

From: Saunders, Mark
Sent: Thursday, November 12, 2009 4:23 PM
To: Richards, Laura <Laura.Richards@dfo-mpo.gc.ca>
Cc: Tompkins, Arlene <Arlene.Tompkins@dfo-mpo.gc.ca>
Subject: FW: Updated SX paper
Attach: Summary Science Workshop Fraser SX_Nov12.doc

Hi Laura,

Here is Fraser Sockeye workshop report. I will use it to develop a briefing note as we discussed. I received the initial note from Gloria this afternoon.

Mark

From: Tompkins, Arlene
Sent: November 12, 2009 10:03 AM
To: Saunders, Mark
Subject: Updated SX paper

I haven't been able to confirm # Fraser SX Cus but my count should be close.
I've made all your suggested changes, check wording on hypothesis 3, now includes downstream mortality.
I will leave it with you to forward to others
Thanks Arlene

<<...>>

*Arlene Tompkins, PhD.
Head, Salmon Assessment Section
Pacific Biological Station
Nanaimo, BC V9T 6N7
phone (250) 729-8382
email: arlene.tompkins@dfo-mpo.gc.ca*

Please note new email address and update your address book

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Update on Science Review 2009 Fraser Sockeye

Background

- The 2009 pre-season forecast of Fraser River sockeye returns at the 50% probability level was set at 10.6 million (M) fish, of which Summer Run stocks (48% Chilkco & 41% Quesnel) were predicted to comprise 82%. The preliminary estimate of return for early, spring & summer Fraser sockeye is 0.9 M, less than ten percent of pre-season forecasted abundance.
- Fraser sockeye forecasts are associated with relatively high uncertainty (Cass et al. 2006, Haeseker et al. 2007 & 2008). Environmental variables (e.g. sea-surface temperature, Fraser discharge, etc.) explored to date have not explained a significant component of salmon survival or recruitment variability (Myers 1998; Mueter et al. 2005; Cass et al. 2006) and individual indicators alone have not been able to explain the extremely poor ocean survival of sockeye that went to sea in 2005 and returned (well below forecast) in 2007. A recent study that explored systemic temporal shifts in productivity between salmon species and stocks, found no consistent productivity trends for Fraser sockeye stocks (Dorner et al. 2008). These results suggest that the survival responses of Fraser sockeye to environmental and other factors are complex and not well understood (Dorner et al. 2008).
- Most Fraser sockeye returning in 2009 are age 4₂ recruited from 2005 brood year. In 2005, the number of effective female spawners for most of the Fraser sockeye stocks for which forecasts are made was average or above average.
- Juvenile production is monitored in 3 of 34 Fraser sockeye CUs. Observed juvenile production from the 2005 brood year spawners varied between stocks, Quesnel fry abundance (5₂ M) was slightly below average while Cultus and Chilkco smolt numbers were 2 to 3 times higher than average (0.1 and 77M respectively).
- In September 2009 DFO Science staff held a workshop to review available knowledge on factors affecting sockeye survival and to compile probable hypotheses to explain their poor performance.

Observations for stocks with same year of sea entry (2007)

Note that 2009 stock status information reported here is preliminary and when finalized will be critically examined and documented.

Salmon populations with poor returns consistent with Fraser sockeye are:

- The preliminary data indicate that sockeye returns to SE Alaska in 2009 were substantially lower (about 64%) than the pre-season forecast, compared to Bristol Bay returns which were higher (about 20%) than forecast.
- Skeena sockeye returns were half of expectation, but jacks in 2008 were also low.

- Returns of 4 year old Puget Sound and coastal Washington sockeye stocks are below expectations. The preliminary estimate of sockeye returns to Lake Washington is 68% of the pre season forecast and the lowest on record. (*migration north via WCVI inconsistent with Fraser sockeye except for Harrison sockeye*).
- Fraser early-timed and spring / summer Chinook (4₂ & 5₂, 2007 and 2006 sea entry respectively) also performed poorly.
- Strait of Georgia (SoG) coho returns in 2008 did poorly (survival <1%).
- Coast wide to Alaska, pink salmon returns in 2008 were poor (*but migration timing of juvenile pink into the ocean is earlier than most sockeye*). Fraser River pink salmon show a cyclic dominant return on odd years.
- Marine survival for Chilko sockeye has been declining since brood year 2000 (return year 2004). Similar declines have been observed for other sockeye stocks and other species. Lake Washington sockeye returns have been declining since 2006 (2006 - 435K, 2007 - 69K, 2008 - 34K, and 2009 - 13K). Marine survival of Strait of Georgia coho has been declining since the early 1990's and average survival is currently <1% for hatchery coho and just over 1% for wild coho. Fraser early-timed and spring / summer Chinook returns have been declining since 2003.

Salmon populations with good returns inconsistent with Fraser sockeye are:

- Harrison, Barkley Sound, Smith Inlet-Long Lake, and Okanagan (Columbia River drainage) sockeye returned as forecast or greater. In particular, Harrison sockeye had exceptionally good returns in 2009.
- Bristol Bay sockeye had a very large return (40 M, 20% above pre-season forecast);
- South Thompson Chinook returns have been increasing.
- Large returns observed for Fraser pink and many other pink stocks in BC and Alaska in 2009 are not analogous as pink juveniles went to sea in 2008.

Observations on Migration & Distribution

- Most Fraser sockeye fry spend two winters in freshwater before entering the SoG as smolts in spring. Juveniles migrate north through the Strait of Georgia, Discovery Passage, and Johnstone Strait as far as Alaska, and spend two winters in the marine environment before returning predominantly at age-4 to spawn.
- The Harrison River sockeye population is the exception. They migrate downstream shortly after emergence from the gravel and ocean entry occurs in late June based on otolith studies. Adults return as three and four year old fish; a higher percentage return as age 3 fish in years when juvenile pink are in low abundance. Harrison smolts rear in the Strait of Georgia till late fall. In recent years relatively large abundances of ocean age 0 fish have been observed in the southern SoG. Harrison juveniles have been caught off WCVI during their first winter suggesting juveniles migrate out of the SOG late in their first ocean year. Harrison sockeye have not been observed in Alaskan waters.
- Historically, jacks were abundant in Fraser sockeye populations and served as reliable indicators of age-4 returns. Since the mid 1990's jacks have virtually disappeared in all populations except Chilko and Gates. It is uncertain what caused the change in maturation rate of Fraser sockeye.

Hypotheses on causes of mortality

1. High mortality in early juvenile freshwater phase (period: fry 2006 - smolt 2007)

Rationale: Mortality of sockeye salmon during their freshwater life is high and historically approximately 50% of variation in recruitment has been attributed to freshwater environments (Bradford 1995). Consistent with declines observed for Fraser sockeye, Fraser early & summer stream-type chinook, that spend one winter in freshwater, have been declining since 2003. Information regarding the potential influence of freshwater factors will provide some insight towards the potential cause of the poor returns of the offspring of the 2005 brood year in 2009.

- a) Spawning success and egg quality
 - In 2005, the adult return migration timing was one of the latest on record. The potential for intergenerational consequences of such a late return are unknown.
 - Egg retention, the proxy used to estimate the total egg deposition and success of spawning, is determined for most stocks and expressed as a proportion of females that effectively spawned (EFS). Egg retention estimates in 2005 were normal, suggesting adults were in good condition during spawning.
 - There is very limited information on egg quality for the 2005 brood. The only proxy for egg to fry survival are estimates from two Early Stuart streams (Forfar and Gluskie), and spawning channels (Weaver, Gates, Nadina). For the vast majority of Fraser sockeye populations there are no estimates of egg to fry survival, nor any subsequent estimates until they return as adults.
- b) Fry migrations into nursery lakes
 - There is little to no estimation of survival of fry and early juvenile littoral zone migrants.
- c) Spawning escapement to fall fry and smolts (freshwater survival, lake component)
 - Juvenile sockeye can be enumerated relatively easily during their lake residence using hydroacoustics and trawl surveys or as outmigrating smolts using fences. The two major stocks that comprised the 2005/09 cycle year were those from Quesnel and Chilko lakes. Fall hydroacoustic surveys of juvenile sockeye have been conducted in most years on Quesnel Lake since 1975 and a smolt fence has enumerated Chilko Lake smolts since 1949.
 - For Quesnel Lake, freshwater survival from effective female spawner (EFS) to fall fry (FF) is density-dependent and at 67 FF/EFS in 2005 was at expected levels. Size of fall fry is also density-dependent but the size of the 2005 BY fall fry, at 2.7g., was somewhat smaller than expected at this EFS abundance. There is no estimate of over-winter survival to smolts for Quesnel Lake.
 - For Chilko Lake, Abundance of age-1 smolts from the 2005 and the 2006 brood years were the highest ever recorded at 77 and 72 million fish migrating through the fence. *[With current methodology, there is no level of precision associated with these estimates.]* The corresponding survivals from EFS to age-1 smolts were also the highest ever recorded at 270 smolts/EFS (ln5.6) for

both years (Fig 5). Chilko and Cultus lakes have the only integrated estimates of survival and growth (but not condition) covering the entire freshwater life history phase (excluding the outmigration corridor).

- d) Lake rearing environments and productive capacity
- Limnological and lake productive capacity studies have been conducted on a one-time basis (ranging from single-season to consecutive-year studies) for most of the major sockeye rearing lakes in the Fraser River system and on a more systematic basis on a few lakes (Quesnel, Chilko, Cultus)
 - Recent revisiting of Fraser River nursery ecosystems (e.g. Chilko, Cultus, Chilliwack lakes) or frequently monitoring them (e.g. Quesnel Lake) is yielding useful insight into freshwater mechanisms (e.g. structural trophic changes) responsible for variations in freshwater survival, smolt size/condition and lake productive capacities
 - While freshwater survival index values (FF/EFS) exist for a number of systems, the only truly integrated survival estimates with information on fry size (but not condition) for the lake life history phase exist for Chilko and Cultus lakes.
- e) Downstream smolt migration
- Despite the sensitivity of juvenile sockeye and hazardous outmigration conditions, there is no information on the downstream survival of Fraser River sockeye smolts after they leave their natal lakes and migrate ~ 100 to 1100 km to the SoG. The only published information suggests that mortality estimates are extremely high (>50%), but this work may not be representative of the majority of Fraser sockeye.
- f) Smolt Quality
- There is limited information on energy density of 2007 smolts from Chilko, Stellako, and E. Stuart. E. Stuart had higher energy values than either Stellako or Chilko, but there is no historical information to put these values into context. The body size, energy status, disease condition, and physiological state of smolts sampled as they leave their natal lake and/or leave the Fraser River would provide some indication of the overall ability to survive the downstream migration and re-establish feeding after the stressful transition from freshwater to saltwater respectively.
- g) Fraser River Environmental conditions
- The environmental conditions during the downstream migration of smolts in 2007 can be characterized as having a very early freshet with localized flooding. However, based upon the limited smolt migration timing information available, the discharge conditions were average during the main out-migration. Other information on water quality, such as temperature, suspended sediments, or contaminants have not been analysed.
 - Exposure to pollutants in freshwater/downstream migration. Possible sources of impact include catastrophic spills, point source emissions, pesticides, release of POPs from glaciers, and cumulative impacts.

- h) Apparent Fraser sockeye survival discrepancies
- The discordance between the recent strength of Harrison sockeye and other Fraser stocks is likely a function of the life history differences. These differences have been documented in both marine and freshwater environments.

Likelihood: Based on observations from the Chilko and Quesnel juvenile sockeye monitoring programs, survival to the time juveniles left the lake was as expected or better. However there is limited information on smolt quality and no information on the downstream survival of Fraser River sockeye smolts after they leave their natal lakes and migrate to the SoG. Environmental conditions could be the plausible cause of long term decline but there is no known anomalous event in 2007 to explain poor performance in that year.

Next Steps: Knowledge gaps related to monitoring of smolt condition and mortality during downstream migration have been identified. Peter Ross IOS is reviewing potential contaminant issues in the Fraser basin. However we have limited capacity in watershed-specific habitat monitoring as DFO no longer monitors freshwater quality.

2. Disease

Rationale: Research by the DFO Genomics lab identified a powerful gene expression signature consistent with the presence of a viral infection in >75% of sockeye salmon returning to the Fraser River in 2005 (the brood year for the 2009 returns). In 2006 returns, individuals carrying this putative anti-viral signature (present before they entered the river) suffered 30-60% higher mortality during their river migration than “healthy” individuals. The anti-viral signature has been observed in gill, liver and brain tissue. Within the last several months, brain dissections of sockeye showing the anti-viral signature revealed the presence of highly vascularized lesions in the optic lobe. In 2009, the prevalence of these lesions was 70% in the ocean, 50% upon river entry, and <30% at spawning, indicative of mortality en route to spawning grounds. Similar reductions in lesion incidence (55% to <20%) were observed in 2008.

Out-migrating smolts of southern BC stocks of sockeye, coho and Chinook salmon collected in the summers of 2008 and 2009 expressed the same anti-viral signature and a high incidence of brain lesions, with levels declining significantly in the first few months in the ocean (from 40-50% June to 10% Sept) in all three species. Importantly, these genomic signatures and brain anomalies were present before salmon left their natal rearing areas within the Fraser River, suggesting that the purported disease agent responsible for the anti-viral signature observed in both smolts and adults was transmitted in the freshwater rearing environment. Molecular assays have not yielded positives for any known viral pathogens. However, viral arrays pointed to the presence of a virus in the retrovirus family.

Likelihood: Disease is a factor that could impact sockeye at any or all life history stages. Fraser sockeye salmon are known to carry a variety of viral, bacterial and parasitic agents

that can cause disease. Based on the work of the DFO Genomics lab, it appears that there may be a disease agent that remains unidentified. It is anticipated that with climate change, significant change to the physical and biological environment will negatively impact sockeye host-pathogen relationships, as well as increase levels of stress experienced by the fish. It is likely that under these conditions naturally occurring pathogens may cause disease with effects at both the individual and population levels.

The very significant reduction in prevalence of brain lesions both in the first few months in the ocean and en route to spawning grounds may be indicative of lesion-associated mortality. If so, the levels of mortality required to bring prevalence levels down by over 30% would be sufficient in magnitude to account for large-scale losses in the ocean. However, the possibility that lesions could regress must also be considered.

Next Steps: Since the meeting, the brain lesions have been examined histologically, and it appears that they are hemorrhagic lesions. Hemorrhagic lesions can result from head trauma, leukemia, viral brain infections, and diseases that disrupt blood coagulation. The powerful gene signatures associated with brains containing these lesions is not consistent with head trauma induced from handling/collections. Spores of *Myxobolus* sp. (believed to be *M. arcticus*), were also observed in 11/12 brains examined histologically (including those negative for lesions). This parasite is known to occur in sockeye salmon and may have a significant negative impact on swimming performance of sockeye smolts. A gene expression study of a related species *Myxobolus cerebralis* (agent of whirling disease) identified the up-regulation of many interferon-regulated genes that can also be upregulated in viral infections. However, the tissue distributions for *Myxobolus* parasites of salmon (nervous system, cartilage, skin, and muscle) are not consistent with the tissue involvement associated with the anti-viral signature (brain, gill, liver and NOT muscle); hence at this time we do not believe that there is a link between the signature and this parasite. More detailed histological studies of brain and other tissues are currently underway by Dr. Mike Kent of Oregon State University.

The most important next steps are to 1) identify the purported novel viral pathogen and develop a molecular screening assay based on its DNA sequence, 2) conduct challenge studies to establish infectivity, 3) conduct smolt holding studies to assess associations of this and other diseases with mortality, and environmental conditions that may impact virulence, and 4) conduct epidemiological studies to establish pathogen distribution.

3. High mortality in early juvenile phase in Strait of Georgia (including downstream migration in freshwater, period May - July 2007)

Rationale: In the 2008 State of the Oceans report, Sweeting *et. al.* assert a positive relationship between catch per unit effort of juvenile sockeye in SoG in July and returns two years later. Early marine mortality is supported by observations of very low sockeye catches (other than Harrison stock which enters the ocean later) in SOG juvenile surveys in July and September 2007. Because sockeye indicator juvenile production is only

monitored by lake acoustic surveys or by fence counts as they leave the lake, it is important to note that measures of marine mortality include any mortality occurring during the downstream migration. There are two explanations for the poor catches of juvenile sockeye salmon in 2007: 1) juveniles left the Strait earlier than usual, or 2) there was an episodic mortality, possibly associated with disease, or individuals were metabolically stressed and susceptible to common diseases. The 2007 SoG survey also indicated low catches of juvenile chum salmon suggesting a common mechanism impacting juvenile sockeye and chum survival.

Possible mechanisms include:

a) Disease

The anti-viral signature observed in migrating adult sockeye salmon has also been observed in smolts leaving the river, with prevalence levels declining during the first few months in the ocean, potentially indicative of disease-associated losses. See above for details.

b) Hazardous Algae Blooms (HAB)

Fish kills due to HABs have previously been reported at aquaculture sites and there is evidence that wild fish can be killed or injured by these blooms. Wild fish kills may not be reported, as dead fish sink or are dispersed, or impacts occur at depths much deeper than commonly observed at fish farms. Observations of "red -water" were common in SoG in May - June 2007 and high phytoplankton biomass was recorded in the June 2007 SoG oceanographic cruise.

Likelihood: Plausible and under consideration.

c) Predators

There is no direct observation of increased predation and increased predator abundance is inconsistent with good survival of Harrison Lake sockeye that entered SoG one month later.

Likelihood: Single species predation (i.e. seals) is unlikely given that there is no evidence of a single year spike in potential predators.

d) Food web related

Species interactions, competition, and food quality should be considered given the continued poor marine survival and production of Strait of Georgia stocks of Chinook, coho, and sockeye.

Likelihood: Plausible cause of long term decline but no known anomalous event in 2007 to explain poor performance in that year.

Next Steps:

Earlier spring SoG juvenile surveys are required to determine the distribution and nature and timing of mortality on juvenile salmonids.

Data have been requested from fish farm companies to confirm number, location and timing of any toxic plankton events observed on B.C. farms in 2007. The Department is investigating potential phytoplankton data collected by monitoring programs conducted by Vancouver Island University and Rensel & Associates.

The effects of early marine growth on the marine survival and adult return of sockeye in southern BC can be investigated. Archived otoliths obtained from research surveys conducted by DFO since 1998 can be used to reconstruct the early marine growth of juvenile sockeye originating from southern BC and to examine the relationship between their marine survival and early marine growth, as well as to ocean conditions measured by DFO during these surveys.

4. Sea lice loads picked up in Discovery Passage on exit from SOG caused subsequent marine mortality (period: early juvenile May-September 2007)

Rationale: The Coastal Aquaculture Alliance observed juvenile sockeye in Discovery Passage in 2007 & 2008 were infected with sea lice and point to fish farms as the source of the infection.

Likelihood: The current indication is that sea lice management procedures effectively kept levels of lice below those known to cause mortality in other species of salmon. Average sea lice loads observed in Discovery Islands in 2007 were much lower than those observed in 2006. Moreover, while Jones et. al.(2008) found that high concentrations of sea lice could result in low mortality rates of juvenile pink salmon under 0.7 grams, there was no mortality of larger fish. Juvenile sockeye are five to 10 grams when they migrate to the ocean. In addition, declines observed for other species that went to sea in 2007, i.e. pink salmon, were coast wide to Alaska and not limited to stocks migrating thru Discovery Passage. Poor returns of sockeye in the Skeena in 2009, which is far removed from any fish farms, also suggests sea lice from fish farms is not a likely explanation.

It is also possible that sea lice could have been picked up from other marine fishes. Beamish observed juvenile salmon infected with *Caligus clemens* in 2008 in spring surveys conducted in the Gulf Islands.

Next Steps: More extensive data have been requested from all fish farms in southern BC to examine sea lice loads and treatments and reports of other fish diseases.

5. High mortality related to food web along marine migration route (Queen Charlotte Sound)

Rationale: Marine birds are good indicators of the state of marine ecosystems because they are readily observed and breeding success is closely tied to the availability of key prey. Sea bird survival on Triangle Island is correlated with satellite-measured chlorophyll off northern Vancouver Island. 2007 chlorophyll concentrations in spring and seabird survival were the lowest in 10 years and 15 years of observations, respectively.

Satellite images of chlorophyll anomalies in April 2007 off the WCVI, Queen Charlotte Sound and Johnstone Strait were all low. By May, 2007, chlorophyll anomalies off WCVI were high but remained low in Johnstone Strait through the entire spring. Chlorophyll anomalies within the Strait of Georgia were generally positive throughout the spring of 2007. These findings reveal ocean conditions in 2007 that could have been poor for juvenile Fraser River lake type sockeye, while acceptable for Harrison and Barkley Sound sockeye.

Likelihood: Plausible and could account for poor performance of southern US sockeye stocks that did not migrate through SoG.

Next Steps: DFO scientists continue to study the relationship between satellite-measured chlorophyll, SST, and marine survival of salmon. Area, time, and stock-specific information are being investigated.

6. High mortality related to food web along marine migration route (SEAK and Gulf of Alaska)

Rationale: Species interactions and competition should be considered, i.e. the very large 2009 return (40 million) of Bristol Bay sockeye and the current large populations of Asian chum.

Likelihood: Competitive interactions are possible but would require differential impacts on stocks that are thought to be mixed together in this area

Next Steps: Investigation of patterns of adults returns for all salmon species and stocks, for different years and regions from Oregon to Alaska, may provide additional insight.

7. Interception in US (Alaska) Fisheries

Rationale: Fraser Sockeye are intercepted in Alaskan fisheries and in recent years catches have been estimated to be at least equal to harvest in Canada.

Likelihood: Fishery interceptions are unlikely to be the whole story with respect to the poor return of Fraser sockeye. Sockeye salmon samples have been obtained from a July 2009 Japanese research cruise in the Bering Sea and Chukchi Sea and the Pacific Rim sockeye DNA baseline has been used to identify the origin of these fish. Two of 419 immature sockeye salmon recovered from the Bering Sea were of Fraser River origin, and two were from other BC stocks. These data indicate that there could potentially be about 290,000 Canadian sockeye rearing in the Bering Sea in 2009. Hence, while BC sockeye salmon are in the Bering Sea, they are not there in enough abundance to account for the large discrepancy in returns. However, unlike various natural mortality factors, fishery interceptions provide an area where mortality rates can be monitored & potentially modified.

Next Steps: Request further samples from research cruises and commercial fisheries conducted by US, Russia, and Japan in the North Pacific.