture that encourages) the belief that current management is the best possible approach.

c. The grave issue that everyone interested in salmon conservation should recognize is this: if little or no action was taken to directly address the implications of worsening marine survival in the past two decades (apart from hoping that it will go away), what improved response can we anticipate from our salmon managers over the next two decades? The concern is that institutional inertia will prevent the true causes of stock decline to be identified and addressed, while at the same time marine survival further deteriorates. It is sobering to remember that roughly a 4% marine survival rate is needed simply to ensure that populations do not go extinct over the long term, and that the period of time in which there is the opportunity to establish what the problem is, and what actions should be taken to reverse the trend, is likely very short.

d. Assuming that "*marine survival can't possibly get any worse than it already is*" (noting that Sakinaw Lake marine survival rates now average[24] only 0.2%) would lead to continued complacency—doing a disservice to British Columbians because things ***could*** get much worse.

e. The current decline in British Columbia salmon abundance is particularly troubling because Pacific salmon abundance for the Pacific Rim as a whole is at all-time record high levels[29]. Our failure to manage salmon populations when salmon stocks in other countries are increasing makes the performance gap even more problematic: If our management systems are working, why has such a profound loss of once vibrant salmon populations and the associated commercial fishing industry occurred? Conversely, if our systems are not working, why have profound changes in management practice not occurred, which would at least save the public purse the expense of a management system that is apparently as expensive as it was 20 years ago, yet seems incapable of turning around the problems caused by the decline in marine survival?

f. There is great emphasis in fisheries science world-wide that when problems arise the preferred approach is to put more effort (i.e., investment of the public purse) in stock assessment. (Stock assessment is the professional art and practice of estimating fish population numbers). This is troubling because few of the fisheries failures worldwide were initially caused because of errors in stock assessment; rather, in most cases the population numbers became small because the productivity of the population changed and inherent limitations in stock assessment methods and data plus institutional inertia then meant that it took too long to recognize that what was formerly an acceptable level of harvest was no longer sustainable. On Canada's East Coast the collapse of the Northern cod and many other groundfish stocks is an example of that point; harvest rates that were roughly sustainable for decades became unsustainable after the biological productivity of the population sharply declined; stock assessment was slow to recognize the problem because the practice depends upon looking backwards in time to estimate previous population numbers and so generally cannot provide reliable assessments of current population size. When combined with rapid climate change affecting fish stocks, a rather

[29] Irvine JR, et al. (2009) Pacific Salmon Status and Abundance Trends. (NPAFC, Vancouver, B.C.), p 153 pp. Available at: http://www.npafc.org/new/publications/Documents/PDF%202009/1199(Rev1)(WGSA).pdf

ineffective and complacent stock assessment process will almost inevitably lead to real problems when environmental change suddenly takes a turn for the worse.

g. This general observation is applicable to the DFO on the west coast as well; accelerating trends to smaller population numbers have been met by calls for increased investment in stock assessment, generally by calling for more individual populations to be monitored and in some cases by redoubling efforts at monitoring important populations[30]. However, with an estimated 6,000 populations on the west coast of Canada, the first test that should be asked is whether additional funds spent on improved abundance estimation would change the success of government management or might simply result in an already overwhelmed staff working harder on the issues that are not at the root of the problems? Put another way, if the problem is with poor marine survival for many of the stocks, why is most of the public purse and effort spent on more precisely defining how few fish are left, rather than finding out what lies at the root of the problem and then applying that new insight to address the problem?

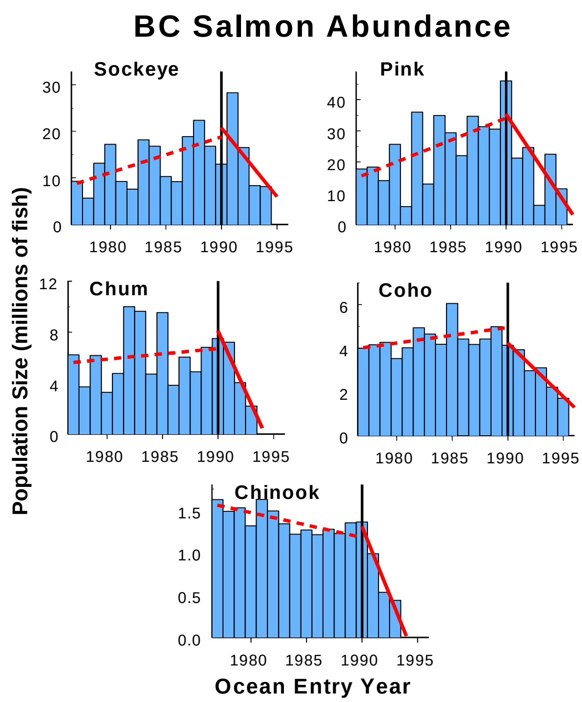

Fig. 5. Changes in total salmon returns (total catch plus total escapement) as observed to the late 1990s (Welch, unpublished). Population size was calculated as the sum of the annual commercial catch plus escapement for all of British Columbia. Provincial totals have been plotted separately by species for the period since ocean entry year 1980 to emphasize trends before and after the ocean climate shift occurring in 1989/90; fitted lines show the rates of change in population size for the two periods. When the trend lines are separately estimated for the commercial catch data and the escapement they the slopes are nearly identical and the change occurs in the same year. As the two data sources are independent, the parallel slopes indicate that an essentially constant fraction of each species was harvested over time.

[30] TCC (2000) Recommendations for a Recovery Plan for the Rivers Inlet and Smith Inlet Sockeye Salmon. Prepared by: Technical Coordinating Committee, Rivers Inlet and Smith Inlet Recovery Plan Working Group. Version 7 (Initially published to the DFO website in June 2000, then withdrawn; a similar version has now been published at http://www.rsseps.ca/recoveryplanTOC.html).

h. Fig. 5 shows the decline in abundance that I put together while an employee of DFO in the 1990s. A substantial change in marine climate occurred in the 1989/90 period, which became evident both from the sharp downturn in the few marine survival time series that were available and in the sharp decreases in commercial catch. To construct this assessment, at that time my staff and I assembled all of the escapement data for British Columbia from an internal DFO data set based on visual counts of abundance from streamside counts that has been collected since about the 1950s by Fisheries Officers. The total return of salmon to BC is composed of two parts: catch and escapement. If catch decreases over time, then escapement must increase if the number of salmon returning has in fact been stable. As a result, we had expected to see that escapement was increasing (or at least stable) while catch was decreasing, indicating that DFO was managing the fisheries to conserve the escapement. Instead we were shocked to find that for each of the five species the decline in escapement to the spawning grounds since 1990 almost exactly mirrored the decline in commercial catch. Both time series had an inflection point in 1989/90 (when lagged back to the year the smolts entered the ocean) and each pair of time series showed identical rates of decline with time both prior to and then after 1990. Important implications from this result were that (a) a major problem was developing that unless reversed would have large impacts on BC salmon and (b) that the management process was in fact almost lacking in influence on the resource, with the catch and escapement just co-varying in essentially fixed proportion—arguments that catch was going down because escapements were being built up were not supported by the data.

i. A subsequent major change in ocean climate in 1998/99 had, I believed, improved BC salmon survival rates. I was stunned to discover in the spring of 2010 with the publication of the Simon Fraser University document[31] that the decline in Fraser River marine survival had continued for another decade (albeit at a slightly less extreme rate of progressive decline). Given the magnitude of this decline, it would be advisable to re-visit the work I had done in the 1990s on the trends in salmon commercial catch and escapement, because they may point to a much more severe and widespread problem than just Fraser River sockeye.

j. I believe that the recent problems for Fraser River sockeye are part of a series of problems that began in the early 1990s but whose potential connections have never been recognized or followed up. First, in 1992 a million returning Early Stuart sockeye were "lost" in the river—a problem that was variously ascribed to an accounting error (poor measurement) or poaching. The same issue developed again in 1994, this time when half a million Early Stuart sockeye went missing again between the hydroacoustic

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[31] Reynolds, J. D. and L. Wood (2009) "*Adapting to Change: Managing Fraser River Sockeye in the Face of Declining Productivity and Increasing Uncertainty. Statement from Think Tank of Scientists*". http://www.sfu.ca/cs/science/resources/adaptingtochange/FraserSockeyeThinkTankStatement.pdf

counting site at Mission (in the lower river) and the upper Fraser River spawning grounds. The ensuing public uproar resulted in the establishment of the Fraser River 1994 Public Review Board chaired by John Fraser[32] and also by major internal re-organization by DFO to improve the strength and credibility of its stock assessment[33]. Subsequent to this, the "late-run sockeye" problem began in either 1995 or 1996, culminating by the year 2000 in 80~90% or greater of the returning adults dying in-river and substantial fractions of the remainder dying on the spawning grounds without spawning[6].

k. All of these problems were interpreted as the result of adult salmon dying in freshwater after entering the river—an understandable bias given the historic freshwater focus for salmon. Most recently, in 2009, all runs appear to have failed, but the evidence is that they failed out at sea, prior to reaching the Strait of Georgia—something that some of our (as yet partially unpublished) work on acoustically tagged Late Run adult sockeye also appears to have measured in 2006.

l. The possibility that the litany of Fraser River sockeye problems for individual stock groupings dating back to at least 1992 are related, and caused by significant mortality in both ocean, and then freshwater for the adults, seems to have never been considered (Early Stuart: 1992 & 1994; Late-Run stocks: 1995 (or 1996) forwards; All Runs: 2009). Instead, in my view, each crisis has been dealt with individually and without questioning whether the serial problems were part of some overall, and more systemic, problem.

m. It would be very useful for the Cohen Commission to consider the 2009 run failure in this broader context, and assess whether the repeated problems beleaguering Fraser River sockeye that now stretch back nearly two decades may be related. Although the paucity of data will likely preclude a clear answer, I believe that the current piecemeal approach to salmon management in British Columbia has slowed the recognition of the broader problems that have already driven salmon populations to record low levels of abundance. Furthermore, it is my view that without this broader perspective, we are doomed to fall into the trap of ever more expensive piecemeal approaches to addressing repeated salmon crises.

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[32] Fraser, J. A. (1995). Fraser River Sockeye 1994: Problems and Discrepancies. Fraser River Sockeye Public Review Board (Canada), Public Works and Government Services Canada: 131 pp.
[33] At the time, the possibility that a million adult sockeye could go missing in the river was dismissed by many observers, and was generally viewed as an excuse by DFO that removed the possibility of poaching as the problem, a highly charged subject as the catch allocations were being re-distributed at the time.

n. The magnitude of the changes that global warming are projected to bring in the near future are unprecedented. As a result, our salmon crises are probably going to get far worse—salmon are a cold water fish in a dramatically warming world. Our demonstrated institutional inability to address the problems that developed over the past two decades leaves me pessimistic about our ability to do better in the future—in my opinion we are unlikely to either rationalize or modernize our fisheries management and associated science without a better sense of whether the current approach of “stasis” served Canadians well. My sense is that current management approaches have not helped, and precious time needed to get the answers required for sensible policy making has already been lost. Given that the Pacific northwest has been in an anomalous period of regional cooling since 1998[34] while much of the rest of the world has been warming rapidly, much more severe salmon crises are likely on the horizon. These may dwarf the present scale of problems; when the Pacific region swings from being below the global warming trend to above it, nothing in our institutional past suggests that we will be likely to get out ahead of the problem and sort out what factors will be driving the collapses of salmon in the face of several conflicting issues—global warming, aquaculture, freshwater habitat disruption, and harvest. Without that clear-headed understanding, much more disruptive argument lies ahead. Failure to clarify the relative role of these contributing factors will be a disservice to both salmon conservation and to the citizens of this country.

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[34] The Pacific northwest is currently experiencing coastal ocean temperatures closely similar to the 1950-70 climatological mean (See Hoegh-Guldberg, O. and J. F. Bruno (2010). "*The Impact of Climate Change on the World's Marine Ecosystems*." Science 328(5985): 1523-1528; Fig. 1), after experiencing substantially warmer sea temperatures in the 1990s. The regional-scale cooling evident since 1998 is inconsistent with the increasing mean temperatures seen worldwide. This suggests that when regional cooling swings to regional warming and adds to the global warming trend already evident in the instrumental record, it will suddenly bring us into an era of sea temperatures not experienced in more than 7,000 years. Given our demonstrated inability to deal with the current (below trend) regional climate, there is little reason to believe that our ability to effectively respond to further sharp decreases in marine survival of salmon—driven at least partly by climate—will be any better. This will set the stage for much worse political conflict over the salmon resource, because a clear understanding of what is causing the problems will be lacking. Lack of knowledge will sow the seeds of an even more acrimonious political debate over the causes of the salmon problem—and ***who*** is to blame.