DRAFT SUMMARY REPORT
DFO synthesis workshop on the decline of Fraser River sockeye
Vancouver Island Conference Centre, Nanaimo, BC
April 14-15, 2011

Executive Summary

Fisheries and Oceans Canada (DFO) scientists convened a 2-day workshop to update and discuss the relevant hypotheses surrounding the Fraser River sockeye salmon situation. The workshop had two primary objectives:

(1) *Review the state of evidence for factors contributing to the Fraser sockeye situation with a focus on disease, aquaculture and marine survival.*
(2) *Develop approach for technical and narrative reports that synthesize the current state of knowledge on reasons for the long term decline and the notable 2009 and 2010 returns.*

The first day of the workshop focused on short presentations from key science personnel to provide an update on the current state of knowledge surrounding each proposed hypothesis, and to reflect on whether this warranted any change in the rating of plausibility assigned by the PSC report from August 2010 (Table E-1; *Synthesis of evidence from a workshop on the decline of Fraser River sockeye*). The second day of the workshop looked in-depth at two of the leading hypotheses: disease and ocean conditions. Within each section, a number of presentations were given relating to specific hypotheses. At the end of each section, a roundtable discussion addressed common issues, questions and next steps.

A total of 15 presentations were given to update current understanding on the various hypotheses. In some cases, new information that was presented resulted in a change in the PLAUSIBILITY ranking of the hypothesis from those given in the PSC report, Table E-1. The changes that were made are outlined below (Table 1).

Based on the most recent analyses, the following factors are viewed as UNLIKELY to have contributed to the poor 2009 return: pollution/contaminants, capture by Canadian fisheries and predation on juveniles in the Strait of Georgia.

The following factors are viewed as having some impact, but not of a magnitude sufficient to explain the poor 2009 returns. These include: predation by Humboldt squid, capture by US fisheries and mortality caused by sea lice.

The following factors are viewed as being those most likely to have had an impact in 2009. These include: low food abundance in the Strait of Georgia, low food abundance in Queen Charlotte Sound and the Gulf of Alaska, disease, and toxic algal blooms within the Strait of Georgia.

Changing climate or ocean conditions are thought to be the most likely factors associated with the long-term decline in Fraser River sockeye although other factors such as disease, delayed

density dependence, competition with pink salmon and the presence of contaminants may also have contributed.

It is generally agreed that multiple factors impact Fraser River sockeye salmon populations in fresh and salt water. In addition to being variable over time and space, these factors interact with each other making it very difficult to predict or rank their individual effects on sockeye populations.

Methods of integrating findings and assessing risks across multiple sources or inter-related mechanisms need to be developed and validated.

It was noted by Mike Bradford that the majority (95-98%) of the mortality (egg to adult returns) occurs in freshwater. The hypotheses that were discussed at the workshop focused exclusively on the marine environment and therefore only address less than 5% of total mortality of Fraser River sockeye.

Short-term next steps include:

1. Lead authors to provide summary bullets or paragraphs outlining synthesis and/or consensus with previous presentations and reports.
2. Development of one page synthesis including a summary table linking to PSC presentations and/or Cohen research papers.
3. Coordinated review of Cohen research papers.
4. Collation of materials on the Sharepoint site.
5. Develop Briefing Note to the Deputy Minister.
6. Review of future research requirements/PSC workshop (potential).

Over the longer term, development of integrating analytical tools and integrated program development needs to be considered.

Table 1. Updated PSC report Table E-1 as a result of workshop discussions. Note: Shaded boxes reflect ratings assigned in the original PSC Report. "**X**" indicates the re-evaluated ranking from the outcomes of this workshop.

Hypothesis	Time Period	Strength of evidence	Relative likelihood that each hypothesis caused observed changes in productivity during the indicated time period				
			Very Likely	Likely	Possible	Unlikely	Very Unlikely
1a. Predation by marine mammals is an important contributor to the Fraser sockeye situation (Section 4.1).	Overall	Fair			X		
	2009	Fair					X
1b. Unreported catch in the ocean outside of the Pacific Salmon Treaty area is an important contributor to the Fraser sockeye situation (Section 4.1).	Overall	~~Good~~ Fair			X		
	2009	~~Good~~ Fair					X
2. Marine and freshwater pathogens (bacteria, parasites, and/or viruses), are important contributors to the Fraser sockeye situation (Section 4.2).	Overall	Fair		X			
	2009	Fair		X			
3a. Ocean conditions (physical and biological) inside Georgia Strait are important indicators of contributors to the Fraser sockeye situation (Section 4.3).	Overall	Fair		X			
	2009	Good	X				
3b. Ocean conditions (physical and biological) outside Georgia Strait are important indicators of contributors to the Fraser sockeye situation (Section 4.3).	Overall	Fair		X			
	2009	Fair		X			
4. Harmful algal blooms in the Strait of Georgia and/or northern Puget Sound/Strait of Juan de Fuca are an important contributor to the Fraser sockeye situation (Sec 4.4).	Overall	Fair			X		
	2009	Fair			X		
5. Contaminants in the Fraser River and/or Strait of Georgia are an important contributor to the Fraser sockeye situation (Section 4.5).	Overall	Poor			X		
	2009	Poor				X	X

Hypothesis	Time Period	Strength of evidence	Relative likelihood that each hypothesis caused observed changes in productivity during the indicated time period: Very Likely	Likely	Possible	Unlikely	Very Unlikely
6. Freshwater habitat conditions in the Fraser River watershed are important contributors to the Fraser sockeye situation (Section 4.6).	Overall	Fair				X	X
	2009	Fair					X
7. Delayed density dependent mortality is an important contributor to the Fraser sockeye situation (Section 4.7).	Overall	Fair		X			
	2009	Fair					X
8a. En-route mortality during upstream migration is an important contributor to the Fraser sockeye situation (Section 4.8). En-route mortality is already considered in estimates of total recruits, so while potentially strongly affecting *spawner abundance*, this hypothesis cannot explain declines in *recruits per spawner*.	Overall	Good					X
	2009	Good					X
8b. The effects of en-route mortality on fitness of the next generation is an important contributor to the Fraser sockeye situation (Section 4.8).	Overall	Poor					X
	2009	Poor					X
9. Competitive interactions with pink salmon are important contributors to the Fraser sockeye situation (Section 4.9).	Overall	Fair		X	X		
	2009	Fair			X		

Reference:

Peterman R.M., D. Marmorek, B. Beckman, M. Bradford, N. Mantua, B.E. Riddell, M. Scheuerell, M. Staley, K. Wieckowski, J.R. Winton, C.C. Wood. 2010. Synthesis of evidence from a workshop on the decline of Fraser River sockeye. June 15-17, 2010. A Report to the Pacific Salmon Commission, Vancouver, B.C., 123 pp. + 35 pp. of appendices. Available from www.psc.org.

Day 1 - Summary of Presentations

1. Current status of Fraser sockeye – Sue Grant

- Most stocks have exhibited declines in productivity, starting as early as the 1950's. For some stocks; there is considerable variability in timing of these declines (when declines commenced) amongst stocks. Three stocks have not exhibited systematic declines in productivity (Late Shuswap, Raft and Weaver) and one stock has increased in productivity (Harrison). A brief summary on freshwater and marine survival for stocks we have this data for was provided.
- The 2010 post-season results confirm that there were no unusual delays in maturation of age-4 sockeye from the 2005 brood year. This is evidenced by no increase in age-5 proportions in 2010 returns relative to expectation.
- The 2005 brood year productivity (age-4's returning in 2009) for most stocks (including Harrison) were generally the lowest or amongst the lowest on record. It is interesting that Harrison also experienced poor productivity in this 2005 brood year (lowest on record for Harrison), since Harrison juveniles would have entered the ocean in 2006 compared to all other stocks from the 2005 brood year that entered the ocean in 2007. This observation is interesting from a hypothesis development perspective in that Harrison and all other stocks, characterized by large differences in life history and ocean entry years, resulted in the lowest, or amongst the lowest productivity on record.
- The 2006 brood year productivities (age-4's returning in 2010) for most stocks returned to average (relative to their long-term time series). Major exceptions are stocks in the Shuswap system (Late Shuswap and Seymour) that exhibited well above average productivity.
- Overall age at maturity for stocks has increased since the 1980's. Harrison exhibits high inter-annual variability in age proportions (ranging from 10%-90% age-3's relative to age-4's plus age-5's).
- Research requirements: need more data on juvenile time series and freshwater research

2. Harmful Algal Blooms (HAB) – Jim Irvine

- The 2010 paper by Jack Rensel was reviewed– it provides a good review of the issue.
- There remains a need to examine consistency of Rensel's hypothesized direct and indirect effects of HABs on early seawater survival over time.
- Confirmed POSSIBLE role of harmful algal blooms in the recent and long term declines. However, data on HABs is very limited both spatially and temporally with the majority of monitoring being conducted by the salmon farming industry.
- Genomics showing promise for screening of survivors for exposure to HAB and potentially related anoxia.
- Research requirements: there is a need for increased monitoring (away from aquaculture operations); examination of diel patterns of distribution; additional HAB

research (species identification., determine levels of lethal toxicity, develop non-microscopic methods of HAB detection)

3. Contaminants – Peter Ross

- No evidence of a direct role in the recent returns but remains a POSSIBLE contributor to the long term decline— *consistent with the Cohen technical report number 2 (Macdonald) conclusions*—though there is insufficient data to determine this conclusively.
- It was reported that the Cohen Technical Report 2 is good but missing key papers and generally provides an oversimplified treatment of the subject.
- Contaminants will likely not kill immediately but may weaken and increase susceptibility of fish to stress, disease and/or alter aspects of their behaviour or reproductive ability.
- With respect to endocrine-disrupting chemicals, an examination of their role in age at maturity should be considered. Such a study could compare variation in age at maturity between upper and lower river salmon stocks, including stocks which rear in areas that may be affected by glacial melt.
- Information and Research needs:
    - information on (proprietary) pesticide formulants used in BC (Health Canada Pest Management Regulatory Agency);
    - information on area-based pesticide applications to forestry and agricultural areas (BC);
    - water, sediment and tissue residue guidelines could be improved with consideration of the vulnerable life history of anadromous fishes including sockeye salmon (Canadian Council of Ministers of the Environment; BC Ministry of Environment);
    - relevant and high-quality water and sediment data for contaminants of concern in sockeye salmon habitat;
    - life history-based toxicological evaluation for priority contaminants in salmonids;
    - more information (research and monitoring) of the freshwater component of sockeye salmon habitat;
    - ‘real world’ studies of salmon health as it relates to anthropogenic impacts (e.g. contaminants, nutrients, land use).

4. Freshwater habitat conditions – Mike Bradford

- Declines related to position in the watershed
- Little known about survival from natal streams to the ocean
- General agreement between the PSC report and Cohen Report 3 conclusions
- Mission smolt trap could be used to estimate the timing and size of smolt outmigration.

- Chilko tagging – mortality very high in freshwater (egg to smolt stages), relatively low mortality in the lower Strait of Georgia. Concerns with the handling and tagging effects, age 2 vs. age 1. Suggests Queen Charlotte Sound and Fraser River are higher areas of mortality than the Strait of Georgia. New tagging technology which will become available in 2011 may solve some issues.
- Research requirements (short term): Evaluation of 2012 smolt run
  - Potential to estimate:
    - The total size of the run
    - Contributions of major conservation units (CU's)
    - Timing, size and condition differences among CU's
  - Costs:
    - Extend sampling 1-2 weeks
    - DNA, physiological samples

5. **En route Loss – Dave Patterson**

- Productivity is not impacted by en route survival (same as catch) but overall ABUNDANCE is declining as a result.
- No strong evidence to support impact of intergenerational effects, though research is ongoing
- Cohen Technical Report Project 9 – generally agrees with this report.
- Papers coming out on fisheries interactions
- Issues with use of differences between estimates (DBEs) as proxy for en route loss; improvements made in the use of run size adjustments (RSAs)
- Poor river conditions may contribute to lower fitness of next generation which could in turn possibly contribute to declining abundance.

6. Over-escapement/Delayed density-dependence (DDD) – Dan Selbie

- Cohen Technical Report 10 – Peterman and Dorner 2011 – agrees there is no evidence of catastrophic stock collapse
- Many stocks sensitive to simple density dependence (DD)
- Evidence of delayed density dependence (DDD) in specific stocks (i.e., Quesnel and Shuswap, but not Chilko to date)
- DD and DDD likely contribute to reduced productivity in a number of stocks, but are unlikely the cause of the widespread declines observed within and beyond the Fraser River
- Chilko and Quesnel 2010 escapements (S_{max}) 200-500% and will likely be hammered in coming years (negative effects observed at S_{max} greater than 200%, and apparent in current brood year, plus at least 3 following years).
- PSC report uncertain LIKELY-UNLIKELY, move to LIKELY for long term decline?
- Research planned.

7. Predation – Peter Olesiuk/John Ford

- PSC report submission reviewed all whales and pinnipeds.
- Pacific white-sided dolphin – role in decline unknown (further studies needed to define seasonal and geographic variation in diet, though there has been no change in abundance or distribution over the past decade).
- Killer whale – not an important role in decline as they feed mainly on Chinook and chum salmon.
- Harbour seals – feed on all five species of salmon; terminal predator – depensatory effect, acting as a predator pit for small depressed stocks. Unlikely contributor to the Fraser River sockeye declines.
- Steller sea lion –
  - population increasing approximately 3-5%/yr since 1960s (current pop. 32,000-48,000 in coastal BC)
  - Annual salmon consumption in southern PSC study area (Cape Caution to the Columbia River) = 17.2 tonnes, comparable to commercial fishery catch in the area – consists of roughly 5-15% sockeye. It is important to remember that this is likely a mixture of stocks not just Fraser River sockeye.
  - DNA analysis of salmon remains recovered in scat samples indicated 5% were sockeye and another 15% were either sockeye or pink salmon, but only about one-third of the scat samples with salmon remains have been genetically analyzed. [Note: genetic tests on the ambiguous sockeye/pink samples conducted subsequent to the workshop indicated that sockeye comprised about 16% of the samples analyzed, and another 3% were sockeye or pink].
  - No evidence that marine mammals played a part in the 2009 decline, but they could be playing a role in the long-term decline.

8. Unreported catch in the ocean outside of the PST area – Terry Beacham

- New 2011 paper by Beacham et al. demonstrates that Canadian origin sockeye rear in the Bering Sea.
- Although limited numbers of fish were available for analysis, the fish that were examined included individuals from small stocks of concern including Fraser River stocks.
- Catch of maturing sockeye in the Alaskan fishery could be impacting some stocks.
- Now consider the hypothesis that unreported catch in the ocean outside the PST area is a POSSIBLE contributor to the long term decline.

9. Humboldt squid – Graham Gillespie

- Hypothesized to be a potential predator.
- Recent evidence confirms salmon as potential prey (though no sockeye found). Small sample sizes and low sampling resolution prevent definitive conclusions.
- Not a cause of the long or short-term decline.

- While they were very abundant in 2009, their impact on returning adults is believed to be minimal since lower 48 US stocks also had to pass through the areas of high squid abundance but experienced strong returns in 2009.

10. Pink/sockeye interactions – Dick Beamish (Presented on Day 2)

- Ruggerone suggests that there is a 22% reduction in sockeye productivity in odd years when pink salmon are abundant in the Strait of Georgia.
- Juvenile pink affect the productivity of other juvenile salmon: decreased abundance of hatchery coho in September Strait of Georgia surveys during dominant pink ocean entry years (even); no similar wild coho association though; higher percentage of empty stomachs for chum salmon in July surveys.
- There is the potential for record pink salmon returns in 2011 with significant interactions occurring in 2012.

Day 2 - Summary of Presentations and Discussions

Topic A: Disease

A.1 Overview – Stewart Johnson

- Pathogens are a natural component of all ecosystems.
- Pathogens have co-evolved with their hosts.
- Presence of pathogen doesn't always mean disease will occur.
- Disease determinants are multifactorial. Features of the host, the pathogen, and the environment determine whether disease will develop and the severity of the disease.
- Disease severity may increase when conditions change (upset the normal balance)
- Effects of disease can include: mortality, behavioural changes, and reductions in physiological and reproductive performance. The presence of pathogens (as a carrier state) can also effect behaviour and physiological and reproductive performance. These are effects are not well understood in wild populations
- Comments on Cohen technical report 1 (Kent et al) thorough and reasonable, however the assessment of risk is based primarily on data for farmed salmonids. Major points raised in his report include:
    1. There are pathogens of sockeye salmon that cause or have the potential to cause significant mortality.
    2. There are no direct links between specific pathogens and sockeye salmon survival at a population level.
    3. There is no evidence of an exotic pathogen having been introduced into BC.
    4. If changes in mortality due to pathogens have occurred these are most likely due to changes in the susceptibility of sockeye rather than a change in the abundance of pathogens.
    5. More research is needed to elucidate the impacts of pathogens on Fraser River sockeye salmon.
- A research program to examine the health of Fraser River sockeye salmon in the Strait of Georgia is ongoing. A review of the program was provided. To date there is no evidence of disease in the 250 fish examined by histology. Generally the fish were in good morphological condition, with no evidence of significant infectious disease problems or inflammation noted in any of the samples. There was a low prevalence of intestinal trematode and intraperitoneal cestode infestations and a moderately high prevalence of intracerebral myxosporidian infections noted. None of these agents were causing significant pathologic changes.
- Results from diagnostic testing for known pathogens of sockeye salmon have not identified pathogen carriers in the fish that have been examined to date. Molecular diagnostic testing is being carried on the remaining fish (> 750 fish) collected in 2010. These results should be available by the summer.

A.2 Diseases in Freshwater – Kyle Garver

- Infectious hematopoietic necrosis virus (IHNV) – is enzootic within the Fraser watershed and is naturally found in sockeye salmon.
- Infection by IHNV can be lethal in fry, whereas adults are often asymptomatic carriers of this virus
- Atlantic salmon are highly susceptible to infection with IHNV and can experience high levels of mortality once infected.
- Over the period of 1992-2002 IHN outbreaks were seen on fish farms in a variety of areas in British Columbia. This included fish farms in the Discovery Passage Area. It is thought that the virus was spread between farms by anthropogenic means (i.e. movement of boats and equipment) but water borne transmission of IHNV between farms is also likely to have been an important route.
- An important question is whether salmon farms are increasing the infection levels of Fraser River sockeye with IHNV? Based on over 20 years of data there is no evidence that outbreaks of IHN on salmon farms has alter the prevalence of IHNV in wild sockeye salmon stocks in the Nadina River and Weaver Creek.
- Research is underway to identify and quantify risks associated with IHNV dispersal from aquaculture sites.
- To assess the risks we need to know: How much virus is produced at a source? How long can the virus last outside of its host (stability)? What is the minimum infectious dose in salmon?
  - Lab studies demonstrate that farmed fish ***could*** be a significant source of virus (unvaccinated Atlantic salmon can shed up to 200,000 viral particles per fish per hour).
  - Studies of virus stability: exposure to UV kills IHNV. Poor penetration of these wave lengths of light may limit killing to the surface waters.
  - IHNV is not very stable in natural seawater even in the absence of light.
  - For Atlantic salmon the minimum infectious dose as low as 10 PFU/ml under laboratory conditions. It is unkown what the minimum infectious dose is for sockeye salmon smolts.
- To asses the risk to wild fish posed by IHNV spreading from a point source this information along with a water circulation model developed for the Discovery Islands has been used to model virus dispersion.
- Future work: refine virus dispersion model and extend to West Coast Vancouver Island; determine shedding rates and minimum infectious dose of IHNV in **sockeye** salmon; investigate shedding rates of **vaccinated** Atlantic salmon, investigate viral shedding rates of sockeye salmon that are carriers of IHNV.

A.3 Genomics – Kristi Miller

- Mortality demonstrated to be associated with the unhealthy genomic signature of returning fish in-river, called "MRS" (mortality-related signature).
- In 2005, overall prevalence of MRS was 75% combining results from 3 tissues (gill, liver and brain)
- Smolts show signs of the MRS well before they leave the river with prevalence decreasing during ocean residence.
- There was a very high percentage of sockeye smolts leaving the Fraser River in 2007 with the MRS in brain, gill and liver tissue (9 out of 10 fish examined) compared to 2008 (roughly 19 of 44 fish examined)
- There was a strong reduction in prevalence in 2007 by the end of June while reductions in prevalence in 2008 were not apparent until the fall.
- In both year classes, the lowest prevalence was observed in returning adults
- There is cumulative evidence for a (viral) pathogen eliciting the MRS signature
- There is evidence that it is <u>not</u> *Parvicapsula*, sea lice or simple stress response
- I.D. of a novel viral sequence from MRS-positive liver tissue
    - Strong hit to Parvovirus, novel to salmon, but present in mammals, lower vertebrates (birds, reptiles), shrimp and insects.
    - Often mediated by environmental conditions
    - Previously speculated that MRS was retroviral, there are similarities between retroviral and parvovirus diseases.
- Future research:
    - Identification and validation of viral origin of the MRS profile to satisfy Koch's revised 21st century postulates
    - Full sequencing of novel parvovirus
    - Molecular epidemiology of novel salmon parvovirus in the North Pacific to assess the evolutionary history of the virus
    - Determine the etiology of the disease—routes of transmission, necessary conditions for viral replication, role of nutrition and impact of co-infections
    - Determine the potential role of this disease in salmon declines:
        - Range of stock/species affected
        - Establish relative role of mortality versus recovery and role of temperature and salinity on disease progression
        - Conduct further studies assessing in additional years the relative role of this disease versus other physiological factors in predicting year-class strength and spawning success
        - Determine the potential role of aquaculture and hatcheries

A.4 Sea lice – Simon Jones

- Do farms represent source of sea lice that affects sockeye?
- Reviewed literature for evidence:
    - Price/Beamish finding high ratio of *Caligus clemensi* to *Lepeophtheirus salmonis* in the Strait of Georgia

    - Sea lice generally have greater impacts on small juvenile fish.
    - Herring and other marine fish are likely reservoir of *C. clemensi*.
    - Sea lice loads on farms seem low but require salmon numbers from farms to determine absolute contribution of sea lice larvae.
    - Limited access to high resolution farm data (i.e., from individual farms) hinders research.
    - *L. salmonis* and *C. clemensi* infections occur in the Strait of Georgia on juvenile sockeye and other species with a much higher abundance of *C. clemensi.*
    - Farmed salmon are a potential source of *L. salmonis*.
    - Effects of sea lice on juvenile sockeye not known.
- Insufficient evidence to conclude that sea lice are an **important** contributor to the Fraser River sockeye situation. Do not have adequate information.
- Research: 3 surveillance programs ongoing
- Levels of lice on some farms near Discovery Islands during spring of 2007 not obviously different from preceding years, suggesting reduced abundance of adult sockeye in 2009 cannot be explained by sea lice from farmed salmon.
- Additional research:
    - Establish inter-annual variations in sea lice levels for juvenile sockeye in Strait of Georgia
      –Related studies in the Broughton Archipelago showed significant interannual variation in sea lice on wild juvenile salmon
    - Establish inter-annual variations of infections with bacteria, virus or other parasites
      –Diseases other than those caused by sea lice may be significant determinants of sockeye health and survival
      –Sea lice may increase the risk of other diseases in juvenile sockeye
    - Determine lethal and other impacts of sea lice on individual sockeye salmon in controlled laboratory experiments
      –Use protocols and methods already developed for the study of sea lice effects on juvenile pink and chum salmon
    - Integrate and analyse health data from farmed and wild salmon in the Strait of Georgia and elsewhere to obtain a global assessment of pathogen dynamics
      –Establish an ecosystem-based perspective of sea lice ecology that includes wild and farmed hosts, multiple lice species and hydrodynamic modelling
      –Inform a rational basis for sea lice management on farms

A.5 Discussion/Roundtable/ Summary

- Sockeye salmon are known to naturally carry a wide variety of pathogens ranging from viruses to parasites.
- Only enzootic pathogens have been identified in sockeye salmon with the possible exception of a recently discovered parvovirus.
- Health surveys of sockeye salmon collected in May to July of 2010 did not identify disease by histology. Samples collected in 2011 are still being processed for histology. Screening by culture of sockeye from Chilko Lake and the Strait of Georgia (collected in 2010) failed to identify any carriers of pathogens. Additional sockeye

salmon from the 2010 collection are being tested for pathogens using molecular methods. These results should be available by Fall 2011. All samples from the 2011 surveys are being screened for pathogens using histology and molecular methods only.

- Based on over 20 years of data, there is no evidence that outbreaks of IHNV on salmon farms has altered the prevalence of IHNV in wild sockeye salmon stocks in the Nadina River or Weaver Creek.
- Recent work has examined the survival of IHNV in seawater under various conditions. Physical oceanographers at the Institute for Ocean Sciences (IOS) are using these data to model possible virus dispersal from point sources in the Discovery Islands area.
- A parvovirus sequence has recently been obtained by Dr. Miller from sockeye salmon containing the Mortality-Related genomic Signature (MRS) published in January 2011 in Science and shown to be associated with premature mortality of returning adult Fraser River sockeye salmon. Preliminary data from liver tissue samples show a correlation between the MRS and the presence of parvovirus. Laboratory challenge studies using parvovirus-infected tissues are planned for late summer and early fall 2011 when the available fish become large enough for challenge. These studies will be used to establish whether this virus is infective, whether it causes disease, and whether it is causative of the MRS.
- Relatively little is know about the effects of pathogens on sockeye salmon.
- There is agreement that pathogens can effect the survival of sockeye salmon at the individual level but how large this impact is at the population level is unclear.
- Early seawater entry is though to be a critical time when mortality from pathogens, exposure to contaminants etc. may occur. For example, effects of budworm spraying on Atlantic salmon in Atlantic Canada only became evident following saltwater challenge.
- Sea lice infections on sockeye salmon throughout the Strait of Georgia are similar with respect to species prevalence and their abundance when compared to a recent publication on sockeye salmon in the Discovery Islands area.
- *Lepeophtheirus salmonis* can carry pathogens but the role of this species in pathogen transfer between individual salmon is likely limited. Based on laboratory studies, there is some evidence for this.
- Sea lice infection may increase susceptibility to infection with pathogens or increase the risk of disease development. This would require sufficient sea lice to be present to cause a stress response.
- The pathogens that are present in sockeye interact directly and indirectly with their hosts and the environment. There is insufficient data to determine for each pathogen, or combination thereof, how they interact with their hosts and how changing environments may affect those interactions (possibly leading to disease).

Topic B: Ocean Conditions

B.1 Physical Oceanography – Rick Thompson

- All areas of the coast were anomalous in 2007 – late spring transition, strong winds, high freshwater runoff (low sea surface salinity)
- Lots of freshwater, blown to the north by big winds – results in VERY shallow mixed layer; a condition which can support the development of harmful algal blooms.
- In 2008, conditions were more "normal"
- Anomalously low productivity conditions in the Gulf of Alaska in winter 2008/09 (strongest La Niña on record) resulted in adverse conditions for sockeye in their 2nd ocean winter.
- In 2011 conditions look good
- Questions:
    - Bill Crawford questioned using winds as a proxy for nutrients?
    - Kim Hyatt asked whether circulation in the Gulf of Alaska may be a factor?
    - Mike Bradford suggested looking at historic reconstruction of Gulf of Alaska conditions?

B.2 Physical Oceanography – Patrick Cummins

- Strong run-off anomalies along the North Coast in 2007 (moderate for Strait of Georgia), and opposite conditions in 2008.
- Data from Strait of Georgia show that the upper water column in spring/summer of 2007 was somewhat fresher than average, but within the normal range of variation.
- Lighthouse data show warm, very fresh water near Egg Island during summer 2007. The spatial extent of these anomalous conditions is unknown.
- ROMS model (3km resolution) was used to examine the spatial extent of anomalous ocean conditions over the North Coast of BC.

B.3 Physical Oceanography – Angelica Peña

- No evidence of mixed layer with a defined depth in Strait of Georgia: 2007 surface stratification in Strait of Georgia not particularly unusual compared to other years
- Euphotic zone – and primary production–is not anomalous in 2007 based on discrete (in time) survey observations
- Considerable variability within any given year, 2007 does not fall outside this range.

B.4 Biology Inside Strait of Georgia – Dick Beamish

- The results of all trawl surveys since 1998 indicate that about 98% of all fish in the surface 30m in the daytime in the Strait of Georgia are juvenile Pacific herring or Pacific salmon.
- Evidence of poor abundance and condition factor across several species (i.e., herring, coho, Chinook, chum, as well as sockeye) in the Strait of Georgia in 2007

- All of these species had exceptionally poor survival and/or growth in the spring of 2007. The 2007 year class of Pacific herring had exceptionally poor survival as indicated by the historic low recruitment into the commercial fishery in 2010.
- The diet of juvenile Chinook salmon in 2007 had the lowest percentage of fish in all surveys and virtually no herring. This indicates that there was a large mortality of Pacific herring prior to mid-July.
- It is estimated that 35 days is the average residence period of sockeye salmon in the Strait of Georgia.
- The author expects that the 2011 return will be higher and the 2012 return will be lower than average.
- A production failure of virtually all species in the surface waters of a major marine ecosystem may be unique.
- The highly anomalous physical conditions reported by Dr. Thomson indicate that the most likely explanation for the poor survival of all fish (Chinook survival is not known yet) is a large reduction in the production of typical prey.
- Juvenile sockeye salmon that survived in the Strait of Georgia also experienced unfavourable conditions for growth and survival in Queen Charlotte Sound and in the Gulf of Alaska. Thus, the explanation for the poor return in 2009 most likely was very poor conditions for growth and survival in the Strait of Georgia with the surviving fish experiencing similar conditions through to their first ocean winter.

B.5 Biology Outside Strait of Georgia – Marc Trudel

- Is the unusually low return of Fraser R. sockeye in 2009 due to events occurring outside the Strait of Georgia?
    - Evidence for: Acoustic tags indicate higher mortality of juvenile Cultus L. sockeye after leaving the Strait of Georgia then within
    - Evidence against: Large smolts were tagged; Small sample size; Do Cultus L. sockeye represent Fraser R. sockeye? Low proportion of juvenile Fraser R. sockeye in Hecate St.
- Is the decline in Fraser R. sockeye productivity and low returns in 2009 related to ocean productivity in Queen Charlotte Sound?
    - Evidence for: Strong positive correlation between Chilko sockeye survival and chlorophyll concentration in Queen Charlotte Sound; anomalous fresh water and low bird production.
    - Evidence against: Marine survival of Smith Inlet sockeye was not abnormally low; salmon growth was not poor north of Vancouver Island.

B.5 Genomics Inside/Outside Strait of Georgia – Kristi Miller

- High prevalence of mortality-related signature (MRS) in brain and liver hypothesized to result from a novel viral infection.
    - Fish with the MRS signature in brain in freshwater quickly disappear in the ocean
- 2007 Fraser sockeye were highly stressed in the marine environment (liver) with some indication of hypoxia, possibly from *Heterosigma* blooms.

- Immunosuppression in the marine environment (liver) may relate, in part, to stronger MRS.
- H_o: reduced feeding (but not outright starvation) may be a factor (liver).
- A high proportion of 2007 Fraser sockeye carried a low-growth type signature in the ocean, whereas fewer 2008 fish and west coast of Vancouver Island fish carried this signature.
- However, the marine environment may not explain all of the variance in physiology and fate of 2007 sockeye salmon, as the brain and muscle tissues from 2007 and 2008 Fraser sockeye salmon were highly divergent, even in the freshwater environment.

B.6 Discussion/Roundtable/ Summary

- The cause of the decline of Fraser River sockeye and the exceptionally low return in 2009 is likely to have occurred prior to reaching Hecate Strait.
- The poor ocean conditions that prevailed in Queen Charlotte Sound and Hecate Strait in 2007 may have been exacerbated the poor conditions they experienced previously in the Strait of Georgia.
- Sockeye may have been physiologically compromised in freshwater and in the marine environment. There is evidence for poor ocean conditions in the Strait of Georgia, and in Queen Charlotte Sound (i.e. anomalous winds, salinity, production, etc.). Harrison River sockeye enter and reside within the Strait of Georgia at different time than other stocks of Fraser River sockeye.
- Future research:
    - How many smolts leave the Fraser River?
    - How long do they remain in the Strait of Georgia?
    - Where and when significant mortality occurs in the marine environment?
    - What is killing salmon in the marine environment? Pathogens? Predators? Starvation?
    - To what extent ocean conditions in the Gulf of Alaska affect the recruitment variability of Fraser River sockeye?

General Discussion, Next Steps and Closing Remarks

General Discussion

- Cannot rule out a catastrophic event.
- Although difficult to determine, differences in residence times in various regions (i.e., Strait of Georgia vs. Queen Charlotte Sound) need to be considered
- Controversy in connecting primary/secondary production
- What is killing fish and what is making fish vulnerable?
- Need to consider apparent differences in marine survival of Harrison River sockeye when compared to other Fraser River stocks. (CHECK WITH SUE)
- Cumulative impacts have not been addressed yet; differences in opinion must be acknowledged; obviously no single cause of mortality; environmental variables are felt at differing scales.
- Must maintain broader scope: North Pacific salmon are just as important as Fraser River sockeye

Next Steps: Short Term

- Work in support of Cohen Commission (evidentiary hearings continue May-September)
- Lead authors to provide summary bullets/paragraph – synthesis/consensus with previous presentations/reports
- Development of one page synthesis including summary table linking to PSC presentations/Cohen research papers
- Coordinated review of Cohen research papers
- Collation of materials on the Sharepoint site
- Develop Briefing Note
- Review of research requirements/PSC workshop (potential)

Next Steps: Long term

- Development of integrating analytical tools and simulations to look at effects of combined factors
- Integration of program development moving forward
- Need to explore the Chilko tagging results in relation to early marine survival work—differing results
- Consider doing a comparable empirical analysis for Fraser Rive sockeye as was done for Atlantic salmon vis-à-vis budworm spraying (i.e., correlate survival or returns with areas of various contaminant applications)

Appendix A. Meeting Agenda

DFO synthesis workshop on the decline of Fraser River Sockeye

Vancouver Island Conference Centre, Nanaimo, BC
Mount Benson Ballroom D
April 14-15, 2011

Meeting objectives:

(1) Review the state of evidence for factors contributing to the Fraser sockeye situation with a focus on disease, aquaculture and marine survival.
(2) Develop approach for technical and narrative reports that synthesize the current state of knowledge on reasons for the long term decline and the notable 2009 and 2010 returns.

April 14, 2011

12:30 Opening remarks – Mark Saunders, Denis D'Amours (Meeting Chair)

12:45 Current status of Fraser Sockeye – Sue Grant

1:30-3:45 Round table updates on hypotheses – 15 min for Short summary and discussion of any recent developments:

- Harmful algal blooms in the Strait of Georgia/Puget Sound/JuandeFuca or Johnstone Strait are an important contributor to the Fraser sockeye situation**:** **Jim Irvine**/Angelica Pena/Dick Beamish/Kristi Miller
- Contaminants in the Fraser River and/or Strait of Georgia are an important contributor to the Fraser Sockeye situation. Including review of Cohen project paper 2: **Peter Ross**/Robbie MacDonald
- Freshwater habitat conditions in the Fraser River watershed are an important contributor to the Fraser sockeye situation. *(Include discussion of lower river and estuary):* **Mike Bradford/**Erl MacIssac/Dave Patterson Dan Selbie/Teri Sutherland
- Enroute mortality (including the effects on fitness of the next generation) is an important contributor to the Fraser sockeye situation: **Dave Patterson**/Timber Whitehouse/Sue Grant/Kristi Miller
- Delayed density dependent mortality is an important contributor to the Fraser sockeye situation: **Dan Selbie**/Arlene Tompkins/Sue Grant/Timber Whitehouse
- Predation by marine mammals is an important contributor to the Fraser Sockeye Situation. **John Ford/**Peter Olesiuk
- Unreported catch in the ocean outside the PST area is an important contributor to the Fraser Sockeye situation: **Terry Beacham**/Arlene Tompkins
- Squid are an important contributor to the Fraser sockeye situation: **Graham Gillespie**

4:00 Adjourn for the day

Appendix A. Meeting Agenda (cont'd…)

April 15, 2011

8:30	Welcome and summary of Day 1 – Mark Saunders
8:45	Round table update carry-over from Thursday: • Competitive interactions with pink salmon are an important contributor to the Fraser sockeye situation: **Dick Beamish**/Marc Trudel/Jim Irvine
9:00	Introduction to disease and review of Kent (2011): **Stewart Johnson**
9:30	Diseases in freshwater and marine systems are an important contributor to the Fraser sockeye situation: **Kyle Garver**
10:00	Break
10:30	Genomic studies suggest that some disease has infected sockeye and has become an important contributor to the Fraser River sockeye situation: **Kristi Miller**
11:00	Sea lice, either naturally occurring or passed from fish farms, are an important contributor to the Fraser sockeye situation: **Simon Jones**
11:30	Round-table discussion of disease as a contributor to the Fraser River sockeye situation
12:00	Lunch
1:00	Ocean conditions INSIDE and OUTSIDE the Strait of Georgia are important contributors to the Fraser Sockeye situation. (*need to also consider high seas)* **Dick Beamish**/**Marc Trudel**/Rick Thomson/Dave Mackas/Angelica Pena/Chrys Neville/Dave Preikshot/ Jim Irvine/Kim Hyatt/Bill Crawford/Kristi Miller
2:30	Discussion of approach to analysis, publication and reporting of synthesis of knowledge on reasons for the long term decline and the notable 2009 and 2010 returns.
3:30	Summary and next steps – Mark Saunders/Denis D'Amours
3:40	Closing remarks – Laura Richards
4:00	Adjourn

Appendix B. Attendance

Attendance	Dept	THU	FRI
Beacham, Terry	DFO	√	√
Beamish, Richard	DFO	N	√
Benner, Keri	DFO	N	N
Bradford, Mike	DFO	√	√
Brown, Laura (Pacific)	DFO	N	√
Brown, Robin	DFO	√	√
Crawford, Bill	DFO	√	√
Cross, Carol	DFO	N	√
Cummins, Patrick	DFO	N	√
Curtis, Janelle	DFO	√	√
D'Amours, Denis	DFO	√	√
Davis, Brad	DFO	√	√
Folkes, Michael	DFO	√	√
Ford, John (Pacific)	DFO	N	N
Garver, Kyle	DFO	√	√
Gillespie, Graham	DFO	√	N
Gillis, Dave	DFO	N	N
Grant, Sue	DFO	√	√
Grout, Jeff	DFO	N	N
Hargreaves, Brent	DFO	N	√
Higgins, Mark	DFO	√	√
Holt, Carrie	DFO	√	√
Hume, Jeremy	DFO	N	√
Hyatt, Kim	DFO	√	√
Irvine, James	DFO	√	√
Johannessen, Sophia	DFO	N	N
Johnson, Stewart	DFO	√	√
Jones, Simon	DFO	N	√
Joyce, Marilyn	DFO	√	√
Kadowaki, Ronald	DFO	N	N
Kristmanson, James	DFO	√	√
Ma, Brian	DFO	N	√
MacAulay, Hugh	DFO	N	N
Macdonald, Robie	DFO	N	N
Macgillivray, Paul	DFO	N	N
MacIsaac, Erland	DFO	√	N
Mackas, Dave	DFO	N	N
MacWilliams, Christine	DFO	√	√

Appendix B. Attendance (cont'd…)

Attendance (cont'd)	**Dept**	**THU**	**FRI**
Miller-Saunders, Kristi	DFO	√	√
Neville, Chrys	DFO	√	√
Olesiuk, Peter	DFO	√	√
Patterson, David	DFO	√	N
Pena, Angelica	DFO	N	√
Perry, Ian	DFO	√	N
Preikshot, Dave	DFO	√	N
Richards, Laura	DFO	N	√
Rosenberger, Barry	DFO	N	N
Ross, Andrew	DFO	N	N
Ross, Cheryl	DFO	√	√
Ross, Peter (Pacific)	DFO	√	√
Ryall, Paul	DFO	N	N
Saunders, Mark	DFO	√	√
Schubert, Neil	DFO	√	N
Selbie, Daniel	DFO	√	√
Sheppard, Mark	DFO	N	√
Sutherland, Terri	DFO	N	N
Sweeting, Ruston	DFO	N	N
Thiess, Mary	DFO	√	√
Thomson, Richard	DFO	√	√
Tompkins, Arlene	DFO	√	√
Trudel, Marc	DFO	√	√
Tucker, Strahan	DFO	√	√
Whitehouse, Timber	DFO	√	√
Withler, Ruth	DFO	N	N
Wood, Chris	DFO	N	N
Grande-McNeill, Geneva	DoJ	√	√
Taylor, Mitch	DoJ	N	N
Timberg, Tim	DoJ	√	√