# APPENDICES

# Appendix A • Terms of Reference

CANADA

PRIVY COUNCIL • CONSEIL PRIVÉ

**P. C. 2009-1860**
**November 5, 2009**

Whereas the decline in sockeye salmon stocks in the Fraser River in British Columbia has necessitated the closure of the fishery for a third consecutive year, despite favourable pre-season estimates of the number of sockeye salmon expected to return to the Fraser River;

Whereas that decline has been attributed to the interplay of a wide range of factors, including environmental changes along the Fraser River, marine environmental conditions and fisheries management;

Whereas the Government of Canada wishes to take all feasible steps to identify the reasons for the decline and the long term prospects for Fraser River sockeye salmon stocks and to determine whether changes need to be made to fisheries management policies, practices and procedures — including establishing a commission of inquiry to investigate the matter;

And whereas the Government of Canada has committed to full cooperation with an inquiry;

Therefore, Her Excellency the Governor General in Council, on the recommendation of the Prime Minister, hereby

*(a)* directs that a Commission do issue under Part I of the *Inquiries Act* and under the Great Seal of Canada appointing the Honourable Bruce Cohen as Commissioner to conduct an inquiry into the decline of sockeye salmon in the Fraser River (the "Inquiry"), which Commission shall

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(i) direct the Commissioner

(A) to conduct the Inquiry without seeking to find fault on the part of any individual, community or organization, and with the overall aim of respecting conservation of the sockeye salmon stock and encouraging broad cooperation among stakeholders,

(B) to consider the policies and practices of the Department of Fisheries and Oceans (the "Department") with respect to the sockeye salmon fishery in the Fraser River — including the Department's scientific advice, its fisheries policies and programs, its risk management strategies, its allocation of Departmental resources and its fisheries management practices and procedures, including monitoring, counting of stocks, forecasting and enforcement,

(C) to investigate and make independent findings of fact regarding

(I) the causes for the decline of Fraser River sockeye salmon including, but not limited to, the impact of environmental changes along the Fraser River, marine environmental conditions, aquaculture, predators, diseases, water temperature and other factors that may have affected the ability of sockeye salmon to reach traditional spawning grounds or reach the ocean, and

(II) the current state of Fraser River sockeye salmon stocks and the long term projections for those stocks, and

(D) to develop recommendations for improving the future sustainability of the sockeye salmon fishery in the Fraser River including, as required, any changes to the policies, practices and procedures of the Department in relation to the management of the Fraser River sockeye salmon fishery,

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(ii) direct the Commissioner to conduct the Inquiry under the name of the Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River,

(iii) authorize the Commissioner to consider findings, as he considers appropriate, of previous examinations, investigations or reports that may have been conducted that he deems relevant to the Inquiry and to give them any weight, including accepting them as conclusive,

(iv) direct the Commissioner to supplement those previous examinations, investigations or reports with his own investigation and to consider the Government's response to previous recommendations,

(v) authorize the Commissioner to rent any space and facilities that may be required for the purposes of the Inquiry, in accordance with Treasury Board policies,

(vi) authorize the Commissioner to adopt any procedures and methods that he may consider expedient for the proper conduct of the Inquiry,, to sit at any times and in any places in Canada that he decides and to conduct consultations in relation to the Inquiry as he sees fit,

(vii) authorize the Commissioner to engage the services of any staff, experts and other persons referred to in section 11 of the Inquiries Act at rates of remuneration and reimbursement as approved by the Treasury Board,

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(viii) despite subparagraphs (v) and (vi), direct the Commissioner not to conduct any hearings during the periods beginning on February 12, 2010 and ending on February 28, 2010, and beginning on March 12, 2010 and ending on March 21, 2010, to minimize the costs of the Inquiry and the inconvenience to witnesses during the Vancouver 2010 Olympic and Paralympic Winter Games,

(ix) authorize the Commissioner to grant, to any person who satisfies him that they have a substantial and direct interest in the subject matter of the Inquiry, an opportunity for appropriate participation in it,

(x) authorize the Commissioner to recommend to the Clerk of the Privy Council that funding be provided, in accordance with terms and conditions approved by the Treasury Board, to ensure the appropriate participation of any person granted standing at the Inquiry under subparagraph (ix), to the extent of the person's interest, if the Commissioner is of the view that the person would not otherwise be able to participate in the Inquiry,

(xi) direct the Commissioner to use the automated documents management program specified by the Attorney General of Canada and to consult with records management officials within the Privy Council Office on the use of standards and systems that are specifically designed for the purpose of managing records,

(xii) direct the Commissioner, in respect of any portion of the Inquiry conducted in public, to ensure that members of the public can, simultaneously in both official languages, communicate with and obtain services from the Inquiry, including any transcripts of proceedings that have been made available to the public,

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**P. C. 2009-1860**

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(xiii) direct the Commissioner to follow established security procedures, including the requirements of the Policy on Government Security, with respect to persons engaged under section 11 of the Inquiries Act and the handling of information at all stages of the Inquiry,

(xiv) direct the Commissioner to perform his duties without expressing any conclusion or recommendation regarding the civil or criminal liability of any person or organization,

(xv) direct the Commissioner to submit, on or before August 1, 2010, an interim report, simultaneously in both official languages, to the Governor in Council, setting out the Commissioner's preliminary views on, and assessment of, any previous examinations, investigations or reports that he deemed relevant to the Inquiry and the Government's responses to those examinations, investigations and reports,

(xvi) direct the Commissioner to submit, on or before May 1, 2011, one or more reports, simultaneously in both official languages, to the Governor in Council, and

(xvii) direct the Commissioner to deposit the records and papers of the Inquiry with the Clerk of the Privy Council as soon after the conclusion of the Inquiry as is reasonably possible, and

*(b)* authorizes, pursuant to section 56 of the *Judges Act,* the Honourable Bruce Cohen of Vancouver, British Columbia, a judge of the Supreme Court of British Columbia, to act as Commissioner.

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CLERK OF THE PRIVY COUNCIL–LE GREFFIER DU CONSEIL PRIVÉ

CANADA

PRIVY COUNCIL • CONSEIL PRIVÉ

**P. C. 2009-1861**
**November 5, 2009**

Her Excellency the Governor General in Council, on the recommendation of the Prime Minister, hereby

(a) pursuant to paragraph *(b)* of the definition "department" in section 2 of the *Financial Administration Act,* designates the Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River as a department for the purposes of that Act; and

(b) pursuant to paragraph *(b)* of the definition "appropriate Minister" in section 2 of the *Financial Administration Act,* designates the Prime Minister as the appropriate Minister with respect to the Commission referred to in paragraph *(a).*

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CLERK OF THE PRIVY COUNCIL–LE GREFFIER DU CONSEIL PRIVÉ

CANADA

PRIVY COUNCIL • CONSEIL PRIVÉ

**P.C. 2010-954**
**July 23, 2010**

Her Excellency the Governor General in Council, on the recommendation of the Prime Minister, hereby directs that a commission do issue under Part I of the *Inquiries Act* and under the Great Seal of Canada amending the commission in relation to the Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River, issued pursuant to Order in Council P.C. 2009-1860 of November 5, 2009, by replacing subparagraph (xv) with the following:

> (xv) direct the Commissioner to submit, on or before October 29, 2010, an interim report, simultaneously in both official languages, to the Governor in Council, setting out the Commissioner's preliminary views on, and assessment of, any previous examinations, investigations or reports that he deemed relevant to the Inquiry and the Government's responses to those examinations, investigations and reports.

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CLERK OF THE PRIVY COUNCIL–LE GREFFIER DU CONSEIL PRIVÉ

CANADA
PRIVY COUNCIL • CONSEIL PRIVÉ

P.C. 2011-23
January 24, 2011

His Excellency the Governor General in Council, on the recommendation of the Prime Minister, hereby directs that a commission do issue under Part I of the *Inquiries Act* and under the Great Seal of Canada amending the commission in relation to the Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River, issued pursuant to Order in Council P.C. 2009-1860 of November 5, 2009, as amended by Order in Council P.C. 2010-0954 of July 23, 2010, by replacing paragraph (*s*) with the following:

(*s*) Our Commissioner to submit, on or before June 30, 2012, one or more reports, simultaneously in both official languages, to the Governor in Council;

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CLERK OF THE PRIVY COUNCIL–LE GREFFIER DU CONSEIL PRIVÉ

CANADA

PRIVY COUNCIL • CONSEIL PRIVÉ

P.C. 2012-340
March 27, 2012

His Excellency the Governor General in Council, on the recommendation of the Prime Minister, hereby directs that a commission do issue under Part I of the *Inquiries Act* and under the Great Seal of Canada amending the commission in relation to the Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River, issued pursuant to Order in Council P.C. 2009-1860 of November 5, 2009, as amended by Order in Council P.C. 2010-0954 of July 23, 2010 and by Order in Council P.C. 2011-23 of January 24, 2011, by replacing paragraph (*s*) with the following:

(*s*) Our Commissioner to submit, on or before September 30, 2012, one or more reports, simultaneously in both official languages, to the Governor in Council;

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CLERK OF THE PRIVY COUNCIL–LE GREFFIER DU CONSEIL PRIVÉ

CANADA

PRIVY COUNCIL • CONSEIL PRIVÉ

P.C. 2012-1132
September 24 2012

His Excellency the Governor General in Council, on the recommendation of the Prime Minister, directs that a commission do issue under Part I of the *Inquiries Act* and under the Great Seal of Canada amending the commission in relation to the Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River, issued pursuant to Order in Council P.C. 2009-1860 of November 5, 2009, as amended by Order in Council P.C. 2010-954 of July 23, 2010, by Order in Council P.C. 2011-23 of January 24, 2011 and by Order in Council P.C. 2012-340 of March 26, 2012, by replacing paragraph (*s*) with the following:

> (*s*) Our Commissioner to submit, on or before October 29, 2012, one or more reports, simultaneously in both official languages, to the Governor in Council;

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CLERK OF THE PRIVY COUNCIL–LE GREFFIER DU CONSEIL PRIVÉ

# Appendix B • Executive summaries and tables of contents of technical reports

## TR1 – Infectious Diseases

Kent, M. 2011. Infectious diseases and potential impacts on survival of Fraser River sockeye salmon. Cohen Commission Tech. Rept. 1: 58p. Vancouver, B.C. www.cohencommission.ca

### Executive Summary

Numerous pathogens have been reported in sockeye salmon and a few of them have been documented to be, or are, potential causes of significant mortality in this salmon species in the Fraser River system. At present, there are no direct links between a specific pathogen and sockeye salmon survival at a population level in British Columbia. This report reviews 5 viral, 6 bacterial, 4 fungal, and 19 parasitic pathogens that are known to or could potentially infect sockeye salmon. Two idiopathic diseases are also discussed. For each pathogen, a subjective assessment of risk for causing significant disease in wild sockeye salmon in the Fraser River system is provided. This risk is based on 1) the known or suspected virulence of the pathogen to Pacific salmon in general, and specifically to sockeye salmon and 2) the likelihood that the pathogen would be prevalent in the Fraser River or British Columbia. These conclusions were based on review of the peer-reviewed literature, government documents from Fisheries and Oceans Canada (DFO), and interviews with DFO fish health scientists. I designated the following pathogens as potential "High Risk": IHN virus, three bacteria (*Vibrio anguillarum*, *Aeromonas salmonicida*, *Renibacterium salmoninarum*), and two parasites (Ich–*Ichthyophtheirus multifillis* and the myxozoan *Parvicapsula minibicornis*).

The IHN virus is well recognized as a lethal pathogen to fry sockeye salmon in freshwater. It also occurs in marine waters in BC, and has caused several outbreaks in pen-reared Atlantic salmon. Post-smolt sockeye salmon are less susceptible, but recent evidence suggests that there is variability in the virulence of this virus between isolates, and thus it is conceivable that some strains may be more pathogenic to sockeye salmon in the ocean. The three bacterial pathogens are included in the High Risk category as they are recognized as virulent pathogens in both hatcheries and netpens. *Vibrio anguillarum* is ubiquitous in the marine environment, the other two bacteria are occasionally reported in wild salmon. However, outbreaks in wild salmon, including sockeye salmon, in British Columbia have not been documented for these pathogens. In contrast, both Ich and *Parvicapsula* have been documented to be associated with pre-spawning mortality in sockeye salmon, and the latter also infects outmigrant smolts.

Pathogens assigned to the Moderate Risk category were *Flavobacterium* spp., fungi belonging to the genus *Saprolegnia*, the fungus-like pathogen *Ichthyophonus hoferi*, the PKX myxozoan, *Eubothrium* spp. tapeworms, and sea lice (*Lepeophtheirus salmonis* and *Caligus clemensi*). *Flavobacterium* and *Saprolegnia* spp. are recognized as significant, but usually opportunistic, pathogens in salmon in freshwater when environmental conditions are suboptimal, and thus could cause severe disease if the Fraser River system or marine environment is compromised. *Icthyophonus hoferi* is of concern as it recently has been increasing in Chinook salmon in the Yukon River. *Eubothrium* is one worm parasite that has been already shown to compromise wild sockeye when infections are heavy. Last, the caligid copepods were included on the list. Whereas not documented to cause mortalities in wild sockeye salmon, recent claims of sea lice killing wild pink salmon in British Columbia warrants investigations on the impact of these copepods on post-smolt sockeye salmon. One putative disease was place designated as "Unknown". Here Dr. K. Miller-Sauders at DFO, Pacific Biological Station (PBS), Nanaimo, recently discovered an unusual gene signature suggestive of a virus infection in sockeye salmon, and temporal studies showed that these fish had reduced survival. The list agrees for the most part with one independently developed by Dr. Kyle Garver, DFO-PBS, where he concluded that IHN virus, *Parvicapsula*, and Ich are the pathogens of most concern in sockeye from this system.

All of these pathogens are endemic to British Columbia and most likely have been present in this area for centuries. Moreover, there is no evidence of an exotic salmonid pathogen being recently introduced to the Province. If there has been a dramatic increase in mortality caused by one or more of them in recent years, it is likely due to changes in the susceptibility of sockeye salmon to them or a change in the abundance in these pathogens. Environmental changes could be an underlying cause of either. Fish are very closely tied to their environment, and thus water quality and other environmental parameters play a very important role in their susceptibility and severity of diseases. Changes in water temperature, either in freshwater or seawater, are important likely candidates. Fish are cold-blooded (poikilothermic) and thus both their pathogens and the fish themselves are extremely influenced by temperature.

There are certainly many pathogens that occur in wild sockeye salmon, but their precise impacts on survival in these stocks are poorly understood. Hence, there are not firm links for these pathogens with significant demise in these sockeye populations overall, but some of these are clearly associated with prespawning mortality in freshwater. The absence of data on pathogens and diseases in wild salmon in British Columbia is a reflection of the historical research focus on fish diseases, in both the Province and other regions. Most research on salmonid diseases has been directed toward those afflicting captive fish, either in government hatcheries or private fish farms.

As with many scientific issues, more research is needed to elucidate the impacts of pathogens on Fraser River sockeye salmon. Surveys for pathogens and diseases in wild sockeye salmon must be conducted and maintained over several years to provide the needed raw data. Surveys must include proper identification of pathogens, geographic and host distribution, and abundance or severity of infection. With these data in hand, researchers can conduct the appropriate analyses to infer or document the role that these pathogens have with survival in various life stages. After a pathogen is shown to be associated with mortality, modelers, mathematicians, statisticians, and ecologists could then conduct investigations to elucidate which factors (e.g., water temperature, river flow, land use practices, netpen farming) influence the distribution and abundance of these pathogens. Isolation, identification of agents, and controlled laboratory studies are needed to elucidate the pathogenesis of newly recognized pathogens, such as the putative virus associated with specific gene functions.

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# TR1A – Enhancement Facility Diseases

Stephen, C., T. Stitt, J. Dawson-Coates and A. McCarthy. 2011. Assessment of the potential effects of diseases present in salmonid enhancement facilities on Fraser River sockeye salmon. Cohen Commission Tech. Rept. 1A: 180p. Vancouver, B.C. www.cohencommission.ca

## Executive Summary

The objectives of this report were; (1) to review disease data and reports from salmon enhancement facilities operated under the authority of Fisheries and Oceans Canada (DFO) and the Freshwater Fisheries Society of British Columbia (FFSBC) and evaluate the potential for a qualitative and/or quantitative assessment of the potential effect of diseases present in enhancement facilities on the production of Fraser River sockeye salmon (*Oncorhynchus nerka*) and, (2) if possible evaluate the disease risks posed by the operation of salmonid enhancement facilities on the production of Fraser River sockeye salmon.

The role of enhancement hatcheries in sustaining wild salmon populations is controversial. Salmonid enhancement is intended to improve the freshwater productivity of native salmonids. Concerns about negative effects from interbreeding of enhanced and wild salmon, ecological competition, and the impacts of mixed fisheries have been the subject of other reviews and remain unresolved. This report only considers the potential infectious disease risks of salmonid enhancement facilities in the Fraser River watershed and Strait of Georgia for approximately the past decade.

Two methods were used to assess the burden of evidence available for risk assessment and to attempt to evaluate the risks. First, a scoping literature review sought direct and indirect evidence of a causal relationship between salmonid enhancement related infectious diseases and Fraser River sockeye salmon production. Second, data provided by the Cohen Commission including, salmonid enhancement disease diagnostic data; hatchery-level health records and; production data were examined using a risk assessment framework.

The disease impacts of salmon enhancement facilities on Fraser River sockeye salmon are largely unexplored in the literature. The published literature failed to provide sufficient direct or indirect evidence to fulfill standard criteria for causation. Infectious diseases and disease causing microorganisms have been reported in the literature in both Fraser River sockeye salmon and other species of enhanced salmonids in British Columbia. These pathogens are capable of causing clinical and sub-clinical impacts on individual fish but the effects on population productivity remain speculative.

The literature was unable to provide sufficient information to determine the likelihood of salmonid enhancement-associated diseases impacting Fraser River sockeye salmon, the magnitude of the hypothetical impacts, or the ability of enhancement facilities to prevent or mitigate the risks. A small number of historic cases have associated the presence of pathogens in Fraser River sockeye salmon with acute and sometimes large scale mortality, but the hypothesized association between crowding at spawning channels and increased risk of disease have not been definitively proven.

The goal of determining the impact of a specific disease on wild fish productivity is largely unachievable due to the high variability in exposure settings, environmental conditions and biological responses; high level of uncertainty due to infrequent or inaccurate measurements; and large number of unknown interacting factors. Past reviews of the impacts of enhancement hatcheries have suggested a negative effect on wild salmon, but supporting evidence is lacking.

Limitations in research designs and the challenges of studying fish disease under natural settings are significant obstacles to understanding the impacts of disease and to establishing with sufficient precision that free-ranging fish are exposed to pathogens of enhancement facility origin. There is biological and epidemiological plausibility that diseases, under certain environmental conditions, could affect wild fish population dynamics and there is experimental evidence that certain pathogens can cause death, disease and impaired physiological function in individual fish. However, there is insufficient information and understanding in the published literature to establish the proportional contribution of infectious diseases alone or in combinations with other host and environmental stressors to Fraser River sockeye salmon production.

We could not find an evidence-based, non-zero standard to define an acceptable frequency or amount of transfer of pathogens from enhanced fish to wild fish that could be used in a risk assessment.

We know of no legal fish health standard that establishes an acceptable level of fish pathogen risk for enhancement operations except for legislation dealing with the exclusion of foreign or exotic disease from Canada. A single standard for acceptable exposure cannot currently be defined as the capacity for individuals and populations to cope with a disease is context specific and would be affected by things such as the pathogen, host species, life stage, habitat quality, water temperature and many other factors.

A health standard of no infectious or parasitic microorganisms or diseases in Fraser River sockeye salmon is unattainable because; infection and disease are normal in wild fish populations and a variety of infectious agents are ubiquitous in aquatic environments or common in cultivated or wild fishes.

Disease data from enhanced salmon in British Columbia did not allow for the construction of a complete hazards list for use in a risk assessment or for estimating the frequency and abundance of infection in enhanced fish populations. The nature of the diagnostic systems restricted our knowledge to the more common infections that are capable of causing overt clinical signs in a sub-set of the population as well as to a small number of pathogens in returning broodstock. The data did reveal that a variety of pathogenic hazards exist in enhanced salmon in British Columbia; none of which were unexpected or exclusive to enhanced salmonids. Enhanced salmon in the province do harbour viruses, bacteria and parasites capable of causing severe clinical disease in infected fish under experimental or culture conditions. We were able to document cases where fish with known or suspected infections were released from salmonid enhancement operations into fish bearing waters. In no case were we provided evidence that post-release monitoring of surrounding wild fish was undertaken. There was no evidence found to assess if these releases did or did not result in exposure or impacts on other fish.

For a risk to exist, an individual or population must be exposed to a hazard. Generally, there are three variables that affect the probability of exposure to an infectious hazard; (1) the geographic distribution of the escaped pathogen; (2) the abundance of the pathogen in the receiving environment and; (3) the frequency with which the fish are involved in an exposure that results in transmission of the pathogen. As there are no data for these 3 variables, exposure assessment was not possible. Fraser River sockeye salmon reared in enhancement hatcheries or spawning channels have the most plausible route of exposure to diseases present in hatcheries or spawning channels. Exposure of Fraser River sockeye salmon outside of enhancement facilities to infectious enhanced salmonids has not been monitored. Biologically plausible routes of exposure exist, but none have been measured.

Federal and provincial salmonid enhancement programs do many things to reduce the risk of disease to wild fish by managing disease abundance in their facilities. Diagnostic services provided to salmonid enhancement facilities allow for identification and treatment of infections; movement restrictions limit the translocation of pathogens; and broodstock screening allows for the reduction of certain vertically transmitted diseases. The operating procedures for risk reduction at the enhancement hatcheries and spawning channels focus on two elements; reducing the prevalence of disease within groups of fish to be released from salmonid enhancement operations; and pre-release assessments of groups of fish with previous disease or infection histories. There is no routine assessment of the infection status of groups that are either not showing clinical signs and/or are not progeny of fish with vertically transmitted infections or at risk of having known vertically transmitted infections. A population-wide fish disease surveillance program does not exist.

All major DFO and FFSBC hatcheries have Fish Health Management Plans that are intended to support the goal of not releasing fish with known infections. The Plans have not been audited. There are inadequate resources to allow fish health professionals to visit enhancement facilities to help adapt Fish Health Management Plans to local conditions, audit their practices and develop ongoing disease prevention programs. The Plans vary in detail and in their adaptation to local conditions. There is little opportunity to apply Fish Health Management Plans to spawning channels and it did not appear that the Community Economic Development Program or Public Involvement Project hatcheries have comprehensive fish health management plans. The amount of risk reduction to Fraser River sockeye salmon realized by these efforts has not been investigated but it is reasonable to assume that reduction of infection in salmonid enhancement facilities will reduce the level of exposure for wild salmonids from this potential source.

The current system for reporting and recording fish health in salmonid enhancement facilities or for documenting the suitability of fish for release, lack consistency, quality and accessibility thus limiting external review and public assurance.

A risk assessment could currently only conclude that the risk of transfer of infectious agents is biologically and epidemiologically plausible. There is a suite of pathogenic hazards present in fish in enhancement facilities and evidence that pathogens have viable means to escape spawning channels and hatcheries via fish or water releases; thus entering fish bearing waters potentially occupied by Fraser River sockeye salmon. The probability and consequence of an exposure to released infectious agents on Fraser River sockeye salmon cannot be specified using the current scope of scientific knowledge.

We could not determine if diseases present in salmon enhancement facilities (hatcheries or spawning channels) present potential for serious or irreversible harms to Fraser River sockeye salmon. Limitations in scientific understanding, lack of ongoing surveillance of wild and cultured fishes, and deficits in data provided to us were the primary reasons for our inability to make specific cause-effect conclusions and to qualitatively or quantitatively assess risk.

We provide management and research recommendations that may improve the effectiveness of fish health programs in risk management as well as increase oversight of fish diseases to provide public assurances that undue disease risks are not arising from salmonid enhancement facilities. Management recommendations fall into 3 themes: (1) shifting the emphasis and organization of fish programs from diagnostic services for disease treatment to comprehensive health management for health promotion and disease prevention; (2) promoting a systems perspective that allows for fish disease and population data to be integrated and (3) improving auditing and oversight. Research recommendations are intended to support these management objectives by developing evidence for strategic management decisions and to create new understandings to better characterize and monitor disease interactions between cultured and free-ranging fish.

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# TR2 – Contaminants

MacDonald, D., J. Sinclair, M. Crawford, H. Prencipe and M. Meneghetti. 2011. Potential effects of contaminants on Fraser River sockeye salmon. MacDonald Environmental Sciences Ltd. Cohen Commission Tech. Rept. 2: 164p & appendices. Vancouver, B.C. www.cohencommission.ca

## Executive Summary

### *ES1.0 Introduction*

This study was conducted to develop an Inventory of Aquatic Contaminants for the Fraser River Basin and to evaluate the potential effects of those contaminants on Fraser River sockeye salmon. A risk-based approach was used to determine if the contaminants that have been released into freshwater ecosystems within the watershed have caused or substantially contributed to the decline of Fraser River sockeye salmon over the past 20 years or to the poor returns of sockeye salmon that were observed in 2009. Implementation of this approach involved the following steps:

- Developing an Inventory of Aquatic Contaminants (which are also referred to as chemicals of potential concern or COPCs);
- Conducting a preliminary evaluation of chemicals of potential concern to identify the substances that pose potential risks to sockeye salmon (which are termed contaminants of concern or COCs) and, hence, required further evaluation;
- Conducting a detailed evaluation of the contaminants of concern to determine if their concentrations in surface water, sediment, or fish tissues were sufficient to adversely affect the survival, growth, or reproduction of sockeye salmon;
- Conducting a qualitative evaluation of the potential effects on sockeye salmon associated with exposure to endocrine disrupting chemicals and other contaminants of emerging concern; and,
- Identifying uncertainties in the assessment and key data gaps.

### *ES1.1 Inventory of Aquatic Contaminants*

To support the development of an Inventory of Aquatic Contaminants, the available information on land and water uses within the Fraser River Basin was compiled. In addition, the substances that have been, or may have been, released to aquatic ecosystems in conjunction with these land and water uses were identified. Subsequent integration of this information facilitated identification of over 200 substances that may have been released into aquatic ecosystems within the study area. All of the substances included in the Inventory of Aquatic Contaminants were considered to be chemicals of potential concern.

### *ES1.2 Preliminary Evaluation of Chemicals of Potential Concern*

In the preliminary evaluation, the maximum concentrations of chemicals of potential concern in water and sediment were compared to toxicity screening values, which were intended to represent no observed effect levels for aquatic organisms. The results of the preliminary assessment indicated that a number of chemicals of potential concern exceeded the toxicity screening values in one or more environmental samples and, hence were identified as contaminants of concern. The water-borne contaminants of concern included conventional variables (total suspended solids, turbidity, pH), nutrients (nitrate, nitrite, phosphorus), major ions (chloride, fluoride, sulfate), metals (aluminum, arsenic, boron, cadmium, chromium, cobalt, copper, iron, lead, mercury, nickel, selenium, silver); and, phenols. The sediment-associated contaminants of concern included metals (arsenic, cadmium, chromium, copper, iron, lead, and nickel), phthalates [bis(2-ethylhexyl)phthalate] and, polycyclic aromatic hydrocarbons [acenaphthalene, benz(a)anthracene, and dibenz(a,h)anthracene]. These substances were retained for further evaluation in the detailed assessment of risks to sockeye salmon in the Fraser River Basin.

Many other substances in the Inventory of Aquatic Contaminants have the potential to adversely affect Fraser River sockeye salmon, including organometals, cyanides, monoaromatic hydrocarbons, chlorinated and non-chlorinated phenolic compounds, resin and fatty acids, polybrominated diphenyl ethers, hormone mimicking substances, pharmaceuticals, personal care products, wood preservation chemicals and nanoparticles. However, insufficient information was available to evaluate the hazards posed to sockeye salmon in the Fraser River associated with exposure to these contaminants. Accordingly, these substances were identified as uncertain contaminants of concern and addressed in the qualitative evaluation of endocrine disrupting chemicals and contaminants of emerging concern.

### *ES1.3 Detailed Evaluation of the Potential Effects of Contaminants of Concern*

In the next step of the process, the list of contaminants of concern was refined to eliminate those substances that were unlikely to be risk drivers. Then, a detailed evaluation was conducted to determine if the concentrations of any of the contaminants of concern in surface water, sediment, or fish tissues in the Fraser River or its tributaries were sufficient to adversely affect the survival, growth, or reproduction of sockeye salmon. In this evaluation, more realistic estimates of exposure to contaminants of concern (i.e., $95^{th}$ percentile concentrations) were compared to toxicity reference values (toxicity thresholds), which represent lowest observed effect levels of contaminants of concern for sockeye salmon or other salmonid fishes. The results of this assessment indicated that exposure to contaminated surface water and sediment or accumulation of contaminants in fish tissues pose potential hazards to sockeye salmon utilizing spawning, rearing, or migration habitats within the Fraser River Basin. The substances that occurred in water at concentrations sufficient to adversely affect the survival, growth, or reproduction of Fraser River sockeye salmon included total suspended solids, six metals (aluminum, chromium, copper, iron, mercury and silver), and phenols. However, analyses of water quality index scores and measures of productivity (i.e., Ricker residuals) suggested that declines in sockeye salmon abundance over the past 20 years or in 2009 were not likely caused by the substances considered in the water quality index. While the results of the sediment risk assessment showed that the concentrations of iron and nickel were elevated at various locations within the basin, exposure to these contaminants of concern in sediment is unlikely to be sufficient to adversely affect the survival, growth or reproduction of sockeye salmon. Nevertheless, the concentrations of selenium, and 2,3,7,8-tetrachlorodibenzo-*p*-dioxin toxic equivalents, occurred or are likely to have occurred in salmon eggs at concentrations sufficient to adversely affect sockeye salmon reproduction.

### *ES1.4 Evaluation of Effects of Endocrine Disrupting Chemicals and Contaminants of Emerging Concern*

Due to limitations on the availability of exposure data and/or toxicity thresholds, a qualitative evaluation was conducted to assess the potential effects on Fraser River sockeye salmon associated with exposure to endocrine disruption chemicals and contaminants of emerging concern. The results of this eco-epidemiological evaluation indicate that it is unlikely that exposure to these contaminants is the sole cause of the observed patterns in sockeye salmon abundance, either over the past 20 years or in 2009. However, contaminant exposures cannot be ruled out as a potential contributing factor for responses of Fraser River sockeye salmon over the past two decades and/or for the low returns of sockeye salmon to the river in 2009.

### *ES1.5 Uncertainty and Data Gap Analysis*

There are a number of sources of uncertainty in assessments of risk to the sockeye salmon associated with exposure to contaminants in the Fraser River Basin, including uncertainties in the conceptual model, uncertainties in the effects assessment, and uncertainties in the exposure assessment. The results of the uncertainty analysis indicated that there are a number of key data gaps that substantively affect the confidence that can be placed in the evaluation of the potential effects of contaminants on Fraser River sockeye salmon. The most important of these uncertainties is the general absence of data that describe the nature and extent (both spatial and temporal) of contamination by total suspended solids, major ions, nutrients, metals, and other chemicals of potential concern in spawning and rearing habitats within the watershed. In addition, data on the concentrations of endocrine disrupting chemicals and other contaminants of emerging concern are generally lacking throughout the study area.

### *ES1.6 Conclusions and Recommendations*

This study was conducted to determine if aquatic contaminants caused or substantially contributed to declines in the abundance of sockeye salmon over the past two decades and/or the low returns of sockeye salmon to the Fraser River in 2009. While limitations on the available data make it difficult to answer this question conclusively, the results of this study suggest that:

- Exposure to contaminants in surface water, sediments, or fish tissues is not the primary factor influencing the productivity or abundance of Fraser River sockeye salmon over the past 20 years or in 2009.
- There is a strong possibility that exposure to contaminants of concern, endocrine disrupting chemicals, and/or contaminants of emerging concern has contributed to the decline of sockeye salmon abundance in the Fraser River Basin over the past 20 years.

This evaluation of the effects of contaminants on Fraser River sockeye salmon was constrained by a number of key data gaps. As insufficient data were available to fully assess the role of contaminant exposures in the declines of sockeye salmon over the past two decades or the low returns of sockeye salmon to the Fraser River in 2009, a number of recommendations are offered to enhance the probability that the data and information required to conduct a more comprehensive evaluation are available in the future.

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# TR3 – Freshwater Ecology

Nelitz, M., M. Porter, E. Parkinson, K. Wieckowski, D. Marmorek, K. Bryan, A. Hall and D. Abraham. 2011. Evaluating the status of Fraser River sockeye salmon and role of freshwater ecology in their decline. ESSA Technologies Ltd. Cohen Commission Tech. Rept. 3: 222p. Vancouver, B.C. www.cohencommission.ca

## Executive Summary

Although changes in marine conditions often play a key role in driving salmon population dynamics, freshwater habitats are also important in how sockeye salmon express their resilience. Watershed processes provide a high level of variability in conditions, which helps salmon express diverse life history tactics, metapopulation structure, and genetic / phenotypic diversity. In Bristol Bay, Alaska the diversity of sockeye salmon has been related to maintaining fish population stability across the region and found to benefit ecosystems (by stabilizing inputs to terrestrial nutrient supplies and food webs), and human communities (by stabilizing catch and reducing the number of fisheries closures).

Fraser River sockeye salmon and its component stocks demonstrate considerable life history diversity. Stocks vary migration according to four adult run timing groups, demonstrate 4 year cycles of abundance, and spend different lengths of time in freshwater / at sea. The abundance of Fraser River sockeye salmon is also dominated by a few large stocks, which co-migrate with many smaller stocks which are often less resilient to environmental stressors. Given this structure in abundance, it is often difficult to maximize both harvest and population diversity. Weak stocks that are the target of conservation are often harvested and become threatened when they co-migrate with the strong stocks that are the target of the fishery. Thus, despite their inherent resilience this co-migration illustrates how sockeye salmon are vulnerable.

This report is focused on evaluating changes in freshwater ecology and its role in recent sockeye salmon declines for the Cohen Commission. This work includes examining the status of sockeye salmon populations and habitats, as well as the impacts of human activities on freshwater habitats (i.e., logging, hydroelectricity, urbanization, agriculture, and mining). Changes in freshwater ecology due to natural and human forces are hypothesized as having three pathways of effects. These pathways include effects on the: (1) quantity and quality of spawning habitats; (2) productivity of nursery lakes for rearing; and/or (3) habitat conditions associated with migration of smolts / adults.

To assess the current status of Fraser River sockeye salmon populations, we have been charged with three tasks: (1) summarizing existing delineations of population diversity into Conservation Units (CUs); (2) evaluating Fisheries and Oceans Canada's (DFO) methods for assessing conservation status; and (3) determining the status of Fraser River sockeye salmon CUs. Delineations of Conservation Units were necessary to quantify habitat conditions, analyze landscape level disturbances, and evaluate the relationship between changes in freshwater ecology and changes in productivity. Strategy 1 of the Wild Salmon Policy includes a framework for delineating salmon populations according to three major axes: ecology, life history, and molecular genetics. Using DFO's delineations, we identified 36 Conservation Units (30 lake and 6 river type CUs) within the Fraser River basin. We use four criteria to evaluate alternative methods for assessing conservation status of these CUs: (1) ecological criteria and indicators; (2) approach for setting benchmarks; (3) data needs and availability; and (4) overall feasibility of implementation. No method is ideal across these criteria; DFO's method and two alternatives have different strengths and weaknesses. An alternative to DFO's method was used to summarize conservation status for 25 of 36 CUs; others were not assessed due to insufficient data. Based on the results of the best available assessments, we found that 17 of 36 Conservation Units have a poor population status and are distributed across all timing groups (<u>Early Stuart</u> – Stuart, Takla / Trembleur; <u>Early Summer</u> – Nahatlatch, Anderson, Francois, Taseko, Bowron, Shuswap Complex; <u>Summer</u> –

Stuart, Takla / Trembleur; Late – Cultus, Harrison u/s, Lillooet, Seton, Kamloops; River – Widgeon). The status of 11 CUs is unknown.

The majority of Fraser River sockeye salmon populations rear in large lakes for their first year of life. Given our review of available data, measures of freshwater habitat condition are generally not available across many CUs even though Strategy 2 of the Wild Salmon Policy is charged with developing relevant habitat indicators. Given this gap, we developed direct and surrogate landscape level indicators of the quantity and quality of migration, spawning, and rearing habitats for each sockeye salmon lake-type CU using: (1) mapped habitat features we extracted or derived from readily available GIS data, and (2) lake productivity datasets provided to us by DFO. These indicators included: total spawn extent (m), ratio of lake influence to total spawning extent, nursery lake area (ha), nursery lake productivity (estimated smolts / ha), migration distance (km), average summer air temperature across adult migration (°C), and average spring air temperature at the nursery lake (°C). Data were not available to describe basic habitat conditions for the river-type CUs.

Given a general lack of information that could be used to reliably define dynamic changes in condition across sockeye salmon spawning, rearing, and migratory habitats we defined habitat "status" as a combination of the: (1) intrinsic habitat vulnerability and (2) intensity of human stressors on those habitats. We used three independent and static indicators to define intrinsic habitat vulnerability for each sockeye salmon freshwater life-stage. These independent indicators are: (1) migration distance; (2) total area of nursery lakes; and (3) ratio of lake influence to total spawning extent. The placement of an individual CU across these dimensions was used to illustrate its vulnerability to watershed disturbances relative to other CUs in the Fraser River basin. The CUs with the greatest relative habitat vulnerability include (i.e., have long migration distances, a low ratio of lake influence to total spawning extent, and a small to moderate nursery lake area): Early Stuart – Stuart, Takla / Trembleur; Early Summer – Bowron, Fraser; and Summer – Mckinley.

To understand the intensity of human stressors on habitats and assess the potential role of freshwater stressors in recent declines of sockeye salmon we compiled and analyzed the best available data describing six categories of human activities which have the potential to affect sockeye salmon: forestry (e.g., forest harvesting activities, Mountain Pine Beetle disturbance, and log storage), mining, hydroelectricity (large scale and run of river power projects), urbanization upstream of Hope, agriculture, and water use. Next, we developed a spatial layer that represented "zones of influence" on core habitats for migration, spawning, and rearing across each Conservation Unit using DFO's sockeye salmon habitat data (e.g., nursery lakes, spawning locations, monitoring sites, and escapement data). We then intersected the stressor layers with our "zones of influence" layer to summarize the intensity of human stresses on each Conservation Unit.

To assess the intensity, spatial distribution, and temporal patterns of forestry related stressors, we examined the level of forest harvesting over time, density of roads and road-stream crossings, and accumulated level of disturbance due to Mountain Pine Beetle (MPB) across sockeye salmon watersheds. We also examined the best available site specific information to qualitatively assess the impacts of log storage in the lower Fraser River. Our findings indicate that the level of forest harvesting within the last 15 years is less than 10% of the area of sockeye salmon watersheds. Drainage areas upstream of lake inlet spawning, tributary spawning, and nursery lakes tend to be more heavily disturbed than the riparian zones adjacent to spawning downstream of lakes or along migration corridors. There is considerable variation in road development across Conservation Units, which tends to be concentrated in areas adjacent to spawning zones downstream of lakes and along migration corridors. The level of MPB disturbance has increased dramatically since 2003, with the level of disturbance being most dramatic in interior Fraser CUs as opposed to coastal CUs whose watersheds are largely absent of ponderosa and lodgepole pine. The intensity of Mountain Pine Beetle disturbance has been very high; up to 90% of the area in some sockeye salmon watersheds. Variation in the intensity of log storage appears to be larger across reaches than across seasons or years within reaches of the lower Fraser River. Based on past studies, the historic intensity of log storage has not appeared to have significant on juvenile salmon.

To assess the effects of mining, we examined the spatial distribution, number, and types of mines occupying sockeye salmon watersheds in the Fraser River basin (e.g., placer mining, gravel mining, industrial mineral production, metal mining, oil and gas production, coal mining, and exploration related to these production activities). The occurrence of mining activity in the watersheds of spawning streams varies substantially across sockeye salmon CUs. Placer mining is the dominant mining activity and appears to have the highest potential to reduce early freshwater survival. However, the data suggest the impacts of mining on sockeye salmon are likely small and difficult to detect because the contrasts among stocks and strength of the effect relative to other factors is low.

To assess the effects of hydroelectricity, we reviewed scientific studies describing the effects of the Bridge / Seton River power project and Alcan's Kemano Project, as well as the spatial distribution of small scale hydroelectric operations across sockeye salmon watersheds. The Bridge / Seton River power project can affect migrations of smolts and adults on the Seton Rivers, but adverse effects have been largely mitigated by changes in flow diversions and operations of the powerhouse. Likewise, the Kemano Project affects water temperature on the lower Nechako River, but a temperature compliance program has been implemented to ensure that water temperatures remain suitable for adult passage. Our findings indicate that the history of interaction between IPPs and sockeye salmon is very short and limited in number and spatial extent.

To assess the effects of urbanization upstream of Hope, we summarized the spatial extent of urbanization and human population across the Fraser River basin. Urban environments have a relatively small footprint within watersheds and riparian zones that influence sockeye salmon, though urban footprints have the most intense interaction with sockeye salmon migration corridors. The extent of urban development along migration corridors is further illustrated by the human population data which shows a similar pattern of concentration.

To assess the effects of agricultural activities (beyond impacts on water quality), we reviewed the spatial distribution of agricultural lands. Compared to other land uses, agriculture has a relatively small footprint within watersheds and riparian zones that influence sockeye salmon spawning and rearing habitats. Agriculture does, however, have a greater interaction with migration corridors.

To assess the effects of water use, we calculated the total allocation of water, density of water allocation restrictions, and distribution of water licenses across uses for all sockeye salmon water sheds. Not surprisingly, high water demand is associated with the greatest concentrations of people across the Fraser River basin. Migration corridors appear to have the greatest allocation of water through licensing and the greatest density of water allocation restrictions, largely allocated to the agricultural sector. The CUs of the Lower Mainland have the highest water allocations.

Given a lack of experimental design in the way population, habitat, and stressor data have been collected, our ability to test for cause and effect relationships between the freshwater environment and Fraser sockeye salmon declines was limited. As a result, we were only able to use a limited set of quantitative techniques and data summaries to assess the role of freshwater influences.

We used three analytical approaches to gain insights into possible hypotheses about the role of freshwater influences on Conservation Units. First, we developed a series of cumulative stressor tables which: (1) aligned the hypothesized stressors to the relevant habitat types and Conservation Units, (2) scored the relative intensity of and trend in disturbance, and (3) summarized the cumulative level of stress on a Conservation Unit. Second, we plotted the measures of cumulative stress against the indicators of habitat vulnerability to generate bivariate plots for each habitat type and Conservation Unit (i.e., a summary of habitat status). Lastly, we developed a "dashboard" summary of the all data available to describe population status, habitat vulnerability, and freshwater stressors specific to each lake Conservation Units across the Fraser River basin.

We undertook three additional analyses to assess whether freshwater habitat conditions have contributed to the recent declines in Fraser River sockeye salmon. First, we summarized key findings from recent research examining alternative hypotheses for the declines in Fraser sockeye salmon. This understanding was important for prioritizing our analytical efforts and developing testable hypotheses that are consistent with these other studies. Second, we analyzed the habitat and stressor data to test whether they could explain declines in productivity. Lastly, for those habitat and stressor variables for which we had time series data (i.e., forest harvesting, Mountain Pine Beetle disturbance, summer air temperatures across adult migration, and spring air temperatures at nursery lakes) we examined correlations with total salmon and juvenile productivity indices.

Due to our inability to rigorously test for cause effect relationships on survival at key life stages we used a "weight of evidence" to reach a conclusion about significance of the role of freshwater influences, drawing upon the data and analyses conducted through this effort. Using this approach we believe that recent declines in Fraser River sockeye salmon are unlikely to be the result of changes in the freshwater environment. An important piece of evidence in reaching this conclusion is that juvenile survival has remained relatively stable across CUs where data are available, even though there is substantial variation in stressor intensity across CUs.

Despite our belief that recent declines are not likely to be directly linked to deterioration in habitat conditions, the protection of freshwater habitats remains important to the conservation of Fraser River sockeye salmon because they contribute to their overall diversity and resilience. Given this context, our recommendations include:

**To improve our understanding about survival at critical freshwater life stages**, scientists need better estimates of juvenile abundance, overwinter survival, and mortality during smolt outmigration.

**To improve our understanding about population status across Conservation Units,** scientists need more information about the abundance and distribution of small lake and all river CUs.

**To improve our understanding about habitat status across Conservation Units,** scientists need information on habitats monitored in a consistent manner on a regular basis across a larger number of rivers and nursery lakes.

**To improve our understanding about the population level effects of stressors on freshwater habitats,** scientists need more precise estimates of the biological consequences of disturbance as a function of increasing stress.

**To improve transparency in the science and related decision making** scientists, managers, and the public need information that is more accessible and collected in a way that is more integrated across federal and provincial agencies.

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# TR4 – Marine Ecology

McKinnell, S.M., E. Curchitser, C. Groot, M. Kaeriyama and K.W. Myers. 2011. The decline of Fraser River sockeye salmon *Oncorhynchus nerka* (Steller, 1743) in relation to marine ecology. PICES Advisory Report. Cohen Commission Tech. Rept. 4: 195p. Vancouver, B.C. www.cohencommission.ca

## Executive Summary:

### *Project 4: The Decline of Fraser River Sockeye Salmon Oncorhynchus nerka (Steller, 1743) in Relation to Marine Ecology*

A major objective that was achieved in this report was to assemble, within an eight week period, as comprehensive a summary as was possible of what is known about Fraser River sockeye salmon (*Oncorhynchus nerka*) in the ocean. While much of this effort involved summarizing information published in data/technical reports and the primary literature, where necessary, original data have been re-examined and new analyses conducted to fulfill the terms of the Statement of Work. The compilation provides a background of knowledge against which to judge what can be known regarding the two major questions posed by the Cohen Commission to PICES:

> *Can the decline in Fraser sockeye in 2009 be explained by the conditions the fish experienced in the marine environment?*
>
> *Is there any evidence for declines in marine productivity or changes in Fraser sockeye distribution that can be associated with the 15 year gradual decrease in Fraser sockeye productivity?*

Most of the Fraser River sockeye salmon that did not survive to produce a fishery in 2009 entered salt water in 2007. The major challenge answering the first question was recognition that the ocean is shared by sockeye salmon from many areas of the Northeast Pacific, some which returned in 2009 in above average abundance. As a result, any hypothesis for the cause of low returns of Fraser River sockeye salmon from an oceanic cause must consider a mixture of contrasting observations:

- Double the average returns of Columbia River sockeye salmon in 2009 (2007 ocean entry year);
- Better than expected returns of Barkley Sound (West coast of Vancouver Island) sockeye salmon in 2009 (2007 ocean entry year);
- Very low returns of age-1.x ecotypes in most populations from the Fraser River that entered the ocean in 2007;
- Record high returns to the Harrison River (lower Fraser R. watershed) in 2010 from underyearlings that reared in the Strait of Georgia in 2007. This rather unique ecotype spends an extra year at sea, so its abundance was not known until 2010;
- Typical survival of acoustically-tagged hatchery-reared sockeye salmon from Cultus Lake northward through the Strait of Georgia in 2007.

Assessing the longer period of decline has its own challenges because impressions of the nature of the decline of Fraser River sockeye salmon are somewhat sensitive to how the production data are summarized. Our approach was to capitalize on the diversity and abundance of many reproductively isolated sockeye salmon populations, the existence of different ecotypes within each population (different ocean entry years by individuals of the same generation), and the lengthy time series of production data for many of these, to provide informative comparisons among populations and informative summary statistics across populations and ecotypes.

## Long-term decline

1. What was described in the key question as a 15-year gradual decline in productivity bears a stronger resemblance to a shift to lower productivity in 12 of 16 stocks, rather than a gradual decline. In some stocks (e.g. Raft River), the data cannot distinguish between these two alternatives. The "best" division of a time series of median total survival of age-1.x ecotypes, into periods of high then low productivity is the 1992 ocean entry year (1990 brood year for age-1.x).

2. The 1992 ocean entry year coincides with an abrupt decline in marine survival of Rivers Inlet sockeye salmon. Markedly diminished returns to Long Lake (Smith Inlet) probably[1] began with the 1992 smolt year. These stocks share a common migration route through Queen Charlotte Strait/Sound.

3. Returns of maturing sockeye salmon to Barkley Sound declined in 1994 (1992 smolt year) and remained relatively low until the 1998/99 la Niña. A similar period of decline was observed in sockeye salmon returns to the Columbia River in the same year. West coast sockeye salmon production remained low from the 1992 ocean entry year through the 1997/98 el Niño, but then experienced an increase in survival that was not reflected in the Fraser River stocks. The difference could be related to variable spatial scales of the oceanic forces that are associated with variable survival among stocks.

4. The winter of 1991/92 was the onset of what has been called a persistent el Niño. The same year was accompanied by relatively dramatic changes in many characteristics of the West coast ocean ecosystem that included the return of sardines to the West coast of British Columbia after more than a 45 year absence. The reappearance of sardines is not considered as having a direct effect on Fraser River sockeye salmon survival, but is reported here as a potential proxy for a persistent oceanographic change that is not fully understood. British Columbia lies in the transition zone between the Alaska Current to the north and the California Current to the south, whose locations and intensities are variable.

5. Apart from the el Niño of that year, 1992 is not recognized especially as a year of significant large-scale climatic change in the North Pacific; that occurred in 1989. How or if the two phenomena are connected is not known at this time.

6. Productivity of the age-2.x ecotypes from the Fraser River did not change in 1992. This may be because larger postsmolts have greater energy reserves for the migration northward to better feeding and growth in Alaska.

7. Not all sockeye salmon that migrate from the Strait of Georgia exhibited a decline in 1992. The endangered Sakinaw Lake population from the mainland side of the Strait of Georgia (northwest of Vancouver) declined in 1987 rather than 1992; perhaps for other reasons. It may be related to greater use of Juan de Fuca Strait as their emigration route;

8. Three years of very low returns of sockeye salmon to the Fraser River and curtailed fisheries from 2007 to 2009 can be explained by a sequence of independent events, two of them related to climate:

9. 2007 returns: Low marine survival of the 2005 ocean entry year of sockeye salmon and coho salmon was expected (and was reflected in experimental forecasts). Canadian and U.S. oceanic and ecological indicators were consistent in recognizing 2005 as a warm and unproductive year which would likely be detrimental to salmon survival;

10. 2008 returns: Median recruits per spawner across stocks were typical of the post-1992 era. The low return was most likely a consequence of one of the lowest numbers of spawners (in 2004) in recent years.

1 Annual returns to the Docee fence include two brood years so the estimate of the decline is ±1 year.

Spawner abundance is the primary determinant of future returns in most Fraser River sockeye salmon populations.

11. 2009 returns: The 2006/07 el Niño and a very anomalous spring/summer climate in 2007 conspired to generate a very atypical coastal ocean in 2007, one that could have been detrimental to Fraser River sockeye salmon growth and survival. The details are described more fully in the following section.

## 2009 returns

Biologists rarely observe death by natural causes of juvenile Fraser River sockeye salmon at sea. As a consequence, the cause and location of mortality must be inferred from general ecological/physiological principles that have been established by the scientific community. An example of one of these principles is that faster growth leads to better survival. It appears to hold across the salmonids and other families of fishes. No one saw the death of large numbers of juvenile Fraser River sockeye salmon in 2007, nor on the high seas from 2008–2009 so the best that can be done to understand the extremely low returns in 2009 is to identify the times and locations where there were extreme conditions that could potentially have caused the extremely low survival of one component of the Fraser River stocks. So the general hypothesis of this study is that there were no extremes [scientific hypotheses are disproved rather than proven] in ocean physics, chemistry, or biology that could have been responsible for extreme mortality of Fraser River sockeye salmon, but not elsewhere (Columbia River or Barkley Sound). At least one scenario suggests that this hypothesis can be rejected.

1. The low return of sockeye salmon to the Fraser River in 2009 was due mostly to high mortality of age-1.x ecotypes of the cohort that was spawned in 2005 and migrated to sea in 2007. When all returns of the 2005 brood year are eventually counted in 2010 and 2011, the lowest median total survival of Fraser River sockeye salmon in contemporary records is the 2003 brood year, not the 2005 brood year. While returns of the 2005 brood year in 2009 were very low, they are noteworthy mostly for their remarkable departure from the official equi-probable[2] forecast, with one exception: Chilko Lake.

2. Since the 1960s, infrequent years of very high numbers of smolts emigrating from Chilko Lake, such as occurred in 2007 and again in 2008, have routinely failed to reach even average postsmolt survival, suggesting that some fraction of the incremental mortality of this stock in the ocean is related to their own abundance. At 77 million, the emigration in 2007 was twice the previously observed maximum. The 2009 return year will be the lowest recorded age-1.x postsmolt survival for this stock.

3. Oceanic conditions with a strong potential to cause incremental sockeye salmon mortality began to develop from the effects of the el Niño of winter of 2006/07. The typical response of North Pacific climate to an el Niño is an intensification of cyclonic atmospheric circulation combined with an eastward shift in the storm tracks. This creates enhanced atmospheric flow from the Southwest that brings warmer, wetter air toward B.C. where it is deposited as snow in the mountain ranges. When winter ended in 2007, the northern and central coast mountains of B.C. had some of the highest snowpacks observed since records began in 1953.

4. The cool spring of 2007 delayed the snow melt. It was followed by rapid warming in late May which was followed by an intense spring storm in early June that brought heavy rain on top of the deep snow. As a consequence of these coincidences, the summer of 2007 featured extreme discharge by Central and North coast rivers. The northern part of the Fraser River drainage was exposed to this phenomenon but it led to high rather than extreme discharge in 2007. The highest weekly discharge in the Fraser River in 2007 ranked 23rd in the record of weekly discharges from records dating back to 1913. Discharges from

2 Equal chance of getting more or less than this number.

the Wannock River into Rivers Inlet (eastern Queen Charlotte Sound) and the Klinaklini River (eastern Queen Charlotte Strait), for example, were the highest values ever recorded for the month of July.

5. A Fisheries and Ocean Canada (DFO) surveys in late June 2007 (and other years) across southern Queen Charlotte Sound, east of Triangle Island, recorded the lowest average surface salinity (five stations) since sampling began in 1998. Closer to the freshwater sources, the Egg Island lighthouse in eastern Queen Charlotte Sound recorded the lowest July/August average salinity on record (since 1970). The extreme freshwater discharge from coastal watersheds created an ocean surface layer in Queen Charlotte Sound that was much fresher than normal. This would have created a very stable water column (resistant to vertical mixing). Enhanced water column stability restricted the volume of water exposed to the overlying atmosphere in summer, and caused the surface ocean to warm more than it would have otherwise. Based on the NOAA (U.S. Government) global database from 1982 to 2010[3], the only appearance of extreme sea surface temperatures in 2007 anywhere in the Gulf of Alaska in any month occurred at three grid points[4] in Queen Charlotte Sound in August.

6. The relatively fresh ocean surface layer was retained within Queen Charlotte Sound by the most extreme southeasterly wind pattern in summer since 1948. Southeasterlies are normally considered as the winter wind regime. From April through July, May was the only month without much stronger than normal southeasterlies.

7. Fraser River sockeye salmon that were obligated to migrate through the Queen Charlotte Strait/Sound region met extreme temperatures[5], and even more extreme salinity/density and wind anomalies.

8. Since 1998, when SeaWiFS satellite ocean colour monitoring began, marine survival of Chilko Lake sockeye salmon has been highly correlated with the date of onset of biological production in Queen Charlotte Strait/Sound. The spring bloom in 2007 was the latest in the in record. No doubt the southeasterly wind regime in April contributed to the very late spring bloom in the Sound in 2007. The coastal migration of postsmolts from southern spawning habitats to northern feeding habitats (Southeast Alaska) requires sufficient energy for the migration. Energy for migration is a function of energy density leaving the Fraser River plus feeding success along the migration route. While the age-1.x postsmolts had poor survival in 2007, the larger age-2.x postsmolts, with their greater initial energy reserves, did not experience unusually low survival that year. The delayed spring in Queen Charlotte Strait/Sound, when combined with the incremental metabolic cost of migrating through a warm surface layer, with potentially lower prey densities in the fresher water, could be combined to reduce growth and survival. Sockeye salmon postsmolts caught in DFO summer surveys of Queen Charlotte Sound in 2007 had the smallest mean size since sampling began in the late 1990s. Where the growth reduction occurred along the migration route is unknown.

9. While the Gulf of Alaska was generally cool in 2007, the sockeye salmon migration route northward along the continental shelf region to Yakutat, Alaska had mean sea surface temperatures in August 2007 that were the second warmest since 1982, and feature the highest increase above spring sea surface temperatures since 1982, perhaps because the effect of the discharge anomalies was not restricted to Queen Charlotte Strait/Sound.

10. The extreme hydrographic and wind events that occurred in Queen Charlotte Sound/Strait during the summer of 2007 did not have equivalent extremes in the Strait of Georgia, nor on the West coast of Vancouver Island or the U.S. mainland. So, if the extreme mortality of age-1.x Fraser River sockeye

3 The satellite remote sensing era.

4 Average monthly values are computed on a 1° ´ 1 ° lat./long. grid.

5 Greater than any SST measurements recorded in that month from 1982–2010.

salmon from the 2007 ocean entry year was caused by an equivalent oceanic extreme, the more likely location is Queen Charlotte Strait/Sound region where extremes in physics and biology were evident in 2007.

11. Fraser River sockeye salmon underyearlings (age-0.x) were found in high abundance in DFO surveys of the Strait of Georgia in September of 2007. These ecotypes returned in 2009/10 in unprecedented numbers to the Harrison River. If the Strait of Georgia was the sight of enhanced mortality in 2007, the unknown force(s) must have:

    a. killed most age-1.x ecotypes in May and June,
    b. allowed age-2.x ecotypes (Chilko) to have average marine survival,
    c. allowed age-0.x ecotypes to survive in record numbers, and
    d. allowed acoustically tagged hatchery-reared smolts (Cultus) to survive through the Strait of Georgia in 2007, as in other years,

…without observing extreme physical, chemical, or biological anomalies in the Strait of Georgia in 2007 that can be linked to sockeye salmon survival. Herring recruitment was observed to be low in the Strait of Georgia in 2007, but the lack of a long term association between herring and Fraser River sockeye salmon mortality suggests a coincidence. The harmful algae, *Heterosigma akashiwo*, bloomed in the southern Strait of Georgia for most of the spring and summer of 2007. It has been implicated as the causative agent for high mortality of the age-1.x ecotype but it did not appear to affect the smaller age-0.x ecotype in that returned in record high abundance.

## 2010 returns

1. Age-1.x Fraser River sockeye salmon postsmolts migrated through a relatively warm surface layer of the Strait of Georgia in 2008 (not significantly different from temperatures in 2007) into a coastal ocean that was significantly colder and more Subarctic in character than had been seen on the B.C. coast in decades. Average summer temperatures in 2008 along the coastal migration route from Johnstone Strait northward were up to 3.5°C cooler in 2008 than in 2007. Annual average sea surface temperature in the Gulf of Alaska in 2008 was the coldest observed since the early 1970s.

2. The Mackas Ecosystem Productivity Index for the coastal ocean off the southwest coast of Vancouver Island reached its highest value on the "cool and productive" scale in 2008.

3. The numbers of effective female spawners in 2006 was the sixth highest since 1948, laying the foundation for a good return in 2010. Spawner abundance is the principal determinant of return abundance in Fraser River sockeye salmon.

4. Early signs of the bonanza that became the 2010 sockeye salmon return to the Fraser River were evident one year earlier in the returns of jack sockeye salmon in 2009 but there were few opportunities to notice their atypically high abundance. The appearance of relatively large numbers of jacks in 2009 in the seine test fisheries suggests that the abundance of the dominant cohort that returned in 2010 was determined before July of 2009.

### *Notes*

1 Rensel, J.E., Nicola, H., Tynan, T.M. 2010. Fraser river sockeye salmon marine survival decline and harmful blooms of *Heterosigma akashiwo*. Harmful Algae 10: 98–11

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# TR5A – Salmon Farms and Sockeye Information

Korman, J. 2011. Summary of information for evaluating impacts of salmon farms on survival of Fraser River sockeye salmon. Cohen Commission Tech. Rept. 5A: 65p. Vancouver, B.C. www.cohencommission.ca

## Executive Summary

The main objective of this report is to summarize spatial and temporal trends in salmon farm data the commission compiled for its evaluation of effects of salmon farms. This includes information on sea lice abundance and the frequency of bacterial and viral diseases. This report provides details on the provincial- and industry-based salmon farm monitoring program, and comments on the utility of these data for meeting the objectives of the commission's salmon farm investigation.

The majority of information on pathogens on salmon farms in BC comes from a fish health database maintained by BC Ministry of Agriculture and Lands (BCMAL), and an industry fish health and production database maintained by the BC Salmon Farmers Association (BCSFA). As part of salmon farm license requirements in BC, all farms must monitor their fish and report the status of health at their farms on a monthly basis. These reports are standardized and include monthly information on the number of fish on each farm, total mortality, causes for the mortality, and data from sea lice monitoring. In addition, industry veterinarians and technicians must report all fish health events (FHEs), which are defined as an active disease occurrence or a suspected infectious event on a farm that triggers veterinary involvement and an action such as a request for a laboratory diagnosis or use of prescription medication. BCMAL conducts approximately 100 audits of randomly selected salmon farms each year. These audits are used to inspect records maintained by salmon farmers, obtain samples of fish that may have died of disease from bacterial and viral infections, and to ensure that lice counts are accurate. The monitoring program was initiated in 2002 and was fully operational by the last quarter of 2003.

Approximately 70% of salmon farm production in BC originates from sites located between the mainland and the east coast of Vancouver Island along the main migratory corridor for Fraser River sockeye. An average of about 75,000 tonnes of salmon is produced annually. Over the last five years, an average of 32 million fish per year were held in net pens in BC waters, and 91% of these fish were Atlantic salmon. Approximately 3 million fish died each year on BC salmon farms (12% mortality rate) over this period, with 20% of that mortality comprised of fish classified as 'fresh silvers,' which potentially died of disease. Thus, an annual average of approximately 600,000 farmed salmon potentially died due to disease.

Across all farms between 2003 and 2010, an annual average of 30 fish health events that indicated the presence of high risk diseases to sockeye salmon (Furunculosis, infectious hematopoietic necrosis virus, bacterial kidney disease, and Vibrio), were reported by industry. All these diseases are endemic in wild fish populations in BC. There was a statistically significant declining trend in the number of high risk diseases reported by salmon farms between 2003 and 2010 (slope = -5.81 events/yr, $r^2$=0.62, n=8, p=0.02). The BCMAL audit program recorded an annual average of 12 farm-level high risk disease diagnoses between 2003 and 2009, and there was a declining but non- significant trend in this frequency over time. In the vast majority of audit cases where 'fresh silver' dead fish from salmon farms were tested, bacterial and viral infections were not found and no sign of disease was observed. For example, between 2002 and 2007, BCMAL tested 496 groups of 5-8 'fresh silver' dead fish from randomly selected farms for the presence of six types of viruses or bacteria that are pathogenic to wild salmon, but only two cases of the Infectious Hematopoietic Necrosis Virus (IHN) and two cases of Viral Haemorrhagic Septicaemia (VHS) were found.

An average of 30,000 farmed Atlantic salmon has been examined per year between 2004 and 2010 to quantify lice abundance. Averaged over all seasons and years, 1.7 motile salmon lice were found per fish examined. There has been a modest but significant decline in the number of lice found per fish examined between 2004 and 2010 in spring (slope=-0.32 lice/fish/yr, $r^2$=0.65, n=7, p=0.03) and throughout the year (slope=-0.25 lice/fish/yr, $r^2$=0.78, n=7, p=0.008). An average of 30,000 Atlantic salmon have escaped from salmon farms or juvenile production facilities annually between 1991 and 2008. Only 33 Atlantic salmon escapes have been caught or sighted in the Fraser River drainage, and there is no documented evidence of reproduction in this system.

Inferences from statistical analyses that correlate trends in abundance or survival of Fraser River sockeye with trends in pathogens found in salmon farms will be extremely limited by the number of years of available data. There are only 3-5 years of overlapping Fraser River sockeye survival and salmon farm data available for statistical evaluation. A simulation analysis was used to demonstrated that as sample size declines, there is an increasing probability of obtaining a negative correlation between a trend in salmon farm pathogens and survival of Fraser River sockeye due to chance alone, and not because a true relationship exists. However, the estimated statistical reliability of such false positive relationships are low when sample size is small, often leading to the correct conclusion that that that there is very little evidence for a relationship between variables if one does not exist. Conversely, the simulation showed that tests based on short-time series have very limited power to detect a negative relationship should one exist.

Our ability to make informed statements about the effects of salmon farms on wild salmon in BC will improve over the next decade as the number of years of monitoring data increases. However, correlation alone cannot be used to establish causation. Research on pathogen transmission from farmed to wild salmon, along with meaningful evaluations of the fraction of wild fish infected and the additional mortality associated with infection, are required to determine if cause-and-effect relationships between Fraser River sockeye returns and pathogens on fish farms exist. Financial resources are always limiting, and there are number of other factors that could have caused the decline in Fraser River sockeye productivity, some of which can be improved by management actions. Investment in research on effects of salmon farms and other factors on Fraser River sockeye should be consistent with the scientific consensus on the most likely causes of the decline in productivity and the feasibility of obtaining useful information.

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# TR5B – Salmon Farms and Sockeye Relationships

Connors, B. 2011. Examination of relationships between salmon aquaculture and sockeye salmon population dynamics. Cohen Commission Tech. Rept. 5B: 115p. Vancouver, B.C. www.cohencommission.ca

## Executive Summary

The objective of this technical report is to quantitatively evaluate the relationship between Fraser River sockeye salmon productivity and (a) sea louse (*Lepeophtheirus salmonis* and *Caligus clemensi*) abundance on farmed salmon, (b) disease frequency and occurrence on farmed salmon, (c) mortalities of farmed salmon, and (d) salmon farm production. These analyses are intended to inform the work of other contractors who are preparing comprehensive reports on salmon aquaculture and Fraser River sockeye salmon dynamics for the Cohen Commission.

While the focus of this report is Fraser River sockeye salmon I included data on non-Fraser River populations insofar as they informed the analysis as reference populations for the aquaculture variables considered. The salmon farm data examined in this report was provided by the British Columbia Salmon Farmers Association, the British Columbia Ministry of Agriculture and Lands and the British Columbia Ministry of Environment and was compiled by Korman (2011). Because it is well established that oceanographic conditions can influence sockeye survival I attempted to account for their influence during early marine life when examining relationships between aquaculture and sockeye dynamics. Specifically, I calculated average sea surface temperature (SST) anomalies in the winter preceding the entry of juvenile sockeye into the marine environment, as a measure of oceanographic conditions in early marine life.

The first part of this report relates sockeye survival anomalies to aquaculture variables. Survival anomalies were calculated as population specific residuals of the Ricker or Larkin stock recruit relationship (depending on which better described stock specific density-dependence) fit to spawner abundance and SST in early marine life. I related survival anomalies to (a) sea louse abundance on farmed salmon in the spring / summer of the year of sockeye marine entry, (b) the occurrence of high-risk pathogens on farmed salmon in the year sockeye migrate to sea, (c) the proportion of farmed fish that died of disease or unknown causes ("fresh silvers" in industry jargon) in the spring / summer in the year sockeye migrate to sea, and (d) the number of salmon being raised in salmon farms in the spring / summer in the year sockeye migrate to sea. My analyses found no statistical support for a relationship between these aquaculture variables and sockeye survival anomalies.

The analyses in the first part of this report are based on short time series of aquaculture variables, beginning no earlier than 2003, with low statistical power to detect relationships should they truly exist. One dataset that does span the entire sockeye time series is the production of farmed salmon (in metric tonnes) compiled by Fisheries and Oceans Canada management area since salmon farming began in British Columbia in the early 1980s. In the second part of this report I related sockeye productivity (i.e., the natural logarithm of the ratio of adult returns [recruits] to the number of spawners that produced them) to this complete time series of salmon farm production as well as two other factors that have been independently identified as likely contributors to declines in Fraser River sockeye salmon: (1) oceanographic conditions and (2) competition with pink salmon in the North Pacific Ocean. This approach allowed for a quantitative comparison of the strength of the relationship between sockeye dynamics and salmon farm production while explicitly accounting for the influence of oceanographic conditions and the abundance of pink salmon in the North Pacific as well as interactions among these hypothesized drivers.

The results of this analysis suggest that increasing farmed salmon production, SST and pink salmon abundance increases sockeye salmon mortality. In addition, the influence of aquaculture production

on sockeye mortality was predicted to be greater when SST anomalies are negative (i.e., cool for British Columbia populations) and when pink salmon abundance in the North Pacific Ocean is high. However, there was large uncertainty around these estimated effects, which precludes drawing strong inference from these results.

The relationships described in this report are correlative, do not on their own establish causation and should be re-examined as more information becomes available. An unavoidable consequence of the structure of the data sets I examined is that multiple populations are compared to environmental time series that have identical values for each population. This makes it more likely that some factor external to the analysis is responsible for the patterns observed. A stronger test of the relationship between sockeye salmon dynamics and aquaculture variables would include independent measures of salmon farm variables for each sockeye population. Because finer scale data on aquaculture are not available, the relationships described in this report should be interpreted with caution. Nonetheless, these findings should be considered a first step towards understanding the role open net pen salmon aquaculture may play in influencing Fraser River sockeye salmon population dynamics.

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Review 2:

Review 3:

**Appendix 3. Alternate analyses of pathogen occurrence, farmed salmon production and mortalities**

**Appendix 4. Alternate analyses of farmed salmon production, sea surface temperature and pink salmon abundance**

**Appendix 5. Model diagnostics**

# TR5C – Noakes Salmon Farms Investigation

Noakes, D.J. 2011. Impacts of salmon farms on Fraser River sockeye salmon: results of the Noakes investigation. Cohen Commission Tech. Rept. 5C: 113p. Vancouver, B.C. www.cohencommission.ca

## Executive Summary

A question that has garnered considerable public attention and one that is the focus of this report is whether there is a relationship between farmed salmon production and the returns of Fraser River sockeye salmon. There are many aspects of this complex issue that need to be considered and the terms of reference for this project include four broad areas of interest (Appendix 3). These include 1) issues associated with Atlantic salmon escapees; 2) the effect of farm wastes on benthic and pelagic habitat quality, and disease issues which are partitioned in two 3) sea lice given the extensive public debate around this issue, and 4) other diseases. The last topic that will be addressed, managing and mitigating risks, will make recommendation specific to salmon farming in British Columbia with respect to Fraser River sockeye salmon.

The information contained in this report is from the analysis and synthesis of a) peer-reviewed publications and other documents including the technical reports submitted to this Commission, b) summaries and analysis of data provided to the Commission by industry and government as well as data that are publically available or provided from other sources, and c) interviews with individuals from government, industry, academia, and others (Appendix 1). The disease data provided by industry and government were extremely useful in assessing the potential impacts of salmon farming on Fraser River sockeye salmon and the assessment of the data provided in this report may help clarify some of the misconceptions that exist in the public's mind.

The debate around salmon farming is highly polarized as evidenced by the media attention it has and continues to receive, the number and tone of aquaculture related comments submitted to this Commission, and the very divergent and strongly held views expressed and advanced in some of the publications reviewed in this study. Some of the publications are highly speculative for a variety of reasons including but not limited to the absence of data from government and industry as well as assumptions used by the researchers. In some cases, the publications were deficient to the point that they were neither objective nor scientific and they generally lack credibility.

The industry is highly regulated with very extensive requirements for monitoring, proactive and reactive intervention to resolve disease and waste issues and problems, and mandatory reporting. The volume, quality, and level of detail of the data provided to the Commission by both industry and government is impressive and I believe providing summaries of this information at an appropriate level will help build confidence in this industry with the general public. While some improvements are certainly possible and desirable, the industry generally leads the world in with respect to the management and control of disease and waste at their farm sites both through proactive policies and practices. Overall, the evidence suggests that salmon farms pose no significant threat to Fraser River sockeye salmon and that salmon farming has not contributed to the recent decline in Fraser River sockeye salmon productivity.

## Key Findings

1. There is no significant correlation between farmed salmon production within the main migration path of Fraser River sockeye salmon, the waters between Vancouver Island and the mainland of British Columbia, and the returns of Fraser River sockeye salmon. No causal relationship was found between the two time series and there was no apparent plausible link between farmed salmon production which is governed by condition of licence and the returns of Fraser River sockeye that are a function of the number of fish that spawned 4 years previous as well as a variety of environmental factors.

2. There is no evidence that escaped Atlantic salmon have contributed to the decline in Fraser River sockeye salmon stocks or that escaped Atlantic salmon pose any threat to sockeye or any other salmon stocks in the Fraser River. No juvenile Atlantic salmon have ever been observed in the Fraser River and only 2 adult Atlantic salmon have been found in the Fraser area (Area 29) in the last decade.

3. There is no obvious plausible link or evidence to support a link between the deposit of waste on the sea bed or into the water column and sockeye salmon survival. The impact of waste appears to be limited to the immediate vicinity of the farms (within 30m).

4. There is no significant correlation between the number of sea lice on farmed salmon and the return of Fraser River sockeye salmon. The average number of lice (*Lepeophtheirus salmonis*) on farmed salmon has decreased from approximately 3 lice/fish in 2004 to between 1.0 lice/fish (annual mean) and 0.5 lice/fish (the April – June average – the time period when juvenile sockeye salmon are migrating past the salmon farms) in 2010.

5. The evidence suggests that disease originating from salmon farms has not contributed to the decline of Fraser River sockeye salmon. Since 2003, no outbreaks of IHN have been reported on any salmon farm. Only 1 or 2 cases (per year) of vibrio were reported on salmon farms for 5 of the 9 years between 2002 and 2010. Since 2003, the majority (29 of 38) reported cases of furunculosis were from farms on the West Coast of Vancouver Island with an average of only 1.3 cases/year on farms located in the main migration path for Fraser River sockeye salmon. Since 2003, there has been a significant decline in the number of farms reporting BKD in BC Fish Health Area 3 (the main migration route for Fraser River sockeye salmon) with an average of 6 farms per year since 2006. In 2006, 3 farms from northern Queen Charlotte Strait, 2 farms from the Broughton, and 1 farm the Sechelt area reported BKD fish health events. Of the 20 cases of BKD reported between 2007 and 2009, 17 were from farms in the Jervis / Sechelt / Salmon inlets area with only 1 farm in each of the 3 years being located within the main migration route for Fraser River sockeye salmon. Overall, the incidence of diseases in farmed salmon that would be classified as high risk to sockeye salmon is very low and do not pose a significant risk.

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# TR5D – Dill Salmon Farms Investigation

Dill, L.M. 2011. Impacts of salmon farms on Fraser River sockeye salmon: results of the Dill investigation. Cohen Commission Tech. Rept. 5D: 81p. Vancouver, B.C. www.cohencommission.ca

## Executive Summary

Open net pen aquaculture, as currently practiced in British Columbia, has the potential to create problems for wild salmon populations because the pens are open to the environment, allowing wastes, chemicals and pathogens to move freely back and forth.

Indeed, wild salmon populations have tended to decline wherever this form of aquaculture is practiced, although the reason for this is not always apparent. In one of the best studied cases, wild Pacific salmon in the Broughton Archipelago, BC appear to have been negatively impacted by sea lice from fish farms.

Declines in Fraser River sockeye salmon returns, and in particular the spectacular crash of 2009, have led many to wonder whether fish farms could be implicated, given that most of the migrating sockeye have to pass through the narrow channels among the Discovery Islands, dotted with numerous Atlantic salmon and Chinook salmon farms, on their way north out of the Strait of Georgia.

The hypothesis that there is an effect of farms on sockeye survival was tested by examining the support for its predictions that there would be negative relationships between fish farm production levels – and such farm metrics as lice levels, disease levels and farm mortality rates – and Fraser sockeye survival. These various relationships were statistically analyzed and reported separately to the Commission by Dr. Brendan Connors (Connors B. 2011. Examination of relationships between salmon aquaculture and sockeye salmon population dynamics. Cohen Commission Tech. Rept. 5B).

Unfortunately, it turned out that the data provided by Provincial government (BCMAL) and the BC Salmon Farmers Association (BCSFA) were insufficient in both quantity and quality to allow a rigorous analyses capable of answering these questions with certainty. The biggest problem was the very short length of the time series available for analysis, basically only 4-5 year classes.

However a longer-term analysis, using production data since 1982, did reveal a relationship between farm production and salmon survival, i.e., the greater the farm production the lower the survival of the sockeye. This analysis also revealed a very interesting interaction with pink salmon abundance in the North Pacific Ocean: the negative effect of the farms appeared stronger when pink salmon were more abundant, suggesting that any farm effect may be mediated through changes in the growth and/or competitive ability of the sockeye.

Despite the a priori predictions, these results cannot be considered conclusive, as they are only correlations in the data. However, the fact that the 2006 brood year interacted with half as many pink salmon as the 2005 brood year, and that the corresponding 2010 returns were much greater than those in 2009, suggests that the Connors statistical model may be capturing some underlying causal relationships, and thus motivates the search for what these might be.

Several potential drivers of any farm effect were considered. If such an effect exists, it is most likely to be due to either disease or sea lice, or both. Impacts on sockeye from other factors, such as escapes or waste and chemical inputs and their effects on the benthic and pelagic zooplankton communities, are likely to be quite local and unlikely to be sufficient, alone or in concert, to cause either the long-term population declines or

the especially low returns in 2009. However, the cumulative impacts of several farms in close proximity have not been adequately addressed.

The viral and/or bacterial pathogens considered the most risky to wild sockeye are Renibacterium salmoninarum (causing bacterial kidney disease, BKD), the IHN virus (causing infectious hematopoietic necrosis, IHN) and Aeromonas salmonicida (causing furunculosis). There are a variety of ways these may be transferred from farmed fish to wild sockeye, including horizontal transfer of shed pathogens, via farmed salmon escapees, via movement of infected sea lice (vectoring), and through discharge of untreated "blood water" from processing facilities. Horizontal transfer and vectoring by sea lice are likely to be the most important routes of transmission, but the role of processing facilities needs to be examined further.

ISA (infectious salmon anemia) has not been confirmed on BC fish farms, but several of the veterinary records refer to symptoms that are highly suggestive. A close watch should be kept for indications of this disease, and biosecurity rigidly enforced, since ISA could be devastating to BC wild salmon populations. Recently there have been reports of a possible retrovirus (the so-called "Miller virus"); its role in Fraser sockeye declines is currently uncertain. It is suspected to be a contributory factor to the recently elevated levels of pre-spawning mortality (PSM) in adult Fraser sockeye, but PSM is not the cause of reduced survival as examined in this report, since the definition of "recruits" includes any mortalities due to PSM. Thus we are looking for the cause of declining survival over and above whatever effects this virus has on returning adults. Of course this does not exonerate the involvement of this presumed virus in mortality of sockeye at earlier life stages.

It is naïve to believe that the present report, and the Cohen Commission in general, will identify ***the*** cause of the sockeye salmon decline, and in particular the return failure of 2009. Nature is complex and factors do not act in isolation on the population dynamics of any species. Pathogens from fish farms are just one factor among many that may influence the mortality rate of sockeye. There are several ways in which these various factors may interact, and a number of these are discussed. Although some are hypothetical at this stage of our knowledge, they highlight the complexities in the real world system in which farms and wild sockeye are embedded, and caution against any simplistic single-factor explanation.

There are a number of knowledge gaps surrounding the farm-wild fish interaction, in particular those related to the dynamics of disease transfer. These are listed in a separate section of the report. Several management options are also briefly considered, with closed containment being the preferred option if it can be shown to be economically feasible, a hypothesis currently under test by several such facilities in BC, both land-based and in the ocean.

It must be understood that the short time series of data available for this investigation precluded identifying salmon farms as an important driver of the decline of Fraser sockeye. But it must be equally understood that at this stage of our knowledge is it ***not*** possible to say they are not implicated. It is recommended that a well-organized farm database be maintained in an ongoing fashion by Fisheries and Oceans Canada, and that annual analyses of the sort performed by Dr. Connors be conducted to firm up conclusions as more data become available.

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# TR6 – Data Synthesis

Marmorek, D., D. Pickard, A. Hall, K. Bryan, L. Martell, C. Alexander, K. Wieckowski, L. Greig and C. Schwarz. 2011. Fraser River sockeye salmon: data synthesis and cumulative impacts. ESSA Technologies Ltd. Cohen Commission Tech. Rept. 6: 273p. Vancouver, B.C. www.cohencommission.ca

## Executive Summary

### *Purpose of This Study and Methods Used*

The overall goal of this study was to synthesize the results of Cohen Commission research projects into an assessment of the cumulative impacts of various factors potentially affecting the Fraser River sockeye fishery over the recent period of declining productivity. Salmon biologists calculate *total productivity* as the number of mature adults produced per spawner[1]. Over the last two decades, there has been a general decline in both Fraser sockeye productivity and the rate of survival of returning adults from the estuary to the spawning ground. However, some Fraser sockeye stocks have not shown productivity declines (i.e., Harrison and Late Shuswap) and some years (e.g, 2010) have shown notable increases in productivity.

We organized our work around five objectives: a workshop involving all Cohen Commission researchers; synthesis and integration of data on stock productivity and potential explanatory factors acquired from these researchers; integrative analyses of cumulative impacts based on the ten technical reports completed to date for the Commission (the aquaculture report is still in progress); quantitative analyses of cumulative impacts based on the available data; and completion of this report.

Prior to considering potential causes of declining productivity, we first summarized the observed patterns of change in various attributes of the Fraser sockeye fishery. We then systematically analyzed potential causes of these patterns, using a framework adapted from the literature on cumulative effects / impacts and retrospective ecological risk assessment. This framework considered the cumulative impacts of all of the factors potentially affecting each of five life history stages, as well as possible interactions across life history stages. We explicitly recognize that combinations of factors are likely responsible for observed effects, and that these combinations will vary in complex, usually unknown ways across years and stocks. The intent of this analysis is to make the best use of the available evidence to improve our understanding of changes to Fraser sockeye populations over the last two decades.

Within each life stage, we considered whether each of the hypothesized stressors:

1. could affect sockeye survival through a plausible mechanism;
2. has generally exposed Fraser sockeye to increased stress over the period of productivity declines;
3. is correlated with variations in sockeye productivity (i.e. over space, time and stocks); and,
4. has other corroborating evidence from cause-effect studies.

Based on the available evidence, we then came to a conclusion whether the factor was *unlikely* (representing the lowest level of confidence), *possible, likely,* or *very likely* (representing the highest level of confidence) to have been a **primary driving factor** behind the overall pattern of declining productivity in Fraser sockeye. Factors

[1] Mature adults (or recruits) are estimated as the number of fish returning to the coast *before* the onset of fishing. This estimate is derived by working backwards from the numbers of adults that eventually reached the spawning ground, plus any en-route mortality between the mouth of the Fraser and the spawning ground, plus harvest. Biologists also estimate *juvenile productivity* (fry or smolts per spawner), and *post-juvenile* productivity (mature adults per fry or spawner).

that were unlikely to have been primary drivers to the overall pattern may still have contributed to changes within particular stocks and years. In some cases, major data gaps led us to the outcome that *no conclusion was possible.* Our synthesis of evidence from the Cohen Commission technical reports was supported by our own statistical analyses to determine the relative ability of various factors (representing different combinations of stressors) to explain changing patterns of productivity in Fraser sockeye.

### *The Pattern We Seek To Explain*

Based on the Cohen Commission's technical reports (Peterman and Dorner 2011, Hinch and Martins 2011), we can describe five key attributes of change in Fraser and non-Fraser sockeye populations:

1. Within the Fraser watershed, 17 of 19 sockeye stocks have shown declines in productivity over the last two decades (the two exceptions are Harrison and Late Shuswap sockeye).
2. Most of 45 non-Fraser sockeye stocks that were examined show a similar recent decrease in productivity. Thus, declining productivity has occurred over a much larger area than just the Fraser River system and is not unique to it.
3. Of the nine Fraser sockeye stocks with data on juvenile abundance, only Gates sockeye have showed declines in juvenile productivity (i.e., from spawners to juveniles) but 7 of the 9 stocks showed consistent reductions in post-juvenile productivity (i.e., from juveniles to returning adult recruits).
4. There have been three separate phases of decline in productivity since 1950. The first started in the 1970s, the second in the mid-1980s, and then the most recent one in the late 1990s or early 2000s, with individual stocks showing these trends to various extents.
5. Over the last two decades there has been an increasing amount of en-route mortality of returning Fraser sockeye spawners (i.e., mortality between the Mission enumeration site and the spawning ground). This results in reduced harvest, as fishery managers do their best to ensure enough spawners return to the spawning ground in spite of considerable mortality along the way.

### *Conclusions Regarding Potential Causes of This Pattern*

We present our conclusions for each life history stage, recognizing that there are interactions both within and between life history stages. These results do not consider aquaculture (report in progress) or other factors not considered by the Cohen Commission (except for a brief consideration of interactions between sockeye and pink salmon).

### *Stage 1: Incubation, Emergence and Freshwater Rearing*

With the exception of **climate change**, which we consider to be a *possible* factor, and **pathogens** (for which *no conclusion is possible* due to data gaps), it is *unlikely* that the other factors considered for this stage, taken cumulatively, were the *primary* drivers behind long term declines in sockeye productivity across the Fraser Basin. These factors included **forestry**, **mining**, **large hydro**, **small hydro, urbanization, agriculture, water use, contaminants, density dependent mortality, predators,** and effects of **Lower Fraser land use** on spawning and rearing habitats. We feel reasonably confident in this conclusion because juvenile productivity (which integrates all stressors in this life history stage except over-wintering in nursery lakes) has not declined over time in eight of the nine Fraser sockeye stocks where it has been measured. We would be even more confident if more stocks had *smolt* enumeration rather than *fry* estimates (only Chilko and Cultus stocks have smolt estimates). Though not primary drivers of the Fraser sockeye situation, each of these factors may still have had some effects on some Fraser stocks in some years (the data are insufficient to reject that possibility). We suspect, based on qualitative arguments alone, that **habitat** and **contaminant** influences on Life Stage 1 were also not the *primary* drivers responsible for productivity declines occurring to most non-Fraser stocks assessed by Peterman and Dorner (2011). However, given the absence of any exposure data and correlation analyses for non-Fraser stocks, it is not possible to make conclusions on the relative likelihoods of factors causing their declining productivities. None of the factors considered for Stage 1 are likely to have been much worse in 2005 and 2006 for Fraser sockeye stocks, sufficient to have significantly decreased egg-to-smolt survival in the salmon that returned in 2009. Similarly, none of these factors are likely to have been much better in 2006 and 2007, sufficient to have substantially improved egg-to-smolt survival in the salmon that returned in 2010.

### *Stage 2: Smolt Outmigration*

We analyzed the same factors for Stage 2 as for Stage 1 and came to the same conclusions. There are however three key differences in our analyses for these two stages. First, regardless of differences in their spawning and rearing habitats, all sockeye stocks pass through the highly developed Lower Fraser region. Second, migrating smolts are exposed to the above-described stressors for a much shorter time than are eggs and fry, which reduces the likelihood of effects. Third, since smolt migration occurs subsequent to enumeration of fry and smolts in rearing lakes, we have no analyses relating survival rates to potential stressors during this life history stage. Thus our conclusions have a lower level of confidence than for Stage 1. While there are some survival estimates for acoustically tagged smolts, these data (which only cover a few stocks) were not analyzed by any of the Cohen Commission technical studies. None of the factors considered for Stage 2 is likely to have been much worse in 2007 for downstream migrating smolts (affecting the 2009 returns), or to have been much better in 2008 (affecting the 2010 returns).

### *Stage 3: Coastal Migration and Migration to Rearing Areas*

There are almost no data on exposure for **pathogens** making *no conclusion possible.* The evidence presented suggests that sockeye salmon in the Strait of Georgia have little direct exposure to **human activities and development**[2], leading to a conclusion that it is *unlikely* that these factors have contributed to the decline of Fraser River sockeye salmon. Sockeye salmon have been exposed to predators, marine conditions, and climate change during this early marine phase. However, there has been no evidence presented on any correlations between key predators and sockeye salmon survival. Some important predators appear to be increasing in abundance, and some potentially important alternate prey appear to be decreasing, but many other known predators are decreasing or remaining stable. It therefore remains *possible* that **predators** have contributed to the observed declines in sockeye salmon. Based on plausible mechanisms, exposure, consistency with observed sockeye productivity changes, and other evidence, **marine conditions** and **climate change** are considered *likely* contributors to the long-term decline of Fraser River sockeye salmon. It is also *very likely* that poor **marine conditions** during the coastal migration life stage in 2007 contributed to the poor returns observed in 2009. Marine conditions were much better in 2008 (much cooler temperatures), which benefited returns in 2010. **Aquaculture** was not considered in our report as the Commission Technical reports on this potential stressor were not available, but will be considered in an addendum to this report.

2 "Human activities and development" refers specifically to those activities and developments considered within Technical Report #12 (Fraser River Sockeye Habitat Use in the Lower Fraser and Strait of Georgia), which do not include salmon farms. Exposure to salmon farms will be covered in the technical report on aquaculture, which is currently in progress. The present report does not provide any conclusions regarding salmon farms.

### *Stage 4: Growth in North Pacific and Return to Fraser*

Our conclusions on this life history stage are similar to those for Stage 3, though we conclude that **marine conditions** and **climate change** remain *possible* contributors to the long-term decline of Fraser River sockeye salmon (whereas in Stage 3, we considered them to be likely contributors).

### *Stage 5: Migration back to Spawn*

While the timing of increased **en-route mortality** coincides generally with the Fraser sockeye situation, the Fraser sockeye productivity indices already account for en-route mortality (i.e., recruits = spawners + harvest + en-route mortality). Therefore, there is no point in examining correlations between en-route mortality and life cycle or post-juvenile productivity indices within the same generation. The only possible effects on productivity are inter-generational effects, for which the evidence is limited and equivocal. We therefore conclude that it is *unlikely* that en-route mortality (or pre-spawn mortality[3], which has only increased for Late Run sockeye) are a primary factor in declining indices of Fraser sockeye productivity. However, en-route mortality has *definitely* had a significant impact on the *sockeye fishery* and the *numbers of adult fish reaching the spawning ground*, particularly for the Early and Late runs. **Pre-spawn mortality**, **habitat changes**, and **contaminants** are *unlikely* to be responsible for the overall pattern of declining sockeye productivity. *No conclusion is possible* regarding **pathogens** due to insufficient data. None of the factors assessed for this life history stage are likely to have shown significant changes between 2009 and 2010.

The above conclusions are based on qualitative and quantitative analyses of existing information. There are two important caveats on these conclusions. First, there are major gaps in both our fundamental understanding of how various factors interact to affect Fraser River sockeye salmon, and in the data available to quantify those factors. Second, all Cohen Commission researchers have had a limited amount of time to analyze existing information; future data syntheses and analyses may provide deeper and different insights. Below, we summarize our recommendations for research, monitoring and synthesis activities.

### *Recommendations for Research, Monitoring and Synthesis*

Researchers at the Cohen Commission workshop agreed with the PSC report (Peterman et al. 2010) that the 2009 and long-term declines in sockeye productivity were likely due to the effects of multiple stressors and factors, and that a strong emphasis should be placed on studying the entire life cycle of sockeye salmon along with their potential stressors. Unlike the PSC report, participants felt that research efforts should be expanded outside the Strait of Georgia as a priority area, as well as increasing efforts inside the Strait.

Section 5.2 of this report describes 23 recommended research and monitoring activities, organized by life history stage, based on four sources: the PSC report (Peterman et al. 2010), the Cohen Commission's research workshop, the Commission's Technical reports, and this cumulative effects assessment. We have highlighted 12 of these 23 recommendations as particularly high priority, but the others are also essential to provide the information needed to properly manage Fraser sockeye. The three dominant themes are: 1) coordinated, multi-agency collection of data on sockeye stock abundance, survival and stressors for each life history stage; 2) development of an integrated database and cumulative assessments both within and across multiple life history stages; and 3) transparent dissemination of information annually to scientists and non-scientists. Since the early marine environment appears to be a major potential source of declining productivity, it is particularly important to improve information on potential stressors affecting sockeye

[3] Pre-spawn mortality is defined as females that have arrived on spawning grounds but die with most of their eggs retained in their body.

along their migratory path from the mouth of the Fraser River through Queen Charlotte Sound, including food, predators, pathogens, and physical, chemical, and biological ocean conditions. Further efforts to prioritize, sequence and refine our recommendations will require a careful consideration of several factors: the ultimate uses of the information; given those uses, the appropriate space and time scales and required / achievable levels of accuracy and precision; and the most cost-effective, well-integrated designs for the overall monitoring and research program.

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# TR6A – Data Synthesis Addendum

Marmorek, D., A. Hall and M. Nelitz. 2011. Addendum to Technical Report 6: Implications of Technical Reports on Salmon Farms and Hatchery Diseases for Technical Report 6 (Data Synthesis and Cumulative Impacts). www.cohencommission.ca

## Executive Summary

This memo represents an addendum to the Cohen Commission's Technical Report 6 on Data Synthesis and Cumulative Impacts (Marmorek et al. 2011). This memo is not an independent, stand-alone document. We assume that the reader will have read Technical Report 6 (herein referred to as TR6), which contains expanded descriptions of the concepts and methodologies applied here and was peer-reviewed.

This memo serves to update the conclusions and recommendations of TR6 based on the findings of technical reports on the potential impacts of hatchery diseases and salmon farms on Fraser River sockeye salmon, since these reports were not available during the preparation of TR6. These additional Technical Reports include:

- Technical Report 1a (Stephen et al. 2011), which evaluates the potential impacts of diseases in enhancement facilities on Fraser River sockeye salmon;
- Technical Report 5a (Korman 2011), which provides a summary of the data acquired by the Cohen Commission for evaluating the potential effects of salmon farms on Fraser River sockeye salmon;
- Technical Report 5b (Connors 2011), which explores statistical relationships between salmon farms and the productivity of Fraser River sockeye salmon; and
- Technical Reports 5c (Noakes 2011) and 5d (Dill 2011), which build on reports 5a and 5b, and provide different syntheses of the available evidence regarding the potential effects of salmon farms on Fraser River sockeye salmon.

The potential for negative interactions between salmon farms and sockeye salmon is, as demonstrated by public submissions to the Cohen Commission, an issue with a high level of public interest. The sentiment that this issue is "highly polarized" is echoed by all of the authors and most of the reviewers in Project 5. In response to the unique context of this particular topic, the Cohen Commission contracted two reports to evaluate the potential impacts of salmon farms, by two respected experts, both tasked with identical statements of work. The two authors (Noakes 2011 and Dill 2011) were provided with two additional reports intended to provide a common foundation for their investigations, a report synthesizing the data compiled specifically for this project (Korman 2011) and a report performing statistical analyses of these data (Connors 2011). Noakes (2011) and Dill (2011) each applied different analytical methods, reviewed substantially different sets of literature[4], and reached divergent conclusions on some issues. Furthermore, peer reviews of these two reports differed substantially amongst the three reviewers.

Project 5 differs from the other Cohen Commission technical projects, in that there are multiple technical reports by independent experts that reach divergent conclusions on some issues. Given this situation, our goal is simply to determine the implications of the range of findings in Project 5 for the overall data synthesis and cumulative impact assessment in TR6. We summarize the areas of agreement and disagreement between the Project 5 reports on salmon farms, considering the areas of disagreement as alternative hypotheses. However, we do not evaluate the impact of salmon farms on sockeye productivity (the role of the salmon farm experts), critically review the findings of the Project 5 reports (the role of the peer

4 Between the two reports, these authors cited 260 distinct references (excluding references to Project 5 reports). However, only 25 of these references appear in both reports.

reviewers), analyze the reasons for differing conclusions, or incorporate other evidence beyond the Project 5 reports. Rather, we simply accept each of the Project 5 reports as evidence, and use this evidence in the methodology we established in TR6.

The evidence presented by both Noakes (2011) and Dill (2011) on **waste**, **escapees**, and **sea lice** suggest that these three potential stressors are each *unlikely* to have made a significant contribution to the observed declines in Fraser River sockeye salmon. Although the evidence from these two reports leads to similar conclusions for these three factors, the pathway by which those conclusions are reached differ between the two reports for waste and sea lice, as described in Sections 3.3.1 and 3.3.3. For **waste**, the two reports disagree on whether the mechanism for impacting sockeye salmon is even plausible but agree that, if such an effect existed, the exposure of sockeye salmon to it would be insignificant. The two reports agree that the mechanism for sea lice having impacts on sockeye salmon is plausible, disagree on whether sockeye salmon are or have been subject to significant exposure to sea lice as a parasite, but agree that the available evidence does not suggest a correlation between sea lice and sockeye salmon productivity. Noakes (2011) presents other forms of evidence that further support the common conclusion. Both reports agree that **escapees** represent a plausible mechanism but that exposure to this factor is insignificant.

Both Noakes (2011) and Dill (2011) agree that **diseases of salmon farm origin** represent a plausible mechanism for salmon farms to adversely affect wild sockeye salmon. However, they completely disagree in their interpretation of the literature and available data regarding whether Fraser River sockeye salmon are exposed to this potential stressor and whether there exists any correlation between salmon farm diseases and sockeye salmon productivity. As a result of these divergent interpretations of the available evidence, each of the reports leads to a different assessment of the overall likelihood that diseases of salmon farm origin have been a primary factor in the observed declines in productivity – the evidence as presented by Noakes (2011) leads to a conclusion of *unlikely* and the evidence as presented by Dill (2011) leads to a conclusion of *possible*.

The evidence presented by Stephen et al. (2011) suggests that there is a plausible mechanism to link **diseases of hatchery origin** with adverse effects on Fraser River sockeye salmon. However, they conclude that virtually no data exist for this potential stressor, precluding any reliable, quantitative evaluation of the exposure of Fraser River sockeye salmon to hatchery diseases or analyses of correlations with productivity. The lack of relevant evidence leads to an assessment of *no conclusion possible*.

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# TR7 – Fisheries Management

English, K.K., T.C. Edgell, R.C. Bocking, M. Link and S.W. Raborn. 2011. Fraser River sockeye fisheries and fisheries management and comparison with Bristol Bay sockeye fisheries. LGL Ltd. Cohen Commission Tech. Rept. 7: 190p. & appendices. Vancouver, B.C. www.cohencommission.ca

## Executive Summary

1. **Catch Monitoring Programs** – The overall ratings for Fraser sockeye catch estimates were: "Good" for accuracy, "Unknown" for precision and "Medium" for reliability since 2001. The catch estimates prior to 2001 are likely to be biased low due to under-reporting of commercial catches in the sale slip system and deficiencies in catch monitoring efforts for First Nation fisheries. The limited documentation for DFO catch monitoring program, few estimates of precision and minimal verification at landing sites for most Canadian commercial fisheries (42% of the harvest) leaves substantial room for improvement in the catch monitoring programs.

2. **Non-Retention Fisheries** – Two types of non-retention fishing affect Fraser sockeye: 1) releases from freshwater recreational and selective beach seine fisheries and 2) net fallout from gillnet fisheries. Recent radio-telemetry studies have shown that survival from releases in the lower Fraser River to spawning areas were 57.0%, 52.2 % and 36.3% for releases of sockeye caught using fishwheels, beach seines and angling, respectively. The data compiled from 2005-09 provide compelling evidence that the largest en-route losses occur at times and locations where upstream-migrating sockeye are stressed by a combination of elevated water temperature, in-river gillnet fisheries, and difficult passage points. While there is little that can be done about annual water temperatures or difficult passage points, it is possible to minimize cumulative environmental effects and fishery related factors by dissociating the timing and location of in-river fisheries from these other stressors.

3. **Pre-season Forecasts** – Fraser River forecasts explained 44% of the year-to-year variation in returns between 1980 and 2009 (i.e., 56% left unexplained), and we can expect total returns in any given year to vary from total forecasts by about 25%. However, the relationship between forecasts and returns was not reliable for seven of the 18 Fraser sockeye indicator stocks. Forecasts for Bowron, Pitt, Chilko, and Stellako have been particularly poor, having explained only 8.7%, 0.4%, 9.1%, and 9.3% of return variation in the past 30 years. This is especially alarming for Chilko because this group contributes (on average) about 24% of the total Fraser return. The recognized challenges with forecasting salmon returns have led most managers to rely on in-season information to manage sockeye fisheries.

4. **In-season Forecasts** – The accuracy and precision of in-season run size estimates varies through the season and between the different run-timing groups. The bias and error rapidly improves for Early Stuart and Summer-run stocks as the run approaches the typical 50% point. The in-season forecasts for Early Summer and Late-run groups tend to be more accurate throughout their respective migration periods and precision remains at about 10-25% for most of the run. In general, in-season forecasts have been sufficiently accurate, precise, and timely to make the necessary management decisions to achieve harvest rate goals defined for each of the four run-timing groups.

5. **Escapement Enumeration** – The reliability of in-season estimates has been questioned on a number of occasions when spawning-ground surveys have estimated substantially fewer or greater numbers of sockeye than the number estimated to have passed Mission. These major discrepancies have undermined confidence in the in-season escapement estimates and have recently led to the development of alternative in-season monitoring systems such as using DIDSON hydroacoustic techniques at Mission and Qualark for fish counts and using fishwheels in the lower Fraser River to

estimate species composition. Post-season escapement estimates are much more reliable than in-season estimates for Fraser sockeye. Virtually every type of enumeration method used to estimate escapement for salmon has been used or tested in the Fraser watershed for Fraser sockeye. The methods currently used are appropriate and the best of the available alternatives for Fraser sockeye.

6. **Escapement Targets** – The methods used to define escapement targets for Fraser sockeye were relatively simple from 1987-2002, more complex from 2004-2010, and are destined to become more complex in the future as Wild Salmon Policy benchmarks are identified for each sockeye Conservation Unit. The large year-to-year variability in escapement targets makes it difficult to regulate fisheries and evaluate management performance. The trend towards increasing complexity in the definition of escapement goals may have become an impediment to achieving these goals. From 2003-2006, observed escapements were substantially less than the escapement targets for three of the four run-timing groups (-42% to -54%). A detailed comparison of observed escapement with the escapement targets for each of the 19 indicator stocks was not possible because the annual targets have not been documented for each of these stocks. A clearly defined set of escapement goals for each run-timing group and indicator stock would be much easier to communicate to fishers than the current complex "Total Allowable Mortality" (TAM) rules. These escapement goals would still offer managers the latitude to implement harvest rate ceilings to protect less productive stocks when returns of the target stocks are large.

7. **Escapements versus Minimum Escapement Goals** – Low Escapement Benchmarks (LEBs) have been defined for each Fraser sockeye indicator stock and run-timing group. These LEBs have been used in the Fraser River Sockeye Spawning Initiative and Marine Stewardship Council certification process to evaluate management options and stock status for Fraser sockeye. For most stocks, the LEBs were set equal to 40% of the 4-year average escapement that maximizes recruitment. Historical escapements for each indicator stock and run-timing group were compared with these LEBs to assess stock status and trends. For three of the four run-timing groups, escapements to spawnng areas have been consistently above the LEBs. Escapements for the fourth run-timing group (Early Stuart) fell below its LEB goal from 2005-09 but no commercial fisheries have been permitted to target early run-timing group in these years. Some harvesting of Early Stuart sockeye has been permitted in middle and upper Fraser First Nations FSC fisheries. Escapement of all summer-run stocks declined rapidly from 2003 to 2009 and most sockeye fisheries were closed from 2007-09 to maximize escapements for these stocks. Within the Early Summer and Late-run timing groups, two stocks (Bowron and Cultus) have been consistently below their LEBs in recent years.

8. **Abundance Estimates** – For most salmon stocks, total abundance is estimated by summing catch and escapement. For Fraser sockeye, en-route losses (fish not accounted for in the catch and escapement estimates) can exceed 90% of fish having entered the Fraser River. The location, timing, and magnitude of these en-route losses are critical for estimating total abundance and exploitation rates. No estimates of en-route loss are available for years prior to 1992 and this may have contributed to a negative bias in abundance and positive bias in exploitation rates (prior to 1992), if substantial en-route losses occurred but were not detected.

9. **Extent of Overharvesting** – Based on available estimates of abundance and exploitation rate, it is likely that overharvesting occurred for Early Stuart sockeye in the period 1984-2000 and for Early Summer sockeye in the period 1960-89. No evidence of overharvesting was detected for the other two run-timing groups as a whole but there is clear evidence that at least one component of the Late-run group (Cultus Lake sockeye) was overharvested during the late 1980's and early 1990's.

10. **Status of Cultus Sockeye** – Progress has been made on reducing the abundance of sockeye predators in Cultus Lake, reducing harvest rates on Cultus adults, and increasing smolt production through hatchery supplementation efforts, yet such efforts have not resulted in meeting any of the defined conservation objectives for the population. Given the current uncertainty associated with the outcomes of various

conservation actions for Cultus sockeye, past and present recovery efforts should be considered "experimental" and thus require ongoing and rigorous monitoring programs.

11. **Bristol Bay** – There are substantial differences between the Fraser River and Bristol Bay fisheries that make many of the approaches used in Bristol Bay inappropriate for Fraser sockeye stocks and fisheries. One aspect of the Bristol Bay fisheries that should be considered seriously for application to the Fraser is the clarity and priority associated with their escapement goals. A clearly defined set of escapement goals for Fraser sockeye would not guarantee success but is one way that the management of stocks could be made simpler and increase the potential for achieving these escapement goals.

12. **State of the Science** – The scientific methods used to prepare pre-season forecasts, monitor catch and escapement, estimate returning abundance during the fishing season and determine the annual returns for each of the major sockeye stocks are consistent with the best practices for salmon fisheries. DFO and PSC have maintained a time series of abundance estimates available for these 19 indicator stocks dating back to 1952. These estimates are widely considered to be some of the best available for sockeye salmon stocks. However, the future of this valuable time series and the conversion of historical and future data into catch, escapement and total abundance estimates for each CU will depend heavily on the resources available to support critical monitoring programs, capture these data in structured databases and complete the necessary analyses.

13. **Recommendations** – The final section of our report provides recommendations which address important data gaps and known deficiencies in the fisheries management system.

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# TR8 – Predation

Christensen, V. and A.W. Trites. 2011. Predation on Fraser River sockeye salmon. Cohen Commission Tech. Rept. 8: 129p. Vancouver, B.C. www.cohencommission.ca

## Executive summary

*Fishes live in the sea, as men do a-land;*
*the great ones eat up the little ones*
William Shakespeare

Surviving in the ocean is living in a state of fear; fear of being eaten by birds, mammals and other fish. To the marine predator, it does not really matter what it consumes as long as the prey is about the right size. From this perspective, the Fraser River sockeye salmon is like many other species — an inviting mouthful swimming in the open water masses.

Sockeye salmon are repeatedly faced with making two choices throughout their life cycle. They can hide and limit risk of predation, but feed little and grow slowly—or they can stay in the open and risk being eaten, but feed a lot and grow quickly. It is a constant tradeoff where they are damned if they do and damned if they don’t. Sockeye salmon, like other fish, have successfully dealt with this dilemma through evolutionary time by developing a complicated life history that includes moving between ranges of habitats varying in the risks they represent. Minimizing predation forms an important part of this strategy.

Spawning in nutrient-poor streams and moving on to lakes has been an important part of the life-history strategy of sockeye salmon because neither of these habitats can maintain year-round predator populations that are abundant enough to severely impact varying numbers of sockeye salmon. A similar strategy may be at play for the larger sockeye in the open blue water ocean — where fish can hide at depth from predators during day, and feed at shallower depths from dawn to dusk under the cover of darkness. Between the lakes and the open ocean lies a dangerous stretch through the Fraser River and the Strait of Georgia, and along the British Columbia coast to Alaska. Predators are likely to gather to prey upon the ample and seasonal supply of outward bound and returning sockeye salmon. Making it through the gauntlet likely depends upon the size and speed of the migrating sockeye, the feeding conditions they encounter — and the species and numbers of predators that seek to eat them.

Naming the predators of sockeye salmon should not be a difficult task given that everyone likely loves sockeye—but scientifically supported ecosystem-level information about predator species (numbers, diets, trends, and distributions) is sparse throughout the sockeye salmon range. Research in freshwater has largely concentrated on fish species of interest to anglers, and has provided some information on stomach contents, but little to no information about the abundance and trends of potential predators. More information is available from marine systems, but it is again almost exclusively for commercially important fish species, and largely absent for other predator species in the ecosystems.

A review of the available scientific literature reveals a wide range of species holding the remains of sockeye salmon in their stomachs, but only a few of these predators have specialized in targeting sockeye, and there are no studies showing that a predator has consumed sufficient numbers over the past three decades to pose a population threat to sockeye salmon. There is no sign of a smoking gun among the long list of potential predators of Fraser River sockeye salmon.

The list of prime predator suspects in the long term-decline in survival rate of Fraser River sockeye salmon as well as in the disappearance of the 2009 run of Fraser River sockeye is relatively short. Caspian terns and double-crested cormorants feed on sockeye smolts in freshwater and may be increasing in numbers, while lamprey may be a major factor in the Fraser River estuary. In the Strait of Georgia, the "usual suspects" among the fish predators (spiny dogfish, and coho and chinook salmon) have all declined in recent decades, and individually seems unlikely to have had any major impacts on sockeye salmon. Through the Strait of Georgia and Queen Charlotte Sound there are a number of potential predators of which sablefish is one of the more surprising. Sablefish is known as a deepwater species, but the juveniles are more coastal and known to feed on salmon smolts in the early summer months when supply is ample. Arrowtooth flounder is another potential predator, which has increased dramatically in recent decades, and could potentially be a predator on sockeye salmon during their first months at sea. Some species of marine mammals have been documented eating salmon smolts, but none have been seen taking sockeye salmon smolts.

Feeding conditions may have changed for the potential predators of sockeye salmon in the Northeast Pacific Ocean in recent decades. Previously abundant prey species such as walleye pollock and Pacific cod in the Gulf of Alaska, and Pacific jack mackerel, Pacific mackerel, and Pacific hake further south have declined, and could have potentially shortchanged the predators. Such a change could have increased predation pressure on sockeye, but data are unavailable to assess this possibility.

Once in the open ocean, sockeye salmon appear to draw the predatory attention of salmon sharks, blue sharks, and an obscure species fittingly called daggertooth. All three species likely increased in recent decades (after the 1992 UN ban on driftnet fisheries) — and two of them (salmon sharks and daggertooth) may favor sockeye. Unfortunately, data for these species is also too sparse to draw conclusions about their potential role in the poor return of Fraser River sockeye in 2009, but their life histories suggest relatively stable numbers that should not have exerted greater predation upon sockeye in any single year relative to others.

In addition to the daggertooth and sharks, marine mammals also consume adult sockeye salmon. However, sockeye are not an important part of marine mammal diets compared to the other species of salmon. No studies have reported marine mammals consuming sockeye salmon in the open ocean. However, small amounts of sockeye have been found in the stomachs or fecal samples collected from Steller sea lions, northern fur seals, harbour seals, killer whales, and white-sided dolphins feeding over the continental shelf and inside waters of British Columbia. Seal and sea lion populations have increased significantly in British Columbia and southeast Alaska since the late 1970s. However, the available data indicate that sockeye salmon is not a preferred prey species among marine mammals.

Overall, the list of potential predators of sockeye salmon is long, but only a few of these species might have individually been a major factor in the decline of Fraser River sockeye salmon based on their diets and indications of increasing population trends. Thus, the evidence that any single predator caused the decline of Fraser River sockeye salmon is weak or nonexistent. Instead, predation is more likely to be part of the cumulative threats that sockeye contend with. Cumulative threats are far more difficult to evaluate than a single factor. In the case of Fraser River sockeye salmon, stress from higher water temperatures, more in-kind competition due to increased escapement with resulting lower growth, and running the gauntlet through predators whose alternative prey may have diminished, may all have had cumulative effects. Assessing the cumulative effects of these and other stresses will require integrated evaluation.

Evaluating why the survival of Fraser River sockeye declined requires knowing what happened in each of the habitats the fish passed through. Finding correlations between survival rates and environmental indicators is not an explanation. An explanation requires uncovering the underlying mechanisms that affect survival, and calls for information about ecosystem resources and interactions. In theory, this information should have been available through the DFO Ecosystem Research Initiatives to study and evaluate ecosystem-level information instead of single species assessments, as has been the case until now. However, this initiative by DFO appears to have been little more than an intention supported with insufficient funding. Integrated management is seemingly at a standstill in British Columbia. This lack of a coordinated system to gather and assess ecosystem-level information limits the overall ability to better assess the effects of predation on Fraser River sockeye salmon.

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# TR9 – Climate Change

Hinch, S.G. and E.G. Martins. 2011. A review of potential climate change effects on survival of Fraser River sockeye salmon and an analysis of interannual trends in en route loss and pre-spawn mortality. Cohen Commission Tech. Rept. 9: 134p. Vancouver, B.C. www.cohencommission.ca

## Executive summary

- **Effects of climate and climate change on survival of Fraser River sockeye salmon**
  - We present an assessment of the possible contribution of climate change to the recent decline in abundance and productivity of Fraser River sockeye salmon. Our assessment was based on a review of the literature evaluating the effects of climate-related variables (i.e. climate variables and other physical variables influenced by climate) on the biology and ecology of sockeye salmon across all life stages.
  - A total of 1799 documents were found in our search for primary (n=1519) and grey (n=280) literature. Of this total, only 114 documents (89 and 25 from the primary and grey literature, respectively) remained after the removal of duplicates, conference abstracts and documents that did not attempt to link a climate-related variable to sockeye salmon biology or ecology. Fraser River sockeye salmon were included in the dataset of 64 (56.1%) publications. The earliest publication resulting from our literature search appeared in the late 1930s. In the subsequent three decades, only a few publications on the effects of climate-related variables on sockeye salmon appeared in the literature and virtually all of them dealt with freshwater life stages. It was not until the 1970s that the number of publications started to increase considerably until the current decade. The great majority of publications dealing with marine life stages only started to appear in the 1980s and their numbers have been growing ever since, though they still lag behind those dealing with freshwater life stages.
  - We synthesized the current state of knowledge on the effects of climate-related variables on survival (estimated by the authors either indirectly using productivity indices or directly through direct observation or the analysis of tagging data) on the life stages of sockeye salmon. Based on our synthesis, we made a qualitative assessment of the likelihood that life-stage-specific survival of Fraser River sockeye salmon has been undergoing a trend in the past 20 years due to the recent trends in climate, particularly in temperature (warming of 0.5 °C and 1.0 °C in marine and freshwater environments, respectively, over the past two decades). For each life stage, we rated potential climate-driven trends in survival as *very likely*, *likely*, *possible* and *unlikely* to have occurred. In general, these ratings were defined so that more weight of evidence was given to findings obtained from field studies.
  - Our assessment concluded that: survival of eggs has *possibly* increased (but not in all stocks); survival of alevins has *unlikely* changed; survival of fry in lakes has *possibly* decreased; survival of smolts and postsmolts has *likely* decreased; survival of immatures in the ocean has *possibly* decreased; survival of returning adults has *very likely* decreased (but not in all stocks); once on the spawning grounds, survival to spawn has *possibly* decreased (but not in all stocks).
  - Our qualitative assessment suggests that the survival of all life stages of Fraser River sockeye salmon, with the possible exception of eggs and alevins, may be declining due to trends in temperature (and the factors that correlate with temperature) in both marine and freshwater environments over the past 20 years. However, where data exist at the stock-level for some life history stages (e.g. eggs, alevin, adult migrants), the picture is complicated by stock-specific patterns indicating that the survival of some stocks may have been less impacted than that of others or not impacted at all.

- Although the recent warming may not have resulted in large declines in survival of individual life stages, the cumulative impacts of climate change on survival across life stages could have been substantial. Overall, the weight of the evidence suggests that climate change may have adversely affected survival of Fraser River sockeye salmon and hence has been a possible contributor to the observed declining trend in abundance and productivity over the past 20 years. It also seems that inter-annual variability in climate conditions have contributed to the extreme variation in the abundance of returning adults that were observed in 2009 (much lower than average) and 2010 (much higher than average), as the years that those cohorts went to sea were characterized by unusually warm (2007) and cool (2008) sea surface temperatures, respectively.

- Recent analyses of the potential effects of future climate change on Fraser River sockeye salmon all point to reduced survival and lower productivity if the climate continues to warm. Although there is some potential for tolerance to warm temperatures to evolve in Pacific salmon, further evolutionary change may already be restricted in populations that have historically experienced high temperatures, such as Summer-run Fraser River sockeye salmon. Phenological (i.e. timing of events such as seaward migration and return migration) changes are likely to be one of the major responses of Pacific salmon to climate change. Several adaptation strategies to lessen the ecological, economic and social impacts of climate change effects on Pacific salmon have been recently proposed.

- **Adult mortality during river migration and on spawning grounds**

  - The primary purposes of this section are to: review the major environmental factors responsible for adult sockeye salmon mortality during Fraser River migrations (termed 'en route mortality') and for premature mortality on spawning grounds (termed 'pre-spawn mortality'), review the early migration / high mortality Late-run sockeye salmon phenomenon, describe interannual and within-year among stock patterns in adult mortality, and provide a mechanistic understanding for several of these patterns.

  - River entry timing and abundance of adult sockeye salmon has been quantitatively assessed since 1977 by the Pacific Salmon Commission (PSC) just upstream of the Fraser River mouth near Mission, B.C., using various forms of hydroacoustic methods linked with stock ID sampling. Fisheries and Oceans Canada (DFO) and the PSC refer to the differences in estimates of stock-specific abundance obtained from the Mission site and those obtained from spawning grounds (after accounting for reported in-river harvest upstream of Mission) as 'escapement discrepancies' which are used to assess en route loss, the percentages of each run that cannot be accounted for during the migration, which is an indirect assessment of migration (en route) mortality.

  - Generally, en route loss begins to be reported in 1992 for Early Stuart, Early summer, and Summer-runs, but not until 1996 for Late-runs. Relative to total catch and spawning ground escapement, levels of en route loss have been increasing, with recent years having some of the relative highest levels. In several years, en route loss is the dominant component of the fate of the Early Stuart and Late-run timing groups, and, since 1996, en route loss of at least 30% has been observed for at least one run-timing group in each year.

  - Eight out of 11 stocks had more than half of years between 1996 and 2008 when en route loss within those stocks exceeded 50%. There is clearly an effect of run timing on this pattern. The earlier runs (e.g. Early Stuart, Scotch, Seymour, Fennell, Gates and Nadina) and the later runs (Harrison, Portage and Weaver) have the most years with high en route loss. Summer-runs (e.g. Quesnel and Chilko) have experienced few if any years with large (> 50%) en route loss. There is good evidence that the among-stock patterns in en route loss are indicative of stock-specific abilities to cope with warming rivers and high river temperatures.

  - Changing thermal conditions have been one of the largest environmental challenges that migrating adult Fraser River sockeye salmon have had to deal with over the past 20 years: 1) the Fraser River has experienced ~ 2.5°C warming in the summer compared to 60 years ago, with average summer temperatures warming ~ 1°C in the most recent 20 years; 2) there have been several recent years with extreme temperatures during mid-summer (water temperatures in 13 of the last 20 summers have been the warmest on record); and 3) since 1996, segments of all Late-run sockeye salmon stocks have been entering the Fraser River 3-6 weeks earlier than normal – they now encounter temperatures up to 5°C warmer than they historically did and are spending longer in freshwater because spawning migration dates have not changed. Therefore Late-run fish have been exposed to freshwater diseases and parasites for much longer periods of time, with disease development being accelerated by higher than normal river temperatures (due to earlier river entry and climate warming), and greater degree day accumulation.

- Over the past decade there have been numerous field telemetry investigations examining en route mortality and the body of evidence indicates that en route mortality is stock-specific with Summer-runs having the greatest thermal tolerance, relative to earlier and later runs, supporting the among-stock patterns in en route loss. Laboratory investigations suggest that Fraser River sockeye salmon stocks vary in both their optimum and critical high temperatures in a manner that reflects local adaptation to temperatures experienced during their historic migration – stocks appear to be physiologically fine-tuned to function best at the river migration temperatures they historically encountered. Summer-run stocks have the highest critical temperatures and the largest aerobic and cardiac scopes of all groups of sockeye salmon. Earlier migrating Late-runs are particularly poorly adept at dealing with the relatively high temperatures and prolonged exposure to freshwater diseases.
- Pre-spawn mortality is highly variable among stocks, run-timing groups and years over the 70-year data series. With the exception of 12 years, pre-spawn mortality has not exceeded 30% at the run-timing group level; only in four years did pre-spawn mortality of a run-timing group exceed 40%. Across all run-timing groups over the entire 70-year period, pre-spawn mortality averaged ~ 10%. There is no clear indication that pre-spawn mortality, at the run-timing level, has been increasing over the recent few decades in concordance with run-timing trends in increasing en route mortality, with the possible exception of the past 25-year trend in Late-run pre-spawn mortality, which shows high variability but a general increase.
- Spawning abundance has declined in Early Stuart and several Late-run stocks during a time period when en route loss became a significant component of the total fate of adult migrants in those groups of fish. Spawning abundance has not declined dramatically in most stocks partly because of reductions in harvest associated with management adjustments made to compensate for en route mortality. Therefore, spawning abundance could have been a great deal higher (or allocations to fisheries greater) in recent years if it were not for en route loss.
- En route loss may be a critical factor contributing to decreasing trends in spawning abundance for some Fraser River sockeye salmon stocks, in particular, those that do not cope well with warming rivers. En route and pre-spawn mortality in adult sockeye salmon are significant factors that reduce the number of effective female spawners, and thus may pose a threat to the long-term viability of the populations that are particularly affected.

## Recommendations

- **We recommend the following research directions:**
  - <u>Telemetry approaches and direct experimentation are needed to better understand sockeye salmon marine survival:</u> An understanding of the mechanisms through which climate-related variables affect sockeye salmon in the marine environment should be sought with the application of electronic tagging technologies and exposing tagged fish to varying temperature, salinity, pH, or parasites.

- Field-based research is needed on early life stages in freshwater: Much of the past work in freshwater has been conducted in the laboratory; little is known on how temperature influences biology and ecology (e.g. interaction with prey and predators) of the early life stages of sockeye salmon in streams and lakes. Future research efforts should also be directed at the effects of increased stream flows on egg survival since higher levels of rainfall during the time of incubation are expected to occur with climate change.

- Improvements are needed in-season and post-season estimates of spawning migration mortality: Fisheries management needs better ways to predict *en route* and pre-spawn mortality prior to fish entering the Fraser River. Also needed are improvements to *en route* loss models (e.g. quantify the contributions of estimation errors and unreported catch).

- Tagging programs are needed for direct and accurate estimates of survival: Accurate estimates of survival from tagged fish are required for efficient monitoring of stocks and analyses of viability using life-cycle models. Telemetry programs as well as programs using other tagging approaches (e.g. Petersen discs, PIT or anchor tags) are needed for this purpose and should be coupled with capture-mark-recapture methods of data analysis.

- Additional stocks need to be examined: Only a few major stocks have been intensively studied to date in terms of *en route* mortality, but adult sockeye salmon from different stocks vary substantially in their life history, energy use and allocation, thermal tolerance, and habitats used. A multi-stock approach to research could provide valuable information on the mechanisms through which climate-related variables will sockeye salmon on the watershed level scale.

- Better assess the extent and consequences of gender differences in survival of migrating adult sockeye salmon: Future research should look into the extent and physiological basis of survival differences between sexes and investigate the consequences of female-specific survival for the viability of Fraser River sockeye salmon, particularly under future climate warming.

- Assess impacts of fisheries capture and release / escape on *en route* and pre-spawn mortality: Managers need to know how release or escape of captured fish affects *en route* loss and escapement. In an era of warming rivers we expect higher stress-related mortality after release / escape but these levels are largely unknown for Fraser River sockeye salmon and most Pacific salmon.

- Cumulative impacts, carry-over and intergenerational effects: There has been little research examining cumulative impacts, both across multiple stressors (e.g. fisheries capture, temperature, pollutants) or life history stages (i.e. carry-over effects), and/or among generations (i.e. intergenerational effects). These information gaps are critical to fill to begin to understand current trends in sockeye salmon productivity and abundance.

- Climate change modelling: Needed are the development of life-cycle models in order to quantify the impact of climate warming on future trends in Fraser River sockeye salmon productivity and abundance. More stock-specific information on the susceptibility to climate change is needed for this purpose. Research aimed at understanding how sockeye salmon will adapt to climate change through genetic and non-genetic mechanisms will also be needed.

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# TR10 – Production Dynamics

Peterman, R.M. and B. Dorner. 2011. Fraser River sockeye production dynamics. Cohen Commission Tech. Rept. 10: 134p. Vancouver, B.C. www.cohencommission.ca

## Executive summary

Our main objective in this report is to present data and analyses that will contribute to the understanding of possible causes of reduced abundance and productivity of Fraser River sockeye salmon. We hope that our data, as well as analyses by other scientists who use them, will help to gain a better understanding of the causes of the dramatic changes in Fraser River sockeye salmon and thereby aid in developing appropriate management responses. Here, "productivity" is the number of adult returns produced per spawner, where "spawners" are the fish that reproduce for a given sockeye population in a given year, and "adult returns" (or "recruits") refer to the number of mature adult salmon resulting from that spawning that return to the coast prior to the onset of fishing.

To achieve our objective, we obtained data sets on abundance of spawners and their resulting adult returns for a total of 64 populations ("stocks") of sockeye salmon. These stocks included 19 from the Fraser River, with the rest from other parts of British Columbia, Washington state, and Alaska. Almost all of our data are from wild populations that are not confounded by hatchery stocking. Data sets were of varying length, some starting as early as 1950. We included data on sockeye populations outside of the Fraser River to determine whether the Fraser's situation is unique, or whether other sockeye populations are suffering the same fate. In addition to obtaining data on adults, we also obtained data on juvenile (i.e., fry or smolt) abundance in fresh water for 24 sockeye populations to help determine whether problems leading to the long-term decline survival arose mainly in fresh water or the ocean. Unfortunately, we were not able to include any 2010 salmon data because the responsible agencies are still processing field samples to determine what portion of the fish belong to which particular stocks.

We used three different measures of productivity: (1) number of adult returns per spawner, (2) an index that accounts for the influence of spawner abundance on returns per spawner and thus specifically represents productivity changes that are attributable to causes other than spawner abundance (e.g., environmental factors), and (3) an extension of the second index that uses a Kalman filter to remove high-frequency year-to-year variation ("noise") in productivity and thereby brings out the long-term trends that are of primary interest to sockeye managers. We compared time trends in these three productivity estimates across sockeye stocks within the Fraser River and among them and non-Fraser sockeye stocks using a variety of methods, including visual comparisons, correlation analysis, Principal Components Analysis, and clustering.

**We found that most Fraser and many non-Fraser sockeye stocks, both in Canada and the U.S.A., show a decrease in productivity, especially over the last decade, and often also over a period of decline starting in the late 1980s or early 1990s. Thus, declines since the late 1980s have occurred over a much larger area than just the Fraser River system and are not unique to it. This observation that productivity has followed shared trends over a much larger area than just the Fraser River system is a very important new finding.** More specifically, there have been relatively large, rapid, and consistent decreases in sockeye productivity since the late 1990s in many areas along the west coast of North America, including the following stocks (from south to north).

Puget Sound (Lake Washington)
Fraser River
Barkley Sound on the West Coast of Vancouver Island (Great Central and Sproat Lakes)
Central Coast of B.C. (Long Lake, Owikeno Lake, South Atnarko Lakes)
North Coast of B.C. (Nass and Skeena)

Southeast Alaska (McDonald, Redoubt, Chilkat).
Yakutat (northern part of Southeast Alaska) (East Alsek, Klukshu, Italio).

The time trends in productivity for these stocks are not identical, but they are similar. This feature of shared variation in productivity across multiple salmon populations is consistent with, but may have occured over a larger spatial extent than, previously published results for sockeye salmon. In contrast, western Alaskan sockeye populations have generally increased in productivity over the same period, rather than decreased.

Historical data on survival rates of Fraser sockeye stocks by life stage show that declines in total-life-cycle productivity from spawners to recruits have usually been associated with declines in **juvenile-to-adult survival**, but not the freshwater stage of spawner-to-juvenile productivity. Specifically, for the nine Fraser sockeye stocks with data on juvenile abundance (fry or seaward-migrating smolts), only the Gates stock showed a long-term reduction over time in **freshwater productivity** (i.e., from spawners to juveniles) concurrent with the entire set of years of its declining total life-cycle productivity from spawners to recruits. In contrast, seven of the nine stocks (excluding Late Shuswap and Cultus) showed reductions in **post-juvenile productivity** (i.e., from juveniles to returning adult recruits) over those years with declining productivity from spawners to recruits. These results indicate either that the primary mortality agents causing the decline in Fraser River sockeye occurred in the post-juvenile stage (marine and/or late fresh water), or that certain stressors (such as pathogens) that were non-lethal in fresh water caused mortality later in the sockeye life history.

The large spatial extent of similarities in productivity patterns that we found across populations suggests that there might be a shared causal mechanism across that large area. Instead, it is also possible that the prevalence of downward trends in productivity across sockeye stocks from Lake Washington, British Columbia, Southeast Alaska, and the Yakutat region of Alaska is entirely or primarily caused by a coincidental combination of processes such as freshwater habitat degradation, contaminants, pathogens, predators, etc., that have each independently affected individual stocks or smaller groups of stocks. However, the fact that declines also occurred outside the Fraser suggests that mechanisms that operate on larger, regional spatial scales, and/or in places where a large number of correlated sockeye stocks overlap, should be seriously examined in other studies, such as the ones being done by the other contractors to the Cohen Commission. Examples of such large-scale phenomena affecting freshwater and/or marine survival of sockeye salmon might include (but are not limited to) increases in predation due to various causes, climate-driven increases in pathogen-induced mortality, or reduced food availability due to oceanographic changes. Further research is required to draw definitive conclusions about the relative influence of such large-scale versus more local processes.

The Harrison River sockeye stock in the Fraser River watershed is an important exception to the decreasing time trends in productivity that have been widely shared across sockeye stocks. Harrison fish have notable differences in their life history strategy from the majority of other sockeye populations that we examined, including other Fraser River stocks. These life history differences may provide an important clue about causes of the decline in other sockeye stocks. Specifically, (1) Harrison fish migrate to sea in their first year of life as fry instead of overwintering in fresh water and migrating to sea in their second year as smolts, (2) they appear to rear for some time in the Fraser River estuary, (3) they remain in the Strait of Georgia later than other Fraser River sockeye, and (4) there is some evidence that the fry migrate out around the southern end of Vancouver Island through the Strait of Juan de Fuca instead of through Johnstone Strait to the north. That southern fry-migration route is shared with Lake Washington sockeye, yet the latter stock was one of those that showed a decrease in productivity similar to that of other B.C. sockeye stocks. Thus, the reason for the Harrison's exceptional trend is probably not attributable simply to its different migration route. We hope that by using our data on productivity trends for Harrison and other stocks, the other contractors to the Cohen Commission will find an explanation for why the Harrison situation is anomalous.

In addition to describing similarities in productivity patterns, we also evaluated the hypothesis that large numbers of spawners could be detrimental to productivity (recruits per spawner) of Fraser sockeye populations. The downward time trend in productivity of these stocks, combined with successful management actions to rebuild spawner abundances, has led to speculation that these unusually large spawner abundances might in fact be to blame for declines in productivity and consequently also substantial declines in returns. For the Quesnel sockeye stock on the Fraser, there is indeed evidence that interactions between successive brood lines that are associated with large spawner abundances may have reduced productivity of subsequent cohorts. Thus, the recent decline in productivity for Quesnel sockeye might be more attributable to increased spawner abundance than to broad-scale environmental factors that affect other sockeye stocks in the Fraser and other regions. However, other Fraser sockeye populations do not show such evidence. Our data do not support the hypothesis that large spawner abundances are responsible for widespread declines.

## Recommendations

We conclude with five recommendations.

**Recommendation 1.** Researchers should put priority on investigating hypotheses that have spatial scales of dynamics that are consistent with the spatial extent of the observed similarities in time trends in productivity across sockeye salmon populations. By examining data on mechanisms that match the scale of the phenomenon they are trying to explain (downward trends in sockeye productivity shared among numerous stocks), scientists are less likely to find spurious relationships with explanatory variables, i.e., those that show relationships by chance alone.

**Recommendation 2.** All agencies in Canada and the U.S.A. that manage or conduct research on sockeye salmon should create and actively participate in a formal, long-term working group devoted to, (a) regularly coordinating the collection and analysis of data on productivity of these populations, and (b) rapidly making those results available to everyone. Such an international collaboration is needed because the widespread similarity of decreasing time trends in productivity of sockeye salmon stocks in Canada and the U.S.A. south of central Alaska strongly suggests that large-scale processes may be affecting these diverse populations in similar ways. A new international working group would facilitate communication of current data and analyses, which would help to increase the rate of learning about causes of widespread t rends across stocks and identification of what might be done about them. Such a working group's role might be critically important if global climatic change is responsible for the declines in sockeye productivity.

**Recommendation 3.** All agencies involved with salmon research and management on the west coast of North America should develop and maintain well-structured databases for storing, verifying, and sharing data across large regions. This step will improve data quality and consistency and make the data more readily accessible to researchers, managers, and stakeholders. They can then be used reliably and in a timely manner in research and provision of advice to managers and stakeholders. If such large-area databases had been created before, scientists might have noticed sooner how widespread the recent decline in sockeye productivity has been, and timely research efforts could have been directed toward understanding the causes of the decline.

**Recommendation 4.** All salmon management and research agencies in Alaska, B.C., and Washington need to strategically increase the number of sockeye stocks for which they annually estimate juvenile abundance, either as outmigrating smolts or fall fry. These additional long-term data sets are needed to permit attribution of causes of future changes in salmon populations to mechanisms occurring either in freshwater or marine regions. Without such juvenile data sets, research or management efforts might be misdirected at the wrong part of the salmon life cycle when productivity decreases.

**Recommendation 5.** Further research is required to better understand salmon migration routes and timing during outmigration, as well as their residence in the marine environment. Scientists also need more information on stressors and mortality that fish are subjected to at each life stage. Without such additional detailed data on late freshwater and marine life stages, most evidence for causal mechanisms of changes in salmon productivity will likely remain indirect and speculative.

Three external reviews of our draft version of this report, dated 15 December 2010, are provided in Appendix 2, along with our responses.

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# TR12 – Lower Fraser Habitat

Johannes, M.R.S., L.H. Nikl, R.J.R. Hoogendoorn and R.E. Scott. 2011. Fraser River sockeye habitat use in the Lower Fraser and Strait of Georgia. Golder Associates Ltd. Cohen Commission Tech. Rept. 12: 114p. & 35 maps. Vancouver, B.C. www.cohencommission.ca

## Executive Summary

There is a general view that Fraser River sockeye face a series of challenges and issues which have influenced freshwater and marine sockeye growth and/or survival over at least the past two decades. The lower Fraser River and Strait of Georgia (also known as the Salish Sea) continue to be centres of human activity and development which have changed the natural landscape and potentially altered the extent and characteristics of sockeye habitats. Salmon are often viewed as a living barometer of the conditions in the environment and their habitat state and stock status could reflect potential impacts from human activities.

As part of the Cohen Commission's inquiry, a series of twelve technical reports have been developed to address potential issues identified during the first phase of the Commission's work as being possible causes of an observed long term decline in the production of Fraser River sockeye. The objective of these technical reports has been to explore causal hypotheses related to the observed declines. Within this context, the primary objective of the technical report presented here is to review and summarize potential human development-related impacts over the recent 1990 to 2010 period and to examine potential interactions between human development and activities in the lower Fraser River and Strait of Georgia and Fraser sockeye salmon habitats. Many of the issues and potential interactions between human development and their impacts summarized in this report could potentially apply to other species of wild salmon or other species of fish as well as their habitats; however, the evaluation of effects in this report is focused on Fraser sockeye.

The population of British Columbia has grown to more than 4 million people in 2005 (census data), with 3.2 million people living in urban areas concentrated around the lower Fraser River and the Strait of Georgia. Over the past century, land and resources have been developed and exploited throughout the lower mainland of BC (Fraser Valley and Fraser Delta areas) and the Strait of Georgia for housing, industry, infrastructure, transportation, forestry, agriculture and mining. Many of these activities are near or adjacent to the lower Fraser River and in urban and industrial centres along shorelines around the Strait of Georgia and thus have the potential to interact with the habitats used by sockeye. The Fraser River and the Strait of Georgia both have significant value for human use as commercial, recreation and transportation corridors and as receiving areas for wastewater, along with other human-related functions like water supplies, recreation, irrigation, and fisheries.

The factors used to examine changes in the level of human activities and or possible outcomes of those activities included: population (size, density), land use (agriculture, forestry), large industrial and infrastructure sites and projects, waste (liquid and solid waste), shipping vessel traffic, lower Fraser River dredging and diking, and the Strait of Georgia biological and physical water characteristics including non indigenous (invasive) species and human derived contaminants.

The approach and methods used to identify and define interactions and analyse their potential extent or overlap between human activity and sockeye habitats reflects a similar process to that used in environmental impact assessments.

## Key Findings

Our review suggests that Fraser sockeye use specific or key life-history-related habitats with different residence periods (extent of habitat use over time), in both freshwater and marine areas of the lower Fraser and Strait of Georgia. The Strait of Georgia and the lower Fraser River are used by both juvenile and adult sockeye salmon as key habitats and migration corridors on their way to and from the North Pacific. While this may not be the case for some other Pacific salmon species, freshwater and marine habitats used by sockeye often have short residence periods (days); with the exception of incubation in freshwater spawning habitats and rearing in lakes (months to years). In the ocean, sockeye exhibit large annual and seasonal variation in spatial distribution dependent on marine water properties encountered and on preferred prey distribution and abundance. Results from other commission technical reports, our information review and examples from the literature suggest the annual variation in the quality of these conditions (water properties and biological characteristics) may have important links and potential effects on sockeye production. Juvenile sockeye in the Strait of Georgia appear to be particularly sensitive to changes in growth experienced during cool productive and warm unproductive conditions related to prey availability, surface currents and swimming speeds, and potentially to competitors and predators.

## Human Activities, Habitat Interactions

Human development across the Georgia basin has seen large changes in population size and density in urban centres. Most of the population is centred in the lower mainland and south-eastern Vancouver Island with population size in most regional districts and municipalities in the lower mainland having increased by 150% over the past 20 years. Changes in population reflects increasing pressures on the environment because of the potential for higher levels of water use and pollution, nutrients and contaminants from wastewater and runoff, conversion of vegetated lands (natural, forests, agricultural) to urban and industrial areas. However, during that same time, programs have been in place to curb and manage runoff and human related discharges. Contaminants in the Strait of Georgia show a general improvement over time, with decreases associated with effluent regulation and improved treatment in recent years. For example, upgrades and efficiencies in the sewage collection and treatment systems in Metro Vancouver have taken place over the period of study. The physical construction of development projects adjacent to sockeye habitats has also been regulated over the period of study and there is evidence that habitat conservation efforts, through regulatory review and through restoration of previously impacted habitats, have resulted in habitat gains in the Fraser River estuary over the period of study for this report (1990 – 2010). However, some of the earlier habitat projects, carried out prior to the present period of study, were not successful at achieving "no net loss" of fish habitat. There is evidence that information learned from those projects has been incorporated into successful compensatory designs on contemporary projects in the Fraser estuary, underlining the importance of continued scientific learning regarding habitat ecology.

The Strait of Georgia and the lower Fraser River, support a large number of non-indigenous species (NIS), greater than twice the number found elsewhere on the Canada's West Coast. With the exception of intertidal benthos, the number of NIS in freshwater and marine environments have remained approximately stable from 1990 to 2010.

Increasing population size, urban density, industrial and infrastructure development and associated land use and waste as factors in the decline of Fraser sockeye were ranked as having low to moderate potential for impacts on juvenile and adult sockeye habitats in the lower Fraser River and adult sockeye habitats in the Fraser estuary. As a result of regulatory pressures and technological changes and despite population growth, solid waste, wastewater, contaminants and non indigenous species introductions appear to have remained mostly stable over the time covered by this review, in contrast to Fraser sockeye production which has declined. Changes in urban and rural land use have implications on increased sediment and erosion, nutrient, contaminant and stormwater runoff which could affect sockeye habitat use in the lower Fraser River, particularly in habitats used in locations off of the main channel. For instance, river-type sockeye will make use of the mouths of urban creeks or off-channel areas for rearing prior to migration to the Strait of Georgia. Stormwater and wastes deposited directly or inadvertently would cause direct exposure to sockeye, particularly in freshwater rearing habitats used by river-type sockeye. The proportion of river-type sockeye within the Fraser sockeye population is estimated to be less than 1%.

In many areas where human activities and development are concentrated, sockeye often have limited residence periods in adjacent habitats. For example, the lower Fraser River and estuary are primarily used by both adult and juvenile sockeye over periods of days as migratory corridors,with some exceptions. Historically (i.e., over the past century), many human activities may have had moderate to severe effects on sockeye habitats, but these impacts have not been generally observed during the last 2 decades and importantly, these impacts have not been observed to coincide with the decline of the Fraser River sockeye. The human activities often exhibited limited spatial and temporal (duration, timing) overlap with spatial and temporal sockeye habitat use. In a number of instances, additional regulatory controls (agricultural and forestry practices, shipping, ballast discharge, regulatory review of project development, non indigenous species introductions), improvements to industrial and municipal practices (solid and liquid waste management), and management regimes and protocols (urban development, agricultural and forestry practices, project development, dredging, dikes) have resulted in reduced or declining potential effects and reduced interactions and risk of loss or degradation of existing sockeye habitats relative to periods prior to the last two decades. There is room for continued improvement in a number of these areas.

This review is specific to sockeye and their habitat use and should not be extrapolated to interactions between human activities and other salmon and fish species' habitats.

Water properties (sea surface temperature, salinity, Fraser River discharge, prevailing winds on the sea surface) and biological conditions (plankton, fish) in the Strait of Georgia show a large range of variation over seasons and years. Potential interactions between biophysical conditions in the Strait of Georgia and sockeye (habitat and habitat use) have been inferred by our findings but limited existing studies and data prevent an adequate analysis of the extent of these interactions and, in particular, causal links cannot be established. Existing studies suggest that there may be an association between changes in biophysical conditions in the Strait of Georgia and the effects on sockeye habitat use, feeding and growth and potentially production. This expectation is not supported by conclusive results and statistical hypothesis tests, but is supported by studies which suggest that Fraser sockeye production is expected to be higher with increased sockeye growth and condition, relative to poorer sockeye production in years, seasons and habitats linked to lower growth and condition. Cooler years in the Strait of Georgia are expected to comprise habitats with higher abundance and availability of preferred (larger sized, higher energy content) sockeye prey and lower levels of competitors and predators. Relative to other human factors examined in our review, the changes and variability in the biophysical conditions associated with cool or warm water years can be widespread, extending over large areas of sockeye habitats and portions of life history for both juvenile and adult stages. In some seasons or years, changes in biophysical conditions and resulting sockeye preferred food availability can be expected to have profound positive or negative effects on sockeye growth and production.

## Habitat Protection Strategies

The habitat protection strategies used in the lower Fraser River and Strait of Georgia, appear to be effective at supporting sockeye habitat conservation. More broadly, a hypothesis that the declines in Fraser River sockeye production over the period 1990 – 2009 are the result of habitat impacts from project development is not supported by the net habitat gains that have occurred over the 1990 – 2010 period.

The development of a project is required to provide compensatory fish habitat to offset project-related disturbances / impacts and often provides an opportunity for habitat gains. However, we also found evidence that habitat losses associated with project development had occurred <u>prior</u> to the period covered by our review. These losses were presumably the result of inadequate knowledge and experience in the design and construction of habitat compensation and/or indicate that the regulatory review process may not have been appropriately used. Therefore, maintaining active review of habitat projects may be a critical habitat management approach and potentially an important requirement for current and future activities and human development projects. Although the effectiveness of habitat compensation projects in the Fraser River appears to be improving, the need for an improved habitat science, monitoring and data management framework is clear and aspects of this need are consistent with recommendations made by others over the past decade or two. In our view, some efforts have been made in this direction, but these have not been adequate and are even less likely to be adequate into the future. Habitat compensation techniques relied upon over the past decade or two may not be effective in the next decade or two as physical space in urban centres for such compensation becomes more limited. Research in habitat ecology to evaluate alternative approaches to those prevailing today will be needed to adequately evaluate habitat compensation projects.

Programs and management initiatives used to examine and understand the quantitative parameters of habitats, potential losses and gains, habitat quality types and the dynamics of habitat productivity do not appear to be sufficient for keeping track of the current and future status of habitats used by sockeye and potential links and associations to variations in sockeye productivity. Habitat science, management, inventory and reporting should be brought together into an integrate framework as habitat compensation projects become more challenging and environments are more strongly influenced by changing climates and diminishing space in which to construct new habitats.

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