Commission of Inquiry
into the Decline of
Sockeye Salmon in the Fraser River

Commission d'enquête
sur le déclin des populations
de saumon rouge du fleuve Fraser

The Uncertain Future of Fraser River Sockeye

Volume 2 • Causes of the Decline

Final Report – October 2012

The Honourable Bruce I. Cohen, Commissioner

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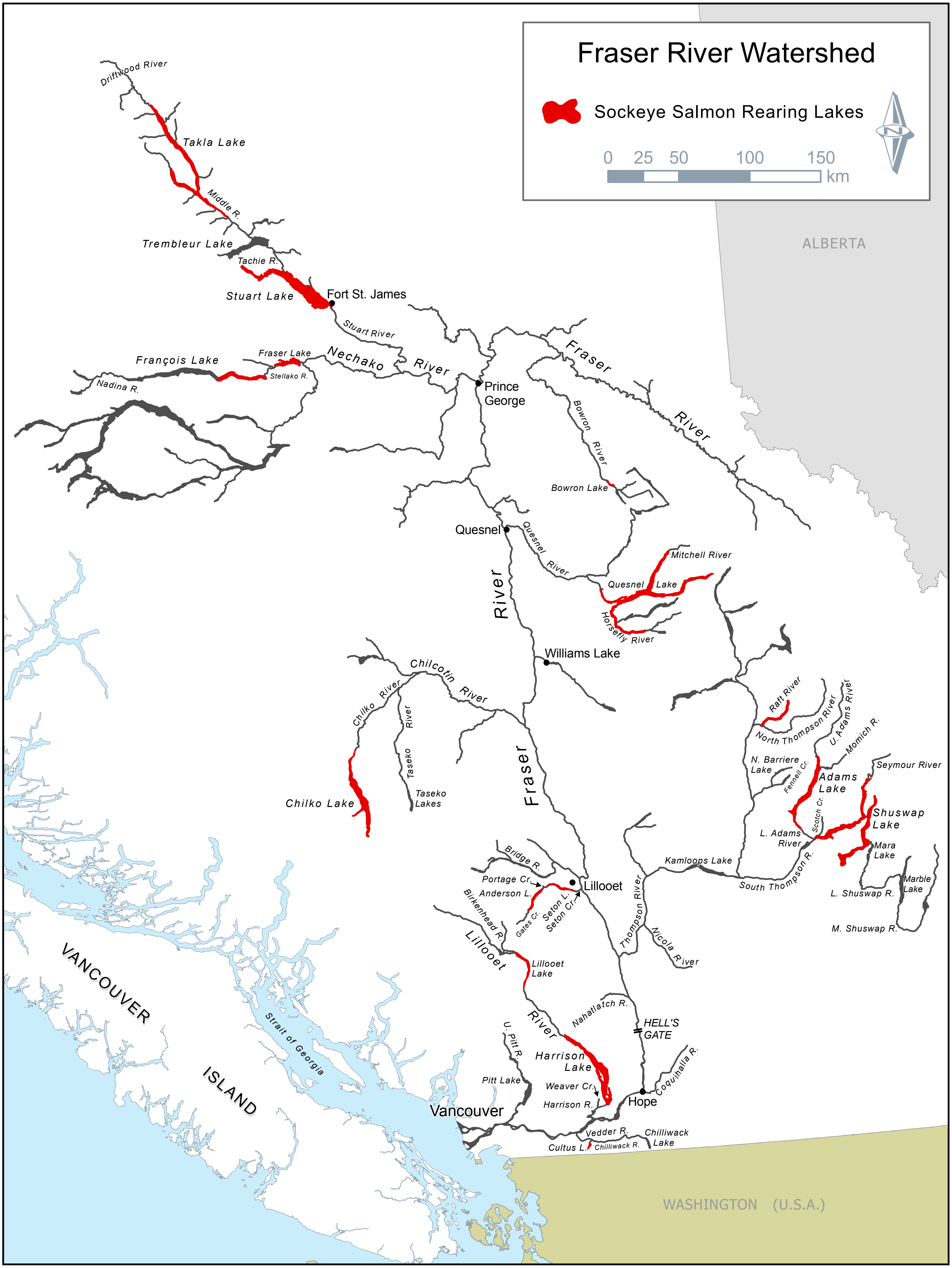
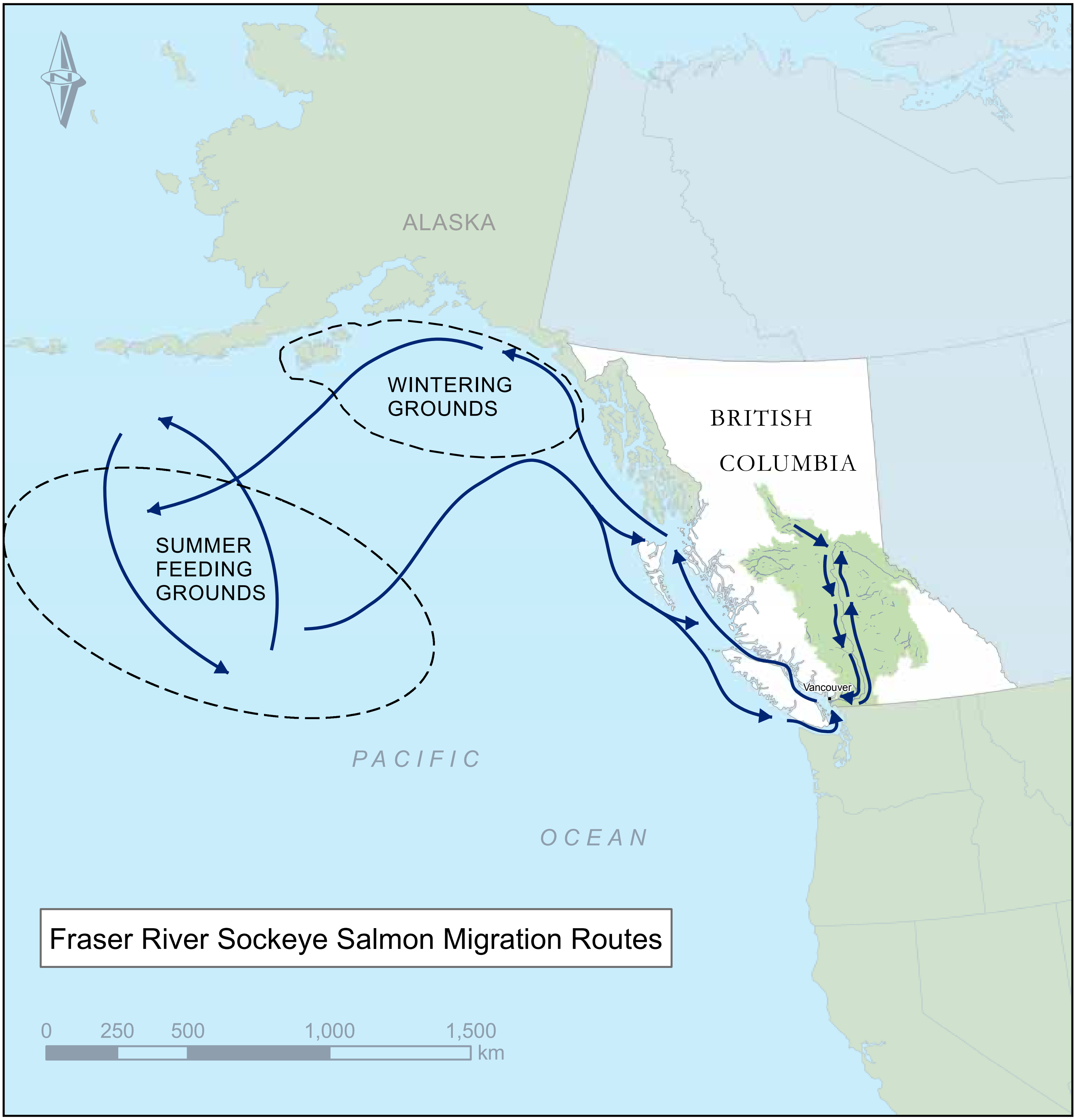


Fraser River Watershed
Sockeye Salmon Rearing Lakes
0 25 50 100 150 km
ALBERTA
WASHINGTON (U.S.A.)
VANCOUVER ISLAND
Strait of Georgia
Driftwood River
Takla Lake
Middle R.
Trembleur Lake
Tachie R.
Stuart Lake
Fort St. James
Stuart River
François Lake
Fraser Lake
Stellako R.
Nadina R.
Nechako River
Prince George
Fraser River
Bowron River
Bowron Lake
Quesnel
Quesnel River
Mitchell River
Quesnel Lake
Horsefly River
Williams Lake
Chilcotin River
Chilko River
Taseko River
Taseko Lakes
Chilko Lake
Raft River
North Thompson River
U. Adams River
Momich R.
Seymour River
N. Barriere Lake
Fennell Cr.
Adams Lake
Shuswap Lake
Scotch Cr.
L. Adams River
Mara Lake
Marble Lake
L. Shuswap R.
M. Shuswap R.
Kamloops Lake
South Thompson R.
Thompson River
Nicola River
Bridge R.
Portage Cr.
Anderson L.
Lillooet
Seton L.
Seton Cr.
Gates Cr.
Birkenhead R.
Lillooet River
Lillooet Lake
Nahatlatch R.
HELL'S GATE
U. Pitt R.
Harrison Lake
Pitt Lake
Weaver Cr.
Harrison R.
Coquihalla R.
Hope
Vancouver
Vedder R.
Chilliwack Lake
Cultus L.
Chilliwack R.



Fraser River Sockeye Salmon Migration Routes

Commission of Inquiry
into the Decline of
Sockeye Salmon in the Fraser River

Commission d'enquête
sur le déclin des populations
de saumon rouge du fleuve Fraser

October 29, 2012

To His Excellency
The Governor General in Council

May it please Your Excellency:

As Commissioner appointed by Order in Council PC 2009-1860, which was promulgated on November 5, 2009, pursuant to Part I of the *Inquiries Act*, and in accordance with the Terms of Reference assigned therein, I respectfully submit my final report.

The report sets out my findings resulting from public forums and submissions, the extensive review of documents, the conduct of evidentiary hearings, and the careful consideration of participants' submissions.

I trust that my report will contribute to an improved understanding of Fraser River sockeye salmon, and that my recommendations will improve the future sustainability of the sockeye salmon fishery in the Fraser River.

I consider it a privilege and an honour to have served as Commissioner.

The Honourable Bruce I. Cohen
Commissioner

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COHEN COMMISSION OF INQUIRY
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Chapter 1 • Introduction

The Commission's Terms of Reference direct me to investigate and make independent findings of fact regarding

> the causes for the decline of Fraser River sockeye salmon including, but not limited to, the impact of environmental changes along the Fraser River, marine environmental conditions, aquaculture, predators, diseases, water temperature and other factors that may have affected the ability of sockeye salmon to reach traditional spawning grounds or reach the ocean[.][1]

In early 2010, the Commission began development of a science program. With the assistance of scientists from outside the Commission and prospective researchers, Commission staff identified the scope and range of the scientific issues that it intended to investigate. It was understood that the Commission had neither the time nor the resources to undertake or commission primary research. Instead, it would engage scientists to conduct secondary research, drawing on published literature and existing data.

In June 2010, the Commission published a discussion paper that identified a wide range of fisheries management, fish biology, and ecosystem issues that I intended to examine.[2] Later that month, Commission counsel convened two days of hearings to solicit the participants' submissions on the issues the Commission had identified. In particular, the Commission wanted to know, first, whether there were issues other than those listed in the discussion paper that ought to be investigated and, second, the relative priority of those issues.

The participants provided valuable input that led to some revisions to the list and description of the issues. In July 2010, Commission counsel wrote to the participants, describing the technical projects, with the names of the proposed researchers, along with biographical information. After further consultation with the participants, the topics of the Commission's technical projects were finalized.

The Commission asked the contractors to produce technical reports detailing their findings. In most cases, contractors delivered their reports to the Commission by December 15, 2010. The reports were then peer reviewed, typically by three experts in the field or related fields. Following this review, the contractors made revisions and delivered their final versions by the end of January 2011.

While the technical reports were being prepared, Commission counsel and the participants discussed several other issues that warranted examination. The Commission ultimately approved additional technical reports relating to the impacts of environmental conditions in the Lower Fraser River and Strait of Georgia, as well as an analysis of infectious diseases originating from salmon enhancement facilities on Fraser River sockeye salmon.

Ultimately, 15 technical reports became exhibits.* A list of these reports appears as Table 2.1.1.

Table 2.1.1 Cohen Commission technical reports

Technical Report number	Full title	Abbreviated title	Exhibit number
1	Infectious Diseases and Potential Impacts on Survival of Fraser River Sockeye Salmon	Infectious Diseases	1449
1A	Assessment of the Potential Effects of Diseases Present in Salmonid Enhancement Facilities on Fraser River Sockeye Salmon	Enhancement Facility Diseases	1454
2	Potential Effects of Contaminants on Fraser River Sockeye Salmon	Contaminants	826
3	Evaluating the Status of Fraser River Sockeye Salmon and Role of Freshwater Ecology in Their Decline	Freshwater Ecology	562
4	The Decline of Fraser River Sockeye Salmon *Oncorhynchus nerka* (Steller, 1743) in Relation to Marine Ecology	Marine Ecology	1291
5A	Summary of Information for Evaluating Impacts of Salmon Farms on Survival of Fraser River Sockeye Salmon	Salmon Farms and Sockeye Information	1543
5B	Examination of Relationships between Salmon Aquaculture and Sockeye Salmon Population Dynamics	Salmon Farms and Sockeye Relationships	1545
5C	Impacts of Salmon Farms on Fraser River Sockeye Salmon: Results of the Noakes Investigation	Noakes Salmon Farms Investigation	1536
5D	Impacts of Salmon Farms on Fraser River Sockeye Salmon: Results of the Dill Investigation	Dill Salmon Farms Investigation	1540
6 6 – Addendum	Fraser River Sockeye Salmon: Data Synthesis and Cumulative Impacts; and Addendum, Implications of Technical Reports on Salmon Farms and Hatchery Diseases for Technical Report 6	Data Synthesis Data Synthesis Addendum	1896 1575
7	Fraser River Sockeye Fisheries and Fisheries Management and Comparison with Bristol Bay Sockeye Fisheries	Fisheries Management	718
8	Predation on Fraser River Sockeye Salmon	Predation	783
9	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	Climate Change	553
10	Fraser River Sockeye Production Dynamics	Production Dynamics	748
12	Fraser River Sockeye Habitat Use in the Lower Fraser and Strait of Georgia	Lower Fraser Habitat	735

* Technical Report 11, DFO Science and Management was not entered as an exhibit and is not listed in Table 2.1.1; however, it is available on the Commission's website at www.cohencommission.ca.

To give readers an appreciation of the breadth and complexity of scientific and technical issues examined, I have included, as Appendix B to this volume, the executive summaries and tables of contents of these technical reports. The summaries include the researchers' conclusions, based on the available information. The complete technical reports are available on the Commission's website and are also included in the DVD accompanying this volume.

The Commission held hearings on all these technical report topics, at which one or more of each report's authors testified, in some cases alongside other witnesses. The Commission also held hearings on marine research and management, on habitat enhancement and restoration, and on other related stressors that were not the primary subject of technical reports, including:

- urbanization;
- pulp and paper effluent, mining effluent;
- municipal wastewater;
- gravel removal;
- forestry; and
- hydroelectric power, water flow, and temperature.

Transcripts of these hearings are available on the Commission's website, and are also included in the DVD accompanying this volume.

In the following chapters of this volume, I summarize the evidence from all these sources and make reference to submissions received from interested members of the public. These chapters consolidate the evidentiary record that is before this Commission. The text is intended to reflect what the contractors wrote in their reports, what witnesses said in their testimony, and what members of the public told me in their submissions. It should not be assumed that I necessarily agree with or endorse everything set out in these chapters – rather, they provide a summary of what I read and heard. My findings of fact and conclusions respecting the causes of the decline of Fraser River sockeye salmon will come later, in the final chapter of this volume.

Notes

1 Terms of Reference, a.i.C.I.
2 Available at http://www.cohencommission.ca and on the DVD accompanying this volume.

Chapter 2 • Summary of public submissions

Members of the public participated in the Inquiry by making oral submissions during community forums and written submissions via mail, email, or the Commission's website. These submissions were analyzed to incorporate public perspectives into the Commission's work. Those submissions that relate directly to causes of the Fraser River sockeye decline are summarized in this chapter. Those that address fisheries management topics are referred to in Volume 1.

I express my sincere appreciation to every person who took the time to write to the Commission or attend one of the Commission's community forums, and to share their views and concerns with me. I was impressed with how knowledgeable many people are about our Fraser River sockeye salmon, the threats sockeye face, and the management of the fishery, and about how passionate British Columbians are about protecting our wild sockeye stocks.

Public Forum, Campbell River, BC, 2010

Effects in the Fraser River watershed

A significant proportion of public submissions addressed how various factors operating in the Fraser River watershed may affect Fraser River sockeye salmon:

- general habitat loss;
- urbanization and development;
- groundwater use;
- gravel extraction and metal mining;
- hydroelectric projects;
- forestry;
- municipal wastewater;
- non–point source contaminants;
- pesticides;
- pulp mill effluent;
- freshwater climate change; and
- wildfires.

General habitat loss

Many people made submissions to the Commission on a range of habitat issues. Numerous individuals were concerned about habitat loss and suggested it could be a cause for the decline of Fraser River sockeye. Human activity was blamed for loss of Fraser River sockeye habitat, especially in the North Arm of the river. One submitter referenced a 2010 report by the Department of Fisheries and Oceans (DFO) which found that coastal and estuarine zones are deteriorating in both extent and condition.[1] Several submitters encouraged me to identify habitat loss as a cause of the decline of Fraser River sockeye, while one submitter called on DFO to reopen inaccessible sloughs and creeks and remove the remaining rocks from the Hell's Gate rock slide. One submission stated that less than 5 percent of salmon smolt habitat remains in the North Arm of the Fraser River. Another submission argued that there are very few salt marshes remaining in the Fraser River estuary, and that salt marshes are critical for salmon as they acclimatize to the marine environment.

Urbanization and development

The Commission received several written and oral public submissions raising concerns about linear development, including railway and pipeline construction, the Gateway Program and South Fraser Perimeter Road,* and the potential impacts on fish and fish habitat from these projects. One submitter noted that the damage caused by urbanization and development is evidenced by the Outdoor Recreation Council's 2010 decision to list the Fraser River as the fourth most endangered river in British Columbia. Other submitters said urbanization and development lead to increased levels of siltation and sedimentation in the Fraser River watershed, the disappearance of riparian ecosystems, and disruptions to flood plains and stream channels. A submission from the Social Ecology Institute of British Columbia stated that industrial and residential development has caused riparian degradation and explained that riparian systems are important for spawning salmon.

Groundwater use

Several public submissions expressed concern about a lack of knowledge regarding the impact that industrial activities have on groundwater sources, and about a lack of legal protection for small streams and groundwater.

Gravel extraction and metal mining

Several submitters said that metal mining introduces toxic chemicals into salmon habitat and increases water temperatures. Others argued that gravel extraction in the Lower Fraser River and metal mining in the Fraser River watershed are among the causes of the decline of Fraser River sockeye. I was told that the collapse of a tailings pond wall in 2008 released toxins into the Stellako River. One submitter said the BC Aggregate Pilot Project's† use of "green zones," or areas where "unregulated" open-pit mining is permitted, threatens

* The Gateway Program is a program of the Province of British Columbia aimed at improving the movement of people, goods, and transit through Metro Vancouver. It includes road and bridge improvements. One such improvement is South Fraser Perimeter Road – a new four-lane highway along the south side of the Fraser River from Delta to Surrey.

† In 2004, the BC minister of state for mining initiated the Aggregate Pilot Project in the Fraser Valley Regional District. The project develops recommendations to industry, local governments, and the province for new approaches to reduce conflict surrounding aggregate operations and secure a long-term supply.

to degrade salmon habitat, while another criticized the project for having an "inadequate" approval process and failing to respond to public inquiries in a timely manner.[2]

Hydroelectric projects

One submitter said that the Kemano Hydroelectric Project's diversion of the Nechako River and groundwater withdrawals are "exacerbating the devastating effects of below-average flows and higher-than-average water temperatures" during the Fraser River sockeye migration period.[3] Several submitters cited hydroelectric projects and run-of-river projects as a cause of the decline of Fraser River sockeye. Some submitters criticized the BC government for failing to implement an "environmentally based planning process" for proposed run-of-river projects.

Forestry

Submitters said that logging practices, such as clear-cutting and high-elevation logging, have made streams more vulnerable to increases in water temperature, surface runoff, debris accumulation, landslides, and channel disturbances. Logs left to drift and sink in the Lower Fraser River crush wetland plants and deplete oxygen from the surrounding water, harming migrating salmon.

Municipal wastewater

Submitters said that effluents released from Metro Vancouver's Annacis Island and Iona Island wastewater treatment plants are harmful to Fraser River sockeye and that the Iona plant may be responsible for post-1995 changed migration timing of Late-run Fraser River sockeye. The Capital Regional District's stormwater management system flushes high-velocity, toxic stormwater into sensitive salmon habitat. I was told that Salmon Arm discharges raw sewage directly into Shuswap Lake, and Lumby sewage seeps into Bessette Creek. Greywater containing harmful chemicals is discharged from houseboats into Shuswap Lake.

Non–point source contaminants

Non–point source contaminants are associated with diffuse discharges of runoff from a variety of areas. People expressed concern about the effect of contaminants on the sustainability of Fraser River sockeye. Contaminants from agriculture, vehicular traffic, consumer goods, industry, and other sources, I was told, have made the Fraser River a toxic soup of harmful chemicals, poisoning Fraser River sockeye as they migrate to and from the marine environment.

Pesticides

The Commission received several public submissions expressing the view that pesticides have affected salmon habitat. One submitter said that a 2002 study attributed the 90 percent mortality of Late-run Fraser River sockeye observed between 1994 and 2001 to pesticide application in our watersheds.[4]

Pulp mill effluent

Several public submissions suggested that effluent from pulp and paper mills is contributing to the decline in Fraser River sockeye. One submitter thought that sodium hydroxide and powdered tree bark discharged by mills in Quesnel, Prince George, and Port Alberni may have caused salmon smolt mortalities observed by the submitter in the 1960s and 1970s.

Freshwater climate change

Climate change is causing dramatic hydrograph changes in the Fraser River watershed, including warmer waters in creeks, declining water levels, reduced productivity in nursery habitats, and changing flows.

Wildfires

Wildfires result in erosion, increased water temperature and turbidity, and reduced refugia and riparian cover over streams, all of which are harmful to salmon. Fire retardants sprayed across the Fraser River watershed may have contributed to the decline of Fraser River sockeye.

Effects on Fraser River sockeye in the marine environment

Many submitters identified factors operating in the marine environment that may affect Fraser River sockeye salmon. These factors included:

- harmful algal blooms;
- interactions with hatchery salmon;
- food abundance in the North Pacific; and
- marine climate change.

Harmful algal blooms

One submission highlighted a study in the journal *Harmful Algae* that found a strong correlation between naturally occurring blooms of the fish-killing alga *Heterosigma akashiwo* in the southern Strait of Georgia during the juvenile outmigration period and poor returns of adult sockeye two years later.[5] The submitter wrote that in 2007, *Heterosigma* was observed in three periods, the first of which (from late May to early June) coincided with the peak of the juvenile sockeye migration from the river and could explain the poor 2009 return.[6]

Interactions with hatchery salmon

I was told that fish from hatcheries in Alaska, Japan, and Russia have a detrimental effect on wild Fraser River sockeye. Hatchery-raised salmon were described as potential disease carriers, and they may also strain the carrying capacity of the ocean, reducing the food available for wild salmon. Population mixing or interbreeding between the two types of salmon may reduce biological diversity and harm population productivity, and bycatch of wild salmon by commercial fisheries targeting hatchery salmon harms the wild stocks.

Food abundance in the North Pacific

One submitter said that periods of food abundance in the marine environment correlate with strong returns of Fraser River sockeye, noting that “the amount of fish in different parts of the ocean is related to differences in primary production,” or the type of organisms at the base of the food chain, such as phytoplankton or crab larvae.[7] The feeding area of each Fraser River sockeye stock may be highly specific and subject to local oceanographic conditions. If true, this specificity would explain why different Fraser River sockeye stocks appear to have different marine survival rates. The same submitter cited a 2010 study by Roberta Hamme and others which found that ash from a volcanic eruption in the Aleutian Islands caused a large phytoplankton bloom in the North Pacific in 2008.[8] The bloom likely provided an abundant food source for the 2006 brood year, improving the sockeye’s rate of survival and leading to the “phenomenally large return” recorded in 2010.[9]

Marine climate change

Several submitters argued that climate change is having detrimental effects, including changed distribution and interactions of predator and prey species, increased water temperature, increased water acidity, increased carbon dioxide levels, higher rates of hypoxia, erratic winds, and reduced food availability. Climate change is creating a less friendly and less predictable ocean environment, lowering ocean productivity, and causing significant mortality among Fraser River sockeye. Another submitter said that, since Alaska’s salmon stocks are healthy, it is more likely that Fraser River sockeye are declining because of local management decisions. I was also told that the effects of ocean environmental changes cannot be determined because the scientific community lacks sufficient data about the marine stage of the Fraser River sockeye life cycle.

Predation

Submitters said a variety of predators, including salmon sharks, mackerel, pilchards, hatchery salmon, and jellyfish, may be a cause of the decline of Fraser River sockeye. In particular, it was submitted that changes in ocean dynamics, such as increased temperatures, may have drawn Humboldt squid north into the migratory route of Fraser River sockeye. The squid, a predator, appeared in massive numbers off Vancouver Island in 2007, during the outmigration of the Fraser River sockeye that would return to spawn in 2009.

It was also submitted that aggressive seal populations in the Puntledge River, the Stikine River, and the Strait of Georgia at the mouth of the Fraser River are growing rampant, killing juvenile salmon during their outmigration.

Naturally occurring diseases and parasites

Submitters urged the Commission to investigate diseases in wild salmon, including those fish dying along the Alouette and Pitt rivers. One submitter said that outbreaks of the infectious hematopoietic necrosis (IHN) virus during the return migration and pre-spawning activities, when the adult sockeye immune system is at its weakest, can negatively affect stock recruitment. Another submitter said the high rates of pre-spawning mortality observed among early-migrating Fraser River sockeye may be due to Parvicapsula minibicornis, a protozoan parasite targeting sockeye gills and the glomerulus of kidneys. The submitter referenced a number of scholarly articles on the sources and effects of the parasite, including a 2010 study by Bradford and others, and suggested that Late-run Fraser River sockeye may be contracting the parasite between the mouth of the Fraser River and the confluence of the Harrison River.[10]

Population dynamics

Several submitters said that scientists lack a sufficient understanding of how population dynamics relate to stock size. For example, fisheries biologists do not understand the biology of populations exhibiting cyclic dominance, and fisheries forecasts based on population dynamics have failed repeatedly.

Several submitters called for an investigation into the number of five-year-old salmon present in the 2010 return, speculating that, rather than returning to spawn, a large portion of the 2005 brood year may have remained in the ocean in 2009 because of "feeding loop changes" due to warm ocean patches or other factors. Others discussed natural, known fluctuations in salmon populations, which could be due to either climatic phenomena (such as the Pacific Decadal Oscillation) or "species dynamics" associated with "gene pool, sex ratio, and age class" factors.[11]

Over-escapement of Fraser River sockeye

I was told that DFO's harvest management policies allow too many Fraser River sockeye back to spawn. This practice leads to crowding on spawning grounds, triggering stress-induced disease outbreaks that cause significant mortality among Fraser River sockeye and lead to poor returns in subsequent years. Commercial fishers, who are prevented from harvesting salmon, suffer ongoing financial hardship. One submitter disputed the alleged negative effects of over-escapement, referring to a 2002 news release by the Pacific Fisheries Resource Conservation Council stating that there is no evidence that higher escapements have resulted in stock collapse.[12]

Salmon farms

For additional discussion of public submissions on this topic, please refer to Volume 1, Chapter 8, Salmon farm management. Opponents of salmon farms said the industry has placed salmon farms in areas where salmon migrate in high concentrations, despite agreeing not to do so several decades ago. I was referred to articles and reports to support the argument that salmon farms are harmful to wild salmon, including work by Alexandra Morton, who testified in September 2011, and the 2004 report of the Auditor General of British Columbia.[13] Many submitters urged me to recommend that salmon farms be permitted only in closed containment systems, preferably based on land, to protect the migratory routes of wild salmon. I was told that industrial-scale closed containment salmon farms are both scientifically and economically feasible.

Other submitters said that the salmon farm industry poses minimal risk to wild salmon, and that farms are unlikely to be the cause of the decline. Several supporters of salmon farming argued that the large 2010 return disproves claims that aquaculture caused the Fraser River sockeye decline. I was told that the industry provides important economic benefits to remote coastal communities and is a source of healthy food, and should be viewed positively by British Columbians and, in fact, all Canadians.

Still others urged caution, saying that there are not enough data about the effects of salmon farms on Fraser River sockeye and that I should, above all, recommend more research. Several submitters argued that the precautionary principle demands that salmon farms be closed or moved (onto land, for example) until the effects of aquaculture are determined.

More specifically, submissions addressed the issues of contaminants and waste, sea lice, escape of Atlantic salmon, and diseases.

Contaminants and waste

I was told that salmon farms discharge a wide range of harmful contaminants and waste into the environment, including growth hormones, antibiotics, pesticides, fecal material, neurotoxins, heavy metals, and polychlorinated biphenyls (PCBs). One submitter referred to the 2004 report of the Commissioner of the Environment and Sustainable Development, which described a significant buildup of organic waste material on the ocean floor beside a salmon farm site.[14] In contrast, another submission explained that all operating salmon farms are monitored for organic waste impacts and that waste data are reported to and audited by regulators. If a farm is found to exceed biomass thresholds, it must remain fallow until it returns to acceptable levels.

Sea lice

Submitters who argued that sea lice are a cause of the decline of Fraser River sockeye relied on “a mountain of evidence” or noted that studies by Scandinavian countries show that sea lice from salmon farms reduce the survival of migrating wild salmon.[15] Others pointed to agreement among the “the world’s most noted scientists and the prestigious journals in which they write” that sea lice are a “recognized, documented and well known problem associated with open net cage fish farming.”[16] Several submitters maintained that the salmon farm industry uses the chemical SLICE irresponsibly to control sea lice and that SLICE is harmful to crustaceans and shellfish. Other submitters disputed the claim that sea lice caused the decline of Fraser River sockeye, citing instead competition from hatchery salmon and overfishing “by foreign nations on the high seas.”[17] One submission emphasized the strength of the industry’s fish health efforts; frequent site visits and sampling by staff responsible for fish health; the use of vaccines; and data-reporting to, and auditing by, regulators.

Escape of Atlantic salmon

Several submitters said that, despite the industry’s best efforts, farmed Atlantic salmon regularly escape from salmon farms, posing a variety of risks to wild Fraser River sockeye that include introducing “exotic or enhanced disease” contaminating the genetics of wild salmon, competing for food and habitat, and preying on juvenile wild salmon.[18] One submitter said that the Auditor General of Canada in 2000 identified an urgent need for DFO to address the lack of research into the effects of farmed and wild stock interaction.

Diseases

Many submitters argued that cramped conditions on salmon farms promote infectious disease outbreaks, which are spread to migrating Fraser River sockeye. Submitters identified three diseases spread in this manner: infectious salmon anemia (ISA), infectious hematopoietic necrosis (IHN), and bacterial kidney disease. Several submitters referred to a correlation between the decline in productivity of Fraser River sockeye and massive IHN outbreaks on salmon farms in the early 2000s. Another submitter said that the likely location of the 2009 Fraser River sockeye run failure – between Queen Charlotte Strait and Hecate Strait – indicates the failure may have been caused by disease transfer from salmon farms during smolt outmigration, causing a latent mortality. Several submitters said the ISA virus is brought into salmon farms in British Columbia via diseased salmon eggs imported from Europe and South America, citing a 2010 article by Dr. Frederick Kibenge, who in December 2011 testified before me. In contrast, another submission described the various techniques used by the industry to test and treat farmed salmon, including vaccinations, pathogen testing, and routine sampling of fresh mortalities. The same submitter explained that each salmon farm company produces the vast majority of farmed salmon eggs it requires in British Columbia and that no eggs have been imported from Norway in a decade.

Cumulative effects

Several submitters suggested the cause of the decline may be the cumulative effects of a number of stressors facing Fraser River sockeye. One submitter said poor returns of Fraser River sockeye in 2009 were most likely caused by poor physical and biological conditions in the Strait of Georgia, high temperatures in the Fraser River, and various environmental stressors. Another submitter attached a paper examining the future impacts of climate change on Fraser River sockeye.[19]

I turn now to a consideration of several other investigations into the Fraser River sockeye salmon decline that were conducted before or during this Inquiry's activities.

Notes

1 Exhibit 1344.
2 Chilliwack Public Forum Summaries, September 29, 2010, pp. 1–2, available at www.cohencommission.ca.
3 Public submission, 0245-HUSBAND, p. 3, available at www.cohencommission.ca.
4 Exhibit 833.
5 Exhibit 1359.
6 Public submission 0358-HAIGH/Exhibit 1365, available at www.cohencommission.ca.
7 Public submission, 0044-PARSONS, p. 1, available at www.cohencommission.ca.
8 Public submission, 0264-PARSONS, available at www.cohencommission.ca; see also Exhibit 1353.
9 Public submission, 0264-PARSONS, p. 1, available at www.cohencommission.ca.
10 Exhibit 931.
11 Public submission, 0231-ONCLIN, p. 2, available at www.cohencommission.ca.
12 Public submission, 0245-HUSBAND, 100916, p. 6, available at www.cohencommission.ca.
13 Exhibit 1862.
14 Public submission, 0053-WOODWORTH, available at www.cohencommission.ca; see also Exhibit 88.
15 Public submission, 0093-WYENBERG; see also Public submission, 0318-COMMANDEUR, available at www.cohencommission.ca.
16 Public submission, 0085-DAWSON, available at www.cohencommission.ca.
17 Public submission, 0094-MACLEOD, available at www.cohencommission.ca.
18 Public submission, 0312-Russell; see also Public submission, 0126-HOLLINGSWORTH, available at www.cohencommission.ca.
19 Exhibit 1320.

Chapter 3 • Other investigations into the causes of the decline

By late summer 2009, it was clear that 2009 would be the third consecutive year of historically poor returns of Fraser River sockeye. The Department of Fisheries and Oceans (DFO) and other interested entities undertook four investigations into the causes for the poor 2009 return and for the long-term decline in Fraser River sockeye productivity.

Most of these investigations took place before this Commission's hearings began. I include a summary of these investigations, which reveals the state of understanding about the decline when this Commission began its work and provides a useful context within which to assess the evidence that was led during the Commission's proceedings.

September 2009 DFO Science workshop

The 2009 pre-season forecast of Fraser River sockeye returns at the 50 percent probability level was set at 10.6 million, of which Chilko and Quesnel stocks were predicted to comprise 82 percent. However, the in-season preliminary estimate of return for early, spring, and summer Fraser River sockeye was 900,000, less than 10 percent of pre-season forecasted abundance.[1]

In September 2009, staff members of DFO's Science Branch held a workshop to review the available knowledge about factors affecting sockeye survival and to compile probable hypotheses to explain their poor performance.[2] The workshop identified other sockeye stocks with poor returns, including Skeena, Lake Washington, coastal Washington, and southeast Alaska. There were, however, sockeye stocks with good returns, including those in Harrison River and Bristol Bay (Alaska).[3]

Workshop participants considered seven hypotheses to explain the poor 2009 Fraser River sockeye return.

- *Early juvenile freshwater mortality.* The workshop reported that, based on observations from the Chilko and Quesnel juvenile sockeye–monitoring programs, survival to the time juveniles left the lake was as expected or better. However, there was limited information on smolt quality and no information on downstream survival. Environmental conditions could be the plausible cause of the long-term decline, but there was no known anomalous event in 2007 to explain poor performance in that year.[4]

- *Disease.* According to work carried out by the DFO Genomics laboratory, there may be a disease agent that remains unidentified. It is likely that, with climate change, naturally occurring pathogens may cause disease with effects at both the individual and population levels.[5]
- *Early juvenile phase in the Strait of Georgia.* Early marine mortality (which includes downstream mortality) is supported by observations of very low sockeye catches in the Strait of Georgia juvenile surveys in July and September 2007. The workshop identified hazardous algal blooms as "plausible and under consideration."[6] Food web mechanisms were considered a plausible cause of the long-term decline, but no known anomalous event in 2007 explained poor performance in that year. There was no direct observation of increased predation.[7]
- *Sea lice loads.* The workshop reported that management procedures effectively appeared to keep levels of sea lice below those known to cause mortality in other species of salmon. One study found that high concentrations of sea lice could result in low mortality rates of juvenile pink salmon under 0.7 grams, but no mortality of larger fish (such as sockeye). Declines observed for other species that went to sea in 2007 but did not migrate through Discovery Passage "also [suggest] sea lice from fish farms is not a likely explanation."[8]
- *Food web along marine migration route (Queen Charlotte Sound).* Satellite images showing low chlorophyll levels in April 2007 off the west coast of Vancouver Island, Queen Charlotte Sound, and Johnstone Strait reveal ocean conditions in 2007 that could have been poor for juvenile Fraser River lake-type sockeye, while acceptable for Harrison River sockeye. The workshop concluded that low food availability was a plausible hypothesis and could also account for poor performance of southern US sockeye stocks that did not migrate through the Strait of Georgia.[9]
- *Food web along marine migration route (southeast Alaska and Gulf of Alaska).* Species interactions and competition (e.g., with 40 million Bristol Bay sockeye) were possible explanations, but this hypothesis would require differential impacts on stocks that were thought to commingle in this area.[10]
- *Interception in Alaska fisheries.* Based on sampling, potentially 290,000 Canadian sockeye could have been rearing in the Bering Sea in 2009. However, they were not there in sufficient abundance to account for the large discrepancy in returns.[11]

Reports to the minister

In early December 2009, DFO's deputy minister reported to the minister on factors affecting the 2009 Fraser River sockeye return.[12] Her report varied in some respects from the conclusions reached during the workshop. It identified:

- *three factors that could possibly have led to sockeye mortality at the scale observed* – toxic algal blooms in the Strait of Georgia, low food abundance in Queen Charlotte Sound, and viral disease;[13]
- *three factors that may have contributed to sockeye mortality, but not at a magnitude sufficient to explain the poor return in 2009* – predation by Humboldt squid, capture by US fisheries, and mortality attributed to sea lice from fish farms in Discovery Passage;[14] and
- *four factors that are unlikely to have contributed to the poor 2009 return* – pollution in the Fraser River, capture by Canadian fisheries, predation on juvenile salmon in the Strait of Georgia, and low food abundance in the Strait of Georgia.[15]

It is noteworthy that, although the workshop had identified hazardous algal blooms as "plausible and under consideration," the report to the minister elevated the significance of these blooms, stating that they "could possibly have led to sockeye mortality at the scale observed."[16] It is not clear from the report what evidence was relied on other than the presence of extensive blooms in the Strait of Georgia during the 2007 juvenile sockeye outmigration, since the report also stated that staff were working to assess any possible link.[17]

Similarly, the workshop concluded only that "there may be a disease agent that remains unidentified," whereas the report to the minister stated more confidently that "preliminary evidence suggests that Fraser River sockeye may be infected with a virus that could lead to mortality throughout the salmon life cycle."[18] However, the report added that "staff are conducting further tests to confirm whether or not a virus could be present."[19]

Later the same month, the deputy minister reported again to the minister, specifically on diseases. She stated that in 2006 staff identified migrating sockeye with a particular pattern of gene response that was consistent with a virus, possibly from the retroviral family.[20] Sockeye with this gene response experienced a 30–60 percent higher mortality during the return migration. In 2009, DFO scientists also found that significant numbers of migrating sockeye contained lesions in the optic lobe of their brain.* The proportion of such fish declined sharply during the return migration, suggesting an association between the lesions and en route mortality. The same pattern had been found in sockeye smolts before leaving the river and in juveniles of three species (sockeye, coho, and chinook) during their first summer at sea.[21]

Simon Fraser University Think Tank

In December 2009, Simon Fraser University convened a think tank of fisheries scientists to consider the poor 2009 return and the long-term decline in productivity.[22] The think tank reported that the total return of Fraser River sockeye in 2009 was the lowest in more than 50 years. Productivity (recruits returning per spawner) had been declining since the mid-1990s, to the point where Fraser River sockeye are almost unable to replace themselves.[23]

The think tank scientists examined the factors involved at the different life cycle stages and, despite incomplete information, agreed that the problem in 2009 could most likely be attributed to what happened between the time when the fish left the lakes in the spring and their early survival at sea over the next few months.

The think tank concluded that there is a need to increase Canadian research and action on the marine coastal environment and on climate impacts. It proposed four research activities to address critical knowledge gaps on the declining productivity problem:

- Assemble and analyze all existing data on Fraser River sockeye health and condition, and estimate survival throughout their life cycle.
- Compile historical data on the abundance and health of farmed salmon along the sockeye migration route to better understand the potential for transmission of disease and parasites to wild salmon.
- Expand programs at various locations in the Fraser River and in the coastal marine environment to assess the timing and survival of migrating juvenile salmon.
- To understand why some populations and species are doing better than others (including links to climate change) and to determine whether there are shared stressors linked to changes in productivity, compare trends in abundance and survival of various stocks and species. These comparisons may help to identify times and locations where lack of food, predation, disease, parasites, and other problems arise.[24]

June 2010 Pacific Salmon Commission workshop

The Pacific Salmon Commission (PSC) arranged a workshop to evaluate evidence relating to possible causes for the long-term decline and the poor 2009 return.[25] An 11-member Expert Advisory Panel was made up of experienced researchers from British Columbia and Washington. About 25 outside

* In testimony before the Inquiry in August 2011, Dr. Kristina Miller, head, Molecular Genetics, DFO, stated that samples she examined carried heavy vascularization on the outside of the optic lobe, but that subsequent analysis showed these to be hemorrhages, not tumours (Transcript, August 24, 2011, p. 27).

experts were invited to attend the workshop, make presentations, and critically evaluate data and hypotheses about causes for the decline. Other observers attended, bringing total attendance to 68 participants.[26]

Following the workshop, the Expert Advisory Panel grouped the possible explanations into nine categories (see Table 2.3.1). The panel rated each of the nine alternative hypotheses in terms of the relative probability or likelihood for which a given hypothesis could explain the Fraser River sockeye salmon situation both in 2009 and over the longer term. The panel concluded that the available evidence for and against each of the nine hypotheses does not point to a single cause of either the poor adult returns in 2009 or the long-term decrease in returns per spawner. The panel agreed that multiple hypothesized causal mechanisms are very likely to be operating simultaneously and that their effects may be additive or multiplicative (i.e., synergistic), or may tend to offset one another's effects.[27]

Table 2.3.1 Expert Advisory Panel's judgment of the relative likelihood that a given hypothesis contributed to the observed spatial and temporal patterns in productivity of Fraser River sockeye populations

Hypothesis	Time Period	Strength of Evidence	Relative likelihood that each hypothesis caused observed changes in productivity during the indicated time period				
			Very Likely	Likely	Possible	Unlikely	Very Unlikely
1a. Predation by marine mammals	Overall	Fair			▒		
	2009	Fair					▒
1b. Unreported catch in the ocean outside of the Pacific Salmon Treaty area	Overall	Good				▒	
	2009	Good					▒
2. Marine and freshwater pathogens (bacteria, parasites, and/or viruses)	Overall	Fair	▒	▒	▒		
	2009	Fair	▒	▒	▒		
3a. Ocean conditions (physical and biological) **<u>inside</u>** Georgia Strait	Overall	Fair		■			
	2009	Good	■				
3b. Ocean conditions (physical and biological) **<u>outside</u>** Georgia Strait	Overall	Fair			▒		
	2009	Fair			▒		
4. Harmful algal blooms in the Strait of Georgia and/or northern Puget Sound / Strait of Juan de Fuca	Overall	Fair			▒	▒	
	2009	Fair			▒		
5. Contaminants in the Fraser River and/or Strait of Georgia	Overall	Poor			▒		
	2009	Poor				▒	▒
6. Freshwater habitat conditions in the Fraser River watershed	Overall	Fair				▒	▒
	2009	Fair					▒
7. Delayed density dependent mortality	Overall	Fair		▒	▒	▒	
	2009	Fair					▒

Table 2.3.1 cont'd

Hypothesis	Time Period	Strength of evidence	Relative likelihood that each hypothesis caused observed changes in productivity during the indicated time period				
			Very Likely	Likely	Possible	Unlikely	Very Unlikely
8a. En-route mortality during upstream migration (en-route mortality is already considered in estimates of total recruits, so while potentially strongly affecting *spawner abundance*, this hypothesis cannot explain declines in *recruits per spawner*)	Overall	Good					■
	2009	Good					■
8b. The effects of en-route mortality on fitness of the next generation	Overall	Poor					■
	2009	Poor					■
9. Competitive interactions with pink salmon	Overall	Fair		■	■		
	2009	Fair			■	■	■

Notes: The Pacific Salmon Commission explains that these likelihoods are based on evidence presented at its June 2010 workshop (during subgroup discussions) and on panellists' background knowledge. The top row for each hypothesis reflects conclusions about overall productivity patterns (i.e., over the long term). Shading of multiple cells reflects a range of opinions among panel members. The second row of each hypothesis considers just the 2009 return year. The shading reflects the panel's conclusion about the degree of importance: black = major factor; grey = contributing factor. The strength-of-evidence column reflects the quantity and quality of data available to evaluate each hypothesis / stressor. Panel members made their best judgments of the relative likelihood of each hypothesis, given the available evidence.
Source: Exhibit 73, pp. 9–10.

The panel concluded that physical and biological conditions inside the Strait of Georgia during the juvenile life stage are very likely the major cause of poor survival of the cohort that returned in 2009. Those conditions in the Strait of Georgia are also likely the major cause of the long-term decrease in productivity of most Fraser River sockeye stocks that has occurred since the late 1980s or early 1990s. The panel also concluded that similar physical and biological conditions affected survival outside the Strait of Georgia, but to a lesser degree. (However, it lacked certain types of information needed to identify the mechanisms more specifically.)[28]

According to the panel, freshwater and marine pathogens (e.g., viruses, bacteria, and/or parasites) are an important contributor to both the poor returns in 2009 and the long-term decrease in productivity. However, there were insufficient data to allow further distinctions among those factors.[29]

Only three other hypothesized mechanisms likely or possibly contributed to the declines:

- Harmful algal blooms in the southern Strait of Georgia in 2007 were a possible explanation for the poor returns in 2009, and a possible to unlikely explanation of the long-term decline in productivity.
- Panellists expressed conclusions ranging from likely to unlikely for the hypothesis that delayed density-dependent mortality (related to the term "over-escapement"; see the discussion below) contributed to the long-term decrease in productivity.
- Competitive interactions between pink salmon and Fraser River sockeye were rated as either a likely or a possible contributor to the long-term decline.[30]

The panel recommended that a coordinated, multidisciplinary two-phase research program be established, with the following seven monitoring and research topics:[31]

- increased numbers of quantitative juvenile assessments and studies of in-lake responses;
- research to assess sockeye smolt survival between lakes and the Fraser River estuary;
- four research and monitoring programs inside the Strait of Georgia and migration channels:
  - a fully integrated oceanographic and ecological investigation of the Strait of Georgia, including establishment of comprehensive sampling of zooplankton, harmful algal blooms, and estimates of predation by marine mammals, which would help partition sources of mortality of Fraser River sockeye salmon
  - studies of residency and migration paths in the Strait of Georgia
  - a review of how pathogens and contaminants may be expressed under different marine conditions (including transmission due to salmon farming)
  - an estimation of the annual relative survival of Fraser River sockeye over the period of residency in the Strait of Georgia; and
- continued evaluation of the accuracy of in-river sockeye assessments and improvements in those assessments, as well as research and monitoring of in-river mortality of sockeye salmon.[32]

April 2011 DFO internal workshop

In April 2011, DFO scientists convened a two-day workshop to update and discuss the relevant hypotheses surrounding the long-term decline in Fraser River sockeye salmon productivity and the poor 2009 return.[33]

The workshop included presentations from science personnel to provide an update on the state of knowledge surrounding each proposed hypothesis, and to discuss changes in the plausibility ratings assigned at the 2010 PSC workshop. Table 2.3.2 sets out the re-evaluated ranking following the DFO internal workshop.

Table 2.3.2 Updated PSC report table as a result of 2011 workshop discussions

Hypothesis	Time Period	Strength of evidence	Relative likelihood that each hypothesis caused observed changes in productivity during the indicated time period				
			Very Likely	Likely	Possible	Unlikely	Very Unlikely
1a. Predation by marine mammals	Overall	Fair			X		
	2009	Fair					X
1b. Unreported catch in the ocean outside of the Pacific Salmon Treaty area	Overall	~~Good~~ Fair			X		
	2009	~~Good~~ Fair					X
2. Marine and freshwater pathogens (bacteria, parasites, and/or viruses)	Overall	Fair		X			
	2009	Fair		X			
3a. Ocean conditions (physical and biological) **<u>inside</u>** Georgia Strait	Overall	Fair					
	2009	Good	X				
3b. Ocean conditions (physical and biological) **<u>outside</u>** Georgia Strait	Overall	Fair		X			
	2009	Fair		X			
4. Harmful algal blooms in the Strait of Georgia and/or northern Puget Sound / Strait of Juan de Fuca	Overall	Fair			X		
	2009	Fair			X		

Table 2.3.2 cont'd

Hypothesis	Time Period	Strength of evidence	Relative likelihood that each hypothesis caused observed changes in productivity during the indicated time period				
			Very Likely	Likely	Possible	Unlikely	Very Unlikely
5. Contaminants in the Fraser River and/or Strait of Georgia	Overall	Poor			X		
	2009	Poor				X	X
6. Freshwater habitat conditions in the Fraser River watershed	Overall	Fair				X	X
	2009	Fair					X
7. Delayed density dependent mortality	Overall	Fair		X			
	2009	Fair					X
8a. En-route mortality during upstream (en-route mortality is already considered in estimates of total recruits, so while potentially strongly affecting *spawner abundance*, this hypothesis cannot explain declines in *recruits per spawner*)	Overall	Good					X
	2009	Good					X
8b. The effects of en-route mortality on fitness of the next generation	Overall	Poor					X
	2009	Poor					X
9. Competitive interactions with pink salmon	Overall	Fair		X	X		
	2009	Fair			X		

Note: Shaded boxes reflect ratings assigned in the original PSC report. "**X**" indicates the re-evaluated ranking from the outcomes of the 2011 DFO internal workshop.
Source: Exhibit 1364, pp. 3–4.

A June 16, 2011, memorandum to the deputy minister stated that, based on the most recent analyses, four factors most likely led to sockeye mortality at the scale observed in 2009:

- *Low food abundance in the Strait of Georgia.* Recent evidence points to extremely poor conditions for juvenile sockeye entering the Strait of Georgia in 2007, as reported at the June 2010 Pacific Salmon Commission workshop.
- *Low food abundance in Queen Charlotte Sound and Gulf of Alaska.* Strong evidence indicates that the timing and intensity of extreme weather in the spring of 2007 led to poor ocean conditions for food production for juvenile sockeye in Queen Charlotte Sound, and poor winter feeding conditions in the high seas of the Gulf of Alaska.
- *Disease.* Many diseases affect sockeye salmon, and mortality from disease could have increased in 2007 when juvenile sockeye were stressed by low food abundance. Of specific interest is a genomic signature associated with premature mortality of returning adult sockeye and a recently identified novel salmon parvovirus.
- *Toxic algal blooms in the Strait of Georgia.* Although data are limited, US research supports the presence of extensive blooms in the Strait of Georgia in 2007, when juvenile sockeye were present.[34]

According to the memorandum, three other factors may have contributed to sockeye mortality, but not at a magnitude sufficient to explain the poor 2009 return:

- *Predation by Humboldt squid.* The Humboldt squid, a voracious predator that can feed on sockeye, was abundant in Canadian waters between 2007 and 2009 but absent in 2010. Washington-California sockeye returns from the 2007 ocean-entry year suggest that Humboldt squid did not have a significant effect.
- *Capture by US fisheries.* Fraser River sockeye are intercepted in the US Gulf of Alaska and Bering Sea fisheries, but the level appears to be very low.
- *Mortality attributable to sea lice.* Sea lice from salmon farms in Discovery Passage could have contributed some mortality of juvenile sockeye in 2007, although the levels of lice present on farms in 2007 were similar to 2008 levels, which produced a strong sockeye return in 2010.[35]

Finally, three other factors are stated to be unlikely to have contributed to the poor 2009 return:

- *Pollution / contaminants in the Fraser River.* There is no record of any Fraser Basin–wide environmental incident that could have had an impact on juvenile sockeye.
- *Capture by Canadian fisheries.* In 2009, the Canadian fishery was minimal and did not contribute to the poor return.
- *Predation on juvenile salmon in the Strait of Georgia.* There are no known shifts in predator abundance during the 2007 outmigration.[36]

Concerning the long-term decline in Fraser River sockeye, the memorandum prepared for the deputy minister stated:

> Climate / ocean conditions are also thought to be the most likely factors associated with the longer term decline in Fraser sockeye, although a number of additional factors (disease, delayed density-dependence, competitive interactions with pink salmon and contaminants) could also contribute.[37]

I will now summarize the technical reports filed as exhibits and the testimony of those who gave evidence during the Commission's hearings about the various stressors that may have caused or contributed to the decline of Fraser River sockeye salmon.

Notes

1 Exhibit 614, p. 2.
2 Exhibit 614.
3 Exhibit 614, pp. 2–3.
4 Exhibit 614, p. 6.
5 Exhibit 614, p. 7.
6 Exhibit 614, p. 7.
7 Exhibit 614, p. 8.
8 Exhibit 614, p. 8.
9 Exhibit 614, p. 10.
10 Exhibit 614, p. 10.
11 Exhibit 614, p. 10.
12 Exhibit 616A.
13 Exhibit 616A, pp. 2–3.
14 Exhibit 616A, p. 2.
15 Exhibit 616A, p. 2.
16 Exhibit 616A, p. 2.
17 Exhibit 616A, p. 2.
18 Exhibit 616A, p. 3.
19 Exhibit 616A, p. 3.
20 Exhibit 616B, p. 3.
21 Exhibit 616B, p. 3.
22 Exhibit 11.
23 Exhibit 11, p. 1.
24 Exhibit 11, p. 1.
25 Exhibits 73 and 203.
26 Exhibits 73/203, p. 3.
27 Exhibits 73/203, p. 5.
28 Exhibits 73/203, p. 5.
29 Exhibits 73/203, p. 5.
30 Exhibits 73/203, p. 5.
31 Exhibits 73/203, p. 7.
32 Exhibits 73/203, pp. 21–22.
33 Exhibit 1364.
34 Exhibit 1371, p. 3.
35 Exhibit 1371, pp. 2–3.
36 Exhibit 1371, pp. 2–3.
37 Exhibit 1371, p. 1.

Chapter 4 • Summary of decline-related evidence

Although it is common to speak about Fraser River sockeye salmon as though they are a singular grouping of genetically identical fish that behave in a uniform manner, the truth is far different. Fisheries managers have traditionally clustered Fraser River sockeye into "stocks," identified principally according to their natal rivers or lakes distributed throughout the watershed. Nineteen such stocks have been the subject of most studies and monitoring. More recently, under the 2005 Wild Salmon Policy, the Department of Fisheries and Oceans (DFO) has grouped Fraser River sockeye into 20 to 30 Conservation Units (CUs) based on genetic differences. Indeed, a CU is defined as "a group of wild salmon sufficiently isolated from other groups that, if extirpated is very unlikely to re-colonize naturally within an acceptable timeframe, such as a human lifetime or a specified number of salmon generations."[1]

In addition to this genetic diversity, Fraser River sockeye exhibit significant behavioural variation. They all begin life in freshwater, grow to maturity in the North Pacific, and return to freshwater to spawn. However, some spend one to two years in nursery lakes while others do not; some migrate out through the Fraser River in days while others spend several months in the estuary; some migrate north through the Strait of Georgia while others migrate south through Juan de Fuca Strait; most return to their natal streams to spawn in their fourth year while others do so in their third or fifth year; and some move directly from the Strait of Georgia into the Fraser River while others hold off at the mouth of the river for four or five weeks before moving upstream. Fisheries managers also group returning adults according to four run-timing groups, depending on when during the summer months they begin their return migration. (For a more detailed discussion of run-timing groups, see Volume 1, Chapter 5, Sockeye fishery management.)

The decline in Fraser River sockeye that triggered the establishment of this Inquiry in 2009 can fairly be described as "a decline" when all stocks are studied on an aggregate basis. However, when individual stocks are examined, important variations in productivity (recruits returning per spawner) are evident. To complicate matters further, some (but not all) Fraser River sockeye stocks show dramatic variations in abundance over a four-year cycle (a pattern called "cyclic dominance") that consists of a dominant year, followed by a sub-dominant year, followed by two much less productive years.

To these fascinating variations in Fraser River sockeye themselves must be added similarly complex variations in freshwater and marine habitat, environmental conditions, and the myriad stressors that affect sockeye differently, depending on the geographical area and the life stage under consideration. Moreover, exposure to stressors in one life stage may not reveal their effects until a later life stage, and stressors may interact in different ways at different life stages.

In light of these complexities, it is prudent to embark on this analysis bearing in mind the caution voiced by the authors of Technical Report 1A, Enhancement Facility Diseases:

> It is tempting to think of a cause as a single entity, event or condition which inevitably leads to a specific outcome. This is rarely the case in biomedical situations, especially when population health and disease are being considered. The presence or absence of a disease typically requires a complex interplay of factors. When referring to wildlife populations, Holmes (1995) said, "Looking for a single, consistent cause for population regulation is not only wishful thinking, but also hinders our efforts to understand population dynamics. Population regulation is not only multifactorial, but interactions among those factors are important; single-factor experiments can miss important interactions. In addition, the ecological context consistently changes, so that regulatory processes track a moving target; experiments can have different results if the context differs."[2]

In the pages that follow, as much as the evidence allows, I examine the various stressors affecting Fraser River sockeye salmon according to their different life stages, adopting a five-life-stages categorization.

This chapter constitutes a summary of the evidentiary record related to the decline that is before this Commission. It is intended to accurately reflect what the researchers wrote in their reports and what witnesses said in their testimony. It should not be assumed that I necessarily agree with or endorse everything set out in this chapter of the Report. Rather, it is a summary of what I read and heard. My findings and conclusions respecting the causes of the decline of Fraser River sockeye salmon will come later, in the following chapter of this volume.

Life stage 1: incubation, emergence, and freshwater rearing

Incubation

After the long return journey to her spawning grounds, the female Fraser River sockeye selects a site for the deposit of her eggs (a redd), digs a nest in the gravel substrate, and deposits 500 to 1,100 eggs, which are simultaneously fertilized by an accompanying male or males. She then covers the eggs by further digging and repeats the digging and spawning process up to several times. Finally, she covers the completed redd, now containing two or several nests of eggs, and then guards the redd site until near death. The eggs develop in the gravel during the winter. In the early spring, after about five months' incubation, alevins emerge from the eggs. A pronounced yolk sac suspended below the body provides nourishment for the next six to 10 weeks, depending on water temperature. During this period, the alevins remain in the gravel for protection from predators and because they are poor swimmers.

Fraser River sockeye salmon are particularly vulnerable during this incubation period. The mortality rate during this seven-month period can be 80 to 86 percent.[3] In the case of a spawning female that lays 3,000 eggs, 2,580 may die during incubation or soon thereafter.[4] Mike Lapointe, chief biologist, Pacific Salmon Commission, identified the following naturally occurring stressors that contribute to egg and alevin mortality:

- Redds may be disturbed or destroyed by later-spawning females, an action that may expose the eggs within to a variety of stressors.
- High water flows may lead to scouring of redds, exposing the eggs within.

- Low water levels in natal streams and lakes can lead to desiccation (dehydration) or freezing of eggs.
- The eggs or alevins may suffocate as a result of the deposition of fine sediment in the gravel, or because of low oxygen levels in the water.
- The eggs or alevins may be exposed to diseases or parasites.
- Predators, either birds or other fish species, may attack eggs or alevins within the redds.[5]

I turn now to a consideration of the stressors that may have caused or contributed to the recent decline during this life stage.

Predation

The authors of Technical Report 8, Predation, Dr. Villy Christensen and Dr. Andrew Trites, stated that several factors must exist before a potential predator can be deemed to have a significant impact on the decline in survival rate of Fraser River sockeye. These factors include:

- The prey and predator must overlap in time and space.
- The prey has to be eaten or preferred by the predator.
- There has to be a sufficient abundance of the predator.
- The abundance of the predator must have been increasing in recent decades, or there must be indications that the predator may have shifted to feed more on sockeye.[6]

The researchers reported that cutthroat trout are known to specialize on salmon eggs between October and January.[7] However, they noted that little information is available about abundance and trend of cutthroat trout in the Fraser River system. They added, "It is our subjective evaluation ... that cutthroat trout are unlikely to be abundant enough to constitute a major factor in the decline."[8]

The researchers also stated that rainbow trout are known to feed on sockeye eggs in Quesnel Lake, but abundance and trend information is not available for the Fraser River system. Based on Kootenay Lake studies and evidence of increased angler effort, they concluded that rainbow trout have been rather stable over the past decades and are unlikely to be a major factor for the Fraser River sockeye decline. They also concluded that steelhead are unlikely to be a major factor in the sockeye decline, given that the steelhead population is reduced throughout British Columbia, and notably in the Fraser River.[9]

Five species of sculpins are predators on sockeye eggs and alevins. A 1998 study of an Alaskan lake found that sculpins move actively to the spawning beaches before the onset of spawning, and the largest sculpins consume up to 50 eggs in a single feeding.[10] It was estimated that they consumed about 16 percent of the total number of sockeye eggs spawned, primarily immediately after the eggs were spawned. The researchers concluded, however, that

> [g]iven that there is nothing to indicate that sculpins should have increased in abundance in recent decades, and that sculpins may only be a factor on the youngest sockeye, it is not likely that sculpins should be of importance for the decline in the survival of Fraser River sockeye salmon over the last three decades.[11]

Climate change

The authors of Technical Report 9, Climate Change, Dr. Scott Hinch and Dr. Eduardo Martins, examined the possible contribution of climate change to the recent decline in abundance and productivity of Fraser River sockeye by reviewing the literature on the effects of climate-related variables, especially increased water temperatures, on sockeye biology and ecology.

The typical temperature during incubation is 5°C.[12] The researchers reported that survival of sockeye eggs (from fertilization to hatching) is highest at about 8°C, and declines under cooler and warmer temperatures. The survival of alevins (from hatching to emergence from the gravel), however, appears to be independent of temperature. The effect of temperature on survival of eggs and alevins varies among populations from interior and coastal areas. The differences are thought to reflect local adaptations to thermal conditions that the fish's ancestors have historically experienced during incubation.[13]

Another climate change factor that can potentially decrease the survival of eggs is scouring from the spawning nest during high stream flows generated by rainfall. However, increased rainfall may also be associated with increased freshwater survival, presumably because it increases the area available for spawning and, hence, reduces mortality caused by superimposition of eggs.[14]

The researchers found that adjacent to freshwater habitats, air temperature in the Pacific Northwest has increased an average of 0.08°C per decade over the past century. Precipitation has increased by 14 percent per century, with more of it now occurring as rainfall. In British Columbia, minimum temperatures have shown the highest rate of increase at 0.17°C per decade, and precipitation has increased by 22 percent per century. The highest increases in precipitation have occurred in the interior area.[15]

Warm winters and springs since the 1950s have caused earlier snowmelt and, hence, an advance in the spring freshet by one to four weeks across a large number of rivers in the Pacific Northwest. In the Fraser River, the dates that mark one-third and one-half of the cumulative annual flow have been occurring approximately one day earlier per decade since the 1950s.[16]

There has also been a noticeable increase in water temperatures of rivers and streams. In the Fraser River, water temperatures in the summer have increased at the rate of 0.33°C per decade since the 1950s, and the river is now 2.0°C warmer than 60 years ago. No long-term records of water temperatures in the winter and spring, when sockeye salmon eggs are incubated, are available, but the Fraser River watershed has likely warmed at the highest rates during that season, since that is when the province's climate has warmed the most.[17]

The researchers made a qualitative assessment that life stage–specific survival has changed in the past 20 years owing to the recent climate patterns, particularly in temperature. Assuming that average stream temperatures through winter and spring have not become warmer than 8°C throughout the Fraser River watershed, survival of sockeye salmon eggs has possibly increased, though that of alevins has unlikely changed. However, climate warming may not have affected the early life stages of all Fraser River stocks equally – the survival of interior-spawning stocks may actually have been negatively affected because their eggs and alevins seem better adapted to colder temperatures.[18]

A confounding factor in this assessment relates to increased precipitation. Higher precipitation in the form of rain may have led to an increase in the mortality of eggs (due to scouring) in recent decades. Interior-spawning stocks would have been more affected because changes in precipitation have been greater in the interior. Also, returning adult Fraser River sockeye are now smaller than in the past and, since smaller females bury their eggs at shallower depths than larger fish, the chances of scouring is increased. On the other hand, as noted above, increased precipitation means an increased area for spawning, which may result in lower levels of mortality due to egg superimposition.[19]

Habitat impacts

I heard from DFO witnesses that habitat degradation and loss pose risks to Fraser River sockeye and that, if trends persist, there is going to be a significant decline in the productive capacity of Fraser River sockeye habitat. These trends will affect sockeye in an incremental way over time because habitat productivity has some direct bearing on the ability of an ecosystem to produce fish (although one DFO witness said habitat is not believed to be implicated in the dramatic fluctuations in sockeye returns).[20] I also heard that spawning, rearing, and all the migration routes, including the Fraser estuary, are critically important for maintaining the productivity of these stocks.[21]

Other freshwater stressors

This section considers evidence of the impact on incubating Fraser River sockeye of forest harvesting, the mountain pine beetle, surface water withdrawals and groundwater extraction, small hydroelectric projects, agriculture, and linear development. Some of the stressors discussed here could also affect the emergence and freshwater-rearing phases, which are discussed later in the chapter.

Technical Report 3: Freshwater Ecology

The authors of Technical Report 3, Marc Nelitz and others, sought to understand the potential role of freshwater stressors in recent Fraser River sockeye declines by compiling and analyzing the best available data describing six categories of human activities that have the potential to affect sockeye salmon: forestry, mining, hydroelectric projects, urbanization upstream of Hope, agriculture, and water use.

Forestry. Three core forest-harvesting activities can have a potential impact on sockeye salmon habitats and survival at different life stages. The first is road construction, which has increased by as much as 20 percent in British Columbia's interior over the past decade and interferes with the natural patterns of water flow through a watershed. As water drains across exposed road surfaces, the increased sediment is carried into streams and can cover spawning redds and reduce oxygenation of incubating eggs. Similarly the second activity, upslope harvesting, can alter hydrology of a watershed, which affects the delivery of water and gravel throughout the stream network. Finally, activities in riparian areas can affect water quality by disturbing stream bank integrity, reducing watershed inputs of nutrients and woody debris, and increasing stream temperatures through reduced streamside shading.[22]

Although our understanding of the effects of the mountain pine beetle disturbance is riddled with uncertainty, some things are known. (The mountain pine beetle is further discussed below.) Hydrologists generally agree that the resulting defoliation of pine forests leads to a decrease in interception of precipitation and loss of transpiration, factors that increase the amount of water in soils and in turn affect surface water and groundwater supplies. The loss of forest canopy will also affect the accumulation of snow and rates of snowmelt. These changes are expected to lead to an increase in total water yields and higher peak flows. Increased soil water and stream flow can lead to decreased slope stability, increased flooding, and alterations in the quality and quantity of freshwater habitats. In particular, the combined effects of beetles and salvage logging on watershed hydrology will affect the delivery of water and sediment and could consequently reduce spawner, egg, and juvenile survival. These effects will be most evident in years with intense storms.[23]

Mining. Several processes associated with mining have a potential impact on sockeye salmon–spawning habitats. For example, permanent habitat loss can occur when a mine site or tailing pond is built directly on top of a lake or stream, and mining of gravel or placer minerals from the stream bed itself leads to a less obvious disruption of the stream bed. Silt and sand from roads, pits, and gravel washing can be transported to spawning areas, thereby reducing egg survival. Mines can produce acid drainage, heavy metals, and other contaminants, and sediment from mining activities can increase lake turbidity, which can reduce light penetration and productivity or, conversely, increase nutrients and productivity.[24]

Placer mining, which targets alluvial deposits in modern or ancient stream beds, has a potentially severe impact on sockeye salmon because many alluvial deposits are closely associated with existing streams, and because water is often used to separate placer minerals from the gravel matrix. Gravel (construction aggregate) mining has a potentially severe impact on sockeye salmon populations because it targets alluvial deposits. The researchers concluded that placer mining appears to have the highest potential to reduce early freshwater survival of Fraser River sockeye. Gravel mining is thought to have less impact on Fraser River sockeye, most of which use the reaches where gravel mining occurs only as migratory corridors. The researchers reported that only one active metal mine in the Fraser River drainage is close to habitat occupied by juvenile sockeye salmon, and that no active coal mining or oil and gas production is found in the Fraser River basin.[25]

Hydroelectric projects. Independent power projects could affect sockeye salmon survival in a number of ways. For example, high total gas pressure can occur when gas or air is entrained in water and can then produce gas bubble trauma for eggs or alevins. Also, dams can disrupt the gravel supply to downstream reaches if sediment is either trapped in a reservoir or periodically removed from an intake structure. This disruption in gravel supply can have serious negative effects on channel integrity and the quality of salmon habitat in reaches downstream of dams.[26] The researchers concluded that, given the available data and the small number of independent power projects close to spawning grounds, these projects have not had a significant impact on sockeye salmon populations.[27]

Urbanization upstream of Hope. Noting that more than two-thirds of British Columbians live in the Fraser River basin, the researchers identified three ways in which urbanization and the related built environment have the potential to affect the freshwater habitats of Fraser River sockeye salmon. First, residential, business, and industrial development and road-related construction can increase the amount of impervious surfaces in urban watersheds, which affects rates of interception, patterns of runoff, and, in turn, the magnitude and timing of instream peak and low flows. Second, construction of roads and buildings along stream channels and lake foreshore areas has the potential to reduce riparian vegetation, channelize streams, and block access to habitats. Finally, roads, stormwater runoff, and municipal and industrial effluents have been known to alter water quality in watercourses across the Fraser River basin by changing concentrations of sediments, nutrients, and contaminants. Nevertheless, the researchers concluded that urban environments have a relatively small footprint within watersheds and riparian zones that influence sockeye spawning and rearing habitats, the majority of which are upstream of Hope.[28]

Agriculture. Livestock grazing and crop production can lead to physical alterations of streams, riparian zones, and flood plains. Cattle crossing through streams can potentially increase sedimentation, destroy spawning redds, and destabilize stream banks or widen stream channels. Removal and disturbance of vegetation in the riparian zone can reduce shading and increase water temperature, affecting spawners and eggs. Direct removal of water from groundwater and surface water supplies for irrigation and livestock purposes can be a significant stressor. Finally, agricultural activities can have a significant impact on the water quality of streams and lakes by increasing biochemical oxygen demand; introducing pathogens; and affecting concentrations of sediments, nutrients, and pesticides into waterways. However, the researchers concluded that agriculture has a relatively small footprint within watersheds and riparian zones that influence sockeye salmon spawning and rearing habitats.[29]

Water use. Potential impacts of water use on sockeye salmon are related to alterations in water flows and temperatures. Surface water use can reduce instream flows that constrain access to spawning habitats or, in extreme cases, de-water redds. Extraction of groundwater for irrigation can reduce flows into streams, increasing water temperatures that affect sockeye salmon adults and eggs.[30]

Nelitz and others concluded:

> Our assessment of the cumulative effect of freshwater stressors suggests that the recent declines in Fraser River sockeye salmon are unlikely to be due to changes in freshwater habitats … An important piece of evidence in reaching this conclusion is that juvenile survival has remained relatively stable across CUs where data are available (see Peterman et al. 2010 [Exhibit 748]), even though there is substantial variation in stressor intensity across CUs.* In the literature, there is strong evidence that the stressors examined here can lead to declines and extinctions of populations in a variety of species, including sockeye salmon. A consideration of individual stressors … suggests that the highest levels of overall stress are generated by forest harvesting and roads, while water use and large hydro also generate significant stress for individual CUs.[31]

During the evidentiary hearings, Mr. Nelitz testified that the timing of some stressors does not coincide with the timing of the pattern of decline in sockeye salmon.[32] For example, the mountain pine beetle infestation did not become serious until 2003, at least a decade after the Fraser River sockeye decline began. Similarly, in many watersheds the intensity of forestry disturbances has been relatively stable.[33] Mr. Nelitz also observed that, generally, the longer the migration distance of a Fraser River sockeye stock, the greater its decline.[34]

Forest harvesting impacts

Dr. Peter Tschaplinski, a research scientist with the BC Ministry of Environment, testified that a number of potential forestry-related impacts on

* The conclusion that juvenile survival has remained relatively stable across CUs is based on data from only nine stocks. See Exhibit 748, p. 2.

Fraser River sockeye habitat, including changes to watershed hydrology, can influence stream flow and processes, channel form, and erosional processes, as well as changes to riparian environments that might affect water temperature, nutrient provision, channel structure, and stream microclimates.[35]

Dr. Tschaplinski is the author of a 2010 report evaluating the effectiveness of DFO's riparian management between 2005 and 2008 (the FREP Evaluation).[36] This evaluation found that 87 percent of streams in the province were in one of three stages of properly functioning condition.[37] Dr. Tschaplinski stated that, concerning their potential to harm fish habitat, forestry practices have improved greatly during the recent 20-year decline in Fraser River sockeye and are thus unlikely to have caused the decline.[38] However, he noted the importance of watershed-based baseline research in ensuring that forestry practices do not harm sockeye habitat.[39]

Mountain pine beetle impacts

In March 2007, the British Columbia Forest Practices Board released a special investigative report entitled *The Effect of Mountain Pine Beetle Attack and Salvage Harvesting on Streamflows*.[40] This study was based on Baker Creek, a western tributary of the Fraser River at Quesnel that contains high-value salmon habitat.[41] The study found that:

- peak flows were 60 percent higher after the beetle moved through this watershed;
- total annual flows were 30 percent higher;
- after salvage logging had removed 80 percent of trees in the watershed, peak flows were even higher, at 92 percent;
- flood frequency also increased significantly, with projections that a former once-every-20-year flood would occur every three years on average; and
- the mountain pine beetle would affect flooding, channel stability, and fish habitat within similar watersheds.[42]

In 2010, the head of DFO's Fish-Forestry Research Program, Erland MacIsaac, stated that Fraser River sockeye natal watersheds are not threatened by the mountain pine beetle:

> There's relatively little pine in most of the Fraser River sockeye natal watersheds. Based on the most recent BC forest health aerial survey reports, most of the southern interior watersheds have declining rates of infestation because the mature pine is dead. Areas where there is some current Mountain pine beetle expansion are in the Skeena / Stikine watersheds and northern forest districts as the beetle moves north to more marginal pine areas, but these are areas outside of the Fraser drainage.
>
> There is always the possibility, in the future, that other conifer beetle and defoliant pests (e.g., western balsam bark beetle, western spruce budworm) may experience similar population booms in the types of forests that dominate in the watersheds of Fraser sockeye. But that's mostly speculation at this point.[43]

However, according to Peter Delaney, former chief, Habitat Policy Unit and Fish Habitat Unit and senior program adviser, DFO, significant amounts of pine are found in the catchment areas of some parts of the Fraser River watershed (for example, the Nechako River drainage).[44]

At the hearings, Dr. Tschaplinski and Ian Miller, manager, Sustainable Forest Management, BC Ministry of Forests, Lands and Natural Resource Operations, testified, and documentary evidence was presented about the potential impact of the mountain pine beetle on Fraser River sockeye. The following points were covered:

- Large-scale salvage harvesting can result in high clear-cut areas in a watershed and high levels of forest removal could mean increased water table levels because of alteration to watershed hydrology and high-energy erosional implications for both spawning and rearing habitats.[45]
- The potential exists for increased forest fires, which may result in increased water temperatures and changes in the dynamics of material delivery.[46]
- There is also the potential for increased terrain instability and landslide frequency.[47]
- Salvage-harvesting activities reduce shade and stream functioning.[48]

Dr. Tschaplinski said that provincial field assessments had not yet shown increased clear-cutting in riparian areas.[49] However, Mr. Miller stated that, under the salvage operation under way, it is reasonable to expect larger clear-cuts in the future.[50] A University of British Columbia study examined the impacts of the mountain pine beetle on channel morphology and woody debris in riparian areas.[51] It found that, in the riparian areas surveyed, there were relatively small volumes of pine. The study concluded that woody debris transferred to the streams in the next 25 years is likely to be relatively small and within the range of typical conditions.[52]

Given the unknowns about the future impact of the mountain pine beetle on fish–forestry interactions, Dr. Tschaplinski recommended researching large-scale clear-cutting impacts on fishery values.[53]

Surface water withdrawals and groundwater extraction

Dr. Michael Bradford is a research scientist with DFO and Simon Fraser University, and during the hearings he was qualified as an expert in aquatic habitat ecology.[54] He testified that the impact of removing water from a stream, for any purpose, is to reduce the magnitude of flow.[55] Low stream flows have the potential to affect salmon in various ways, for example, by limiting access to spawning and rearing habitat, interrupting the passage of adults to spawning grounds, and contributing to the problem of high water temperatures during the summer migration period.[56] In some parts of the BC interior, extensive water withdrawals occur in the summer for irrigation, at a time when streams have naturally lower flows and maximum temperatures.[57]

However, impacts from water withdrawals may be less of a concern for sockeye as compared with other species of salmon because major sockeye-producing areas such as the Adams River are generally located downstream of large lakes, which provide a buffering influence on stream flows.[56] Water withdrawals may have some effect on sockeye in the Shuswap Basin, although Dr. Bradford did not think it is as big a problem for sockeye as for coho.[59]

According to Jason Hwang, area manager, BC Interior office, Oceans, Habitat and Enhancement Branch (OHEB), his staff have generally not observed any impact to sockeye related to water withdrawals.[60] However, he said that water withdrawals could become a concern in the future as demand for water increases.[61] Dr. Bradford agreed that population growth, particularly in the drier Okanagan and Cariboo areas, could have impacts on sockeye in the future.[62]

Dr. Steve MacDonald, a research scientist with both DFO and Simon Fraser University, testified as an expert in aquatic habitat ecology. He described how groundwater has a number of functions that may contribute to the survival of salmon, which may be affected by extraction. Groundwater delivers ions and nutrients to streams and generally has a moderating influence on stream temperatures. In winter, particularly in the northern parts of the Fraser River watershed, it prevents streams from freezing and anchor ice from forming. In summer, groundwater provides a cooling influence on the spawning grounds, which is important in areas such as the Nechako watershed. Groundwater may also have a cooling influence on streams, which are used by adult sockeye as “thermal refugia” en route to the spawning grounds.[63]

Dr. Bradford indicated that groundwater extraction is potentially a concern for Cultus Lake sockeye.[64] Dr. Craig Orr, executive director of the Watershed Watch Salmon Society and qualified at the hearings as an expert in behavioural ecology with a specialty in salmon habitat ecology, said that, to maintain the Early Stuart sockeye stocks, something has to be done to protect groundwater.[65] He also said that groundwater is the “key to resilience of the salmon habitat.”[66]

Independent power projects

DFO has identified a number of potential impacts of independent power projects (IPPs) on fish and fish habitat, including the following:

- Construction and installation of powerhouses, intakes, and other hydro infrastructure may cause a harmful alteration, disruption, or destruction of fish habitat (a HADD, which is prohibited by section 35 of the *Fisheries Act*).
- Operating requirements of a facility may alter natural flow regimes and cause a flow-related HADD (where instream flows are insufficient for the protection of fish and fish habitat).
- Entrainment in pen stocks and turbines may lead to mortality of fish.[67]

According to Mr. Hwang, DFO does not consider IPPs to be a "particular imminent concern" for sockeye, given that most of the projects reviewed by DFO are not interacting or intersecting with sockeye.[68] This situation could change, however, if IPPs "continue to be something that is emphasized and development is pursued across a wide portion of the landscape."[69] Neither Dr. Bradford nor Mr. Hwang was aware of any IPPs in the Fraser River watershed that are affecting sockeye or their habitat.[70] However, Dr. Orr cautioned that "these projects are slowly creeping into anadromous fish habitat" and gave two examples of proposed projects with potential to affect steelhead and coho.[71] He also pointed out that it is difficult to assess the impacts of IPPs because there is no planning process, no public input on siting, and a lack of transparency with the monitoring program, and because the impacts are not well understood.[72]

Agriculture

Michael Crowe, section head, BC Interior office, OHEB, testified that agriculture affects fish habitat through runoff that carries pesticides and fertilizers into salmon habitat; water extraction; cattle grazing in and trampling riparian areas; ditching, diking, and stream channelization; and impediments to fish passage.[73]

Use of fertilizers is compounded by increased livestock densities that increase natural fertilizer nitrate and phosphate loading.[74] Runoff from this natural fertilizer can also be laced with chemicals and hormones deriving from animal feed made to augment growth and development.[75] Fertilizer runoff can cause the loss of aquatic plants, lowered oxygen levels, changes in local phytoplankton community structure, and increased biochemical oxygen demand in sediments.[76] Biosolids are also used in the Fraser River basin as fertilizer, and runoff from these application sites is a potential source of municipal wastewater chemicals in the Fraser River watershed.[77]

Linear development

Linear developments in the Fraser River basin include road networks, rail networks, electrical transmission lines, and seismic lines used in the oil and gas industry.[78] Road development can increase the number of stream crossings, which impede fish passage and may affect fish habitat.[79] Road and highway construction can affect local stream habitat and biota, but some of the impact will also be felt downstream.[80] The main threat is fine sediment pollution that can cause direct mortality, reduce reproductive success, and reduce food availability for fish.[81] Other threats include encroachment of development onto flood plains and riparian areas; loss of critical riparian vegetation; and modifications of the stream channel – which can alter flow characteristics, causing further impacts downstream.[82]

The construction of bridges may affect banks only minimally, but channelization and poor construction practices may destabilize channels.[83] Culverts, which are often used as alternatives to spanning structures on streams, can destabilize stream channels by disrupting the flow of woody debris, sediment, and water.[84] Culverts also tend to cause the stream channel to widen above the constriction, reducing current velocities and trapping sediment.[85]

Human development–related impacts in the Lower Fraser River

The authors of Technical Report 12, Lower Fraser Habitat, Dr. Mark Johannes and others, focused exclusively on stressors in the Lower Fraser River, from Hope to the estuary. They summarized potential human development–related impacts from 1990 to 2010, and qualitatively examined potential interactions between human development and activities in the Lower Fraser River for sockeye salmon habitats. Their findings are summarized below, under the heading Life stage 2: smolt outmigration.

Emergence and freshwater rearing

In about May, approximately eight months after spawning, the yolk sac is absorbed into the body cavity, and the alevin becomes a fry.[86] The fry, now typically about 3 cm long, migrates downstream (or more rarely upstream) into a nursery lake in search of food.[87]

The fry typically live in the nursery lake for one year (or in some cases two years), feeding on zooplankton such as *Daphnia*. They tend to remain near the surface at dawn and dusk while they are feeding, and migrate deeper during the bright daylight hours to avoid predators.[88]

Several Fraser River sockeye populations, including the Harrison River population, do not spend a year in a nursery lake and are thought to have a different outmigration pattern. They migrate downstream almost immediately after emerging from the gravel and, after spending a few months in sloughs and estuaries of the Lower Fraser River, enter the Strait of Georgia before they are one year old.[89]

Mr. Lapointe testified that, in the case of a spawning female that lays 3,000 eggs, only about 420 eggs survive to become fry.[90] He identified the following naturally occurring stressors that contribute to fry mortality: lack of food, predation, diseases, and environmental stresses such as water temperature.[91]

Several of the Commission's technical reports examined, and witnesses testified about, the stressors at these two life history stages that may have caused or contributed to the recent decline. I summarize these discussions below.

Predation

In Technical Report 8, Predation, Dr. Christensen and Dr. Trites reported that, as both coho and chinook salmon age, they increasingly prey on other fish. Because they tend to have a longer residence in freshwater, these species typically reach a size where they potentially can prey on small sockeye fry. However, Dr. Christensen and Dr. Trites concluded that the recent decline in population estimates for chinook and coho in the Strait of Georgia indicates that these species are not likely responsible for the decline in survival of Fraser River sockeye.[92]

The researchers stated that, although a 1996 study in Lake Washington found that cutthroat trout was the only important predator on sockeye fry, little information is available on the abundance and trend of coastal cutthroat trout in the Fraser River system. Dr. Christensen and Dr. Trites concluded that cutthroat trout are unlikely to be abundant enough to constitute a major factor in the decline.[93] They reported that, although steelhead can consume a significant amount of emergent sockeye smolt salmon, steelhead are unlikely to be a major factor in the Fraser River sockeye decline, given that the steelhead population is reduced in the Fraser River. They reached a similar conclusion about bull trout.[94]

Several studies in Washington and Oregon found that a significant proportion of the annual diet of large northern pikeminnows consists of sockeye salmon. A pikeminnow eradication program has been in place in Cultus Lake since 2005.[95] The researchers concluded that pikeminnow "may also be important predators of Fraser River sockeye salmon, but there does not seem to be abundance or trend estimates for the pikeminnow, and, hence, their importance cannot be quantified."[96]

During the evidentiary hearings, Jeremy Hume, research biologist, Lakes Research Program, Science Branch, testified that, in 2005, DFO removed about 45,000 northern pikeminnows from Cultus Lake, a practice that has led to increased survival of sockeye salmon.[97]

Dr. Christensen and Dr. Trites also considered several introduced fish species and made the following observations:

- A previous study had identified smallmouth and largemouth bass as predators on juvenile salmon, and considered the risk very high in small lakes. However, notwithstanding the absence of abundance and trend estimates in the Fraser River system, the researchers found it unlikely that these species were abundant enough to have had major influence on the recent decline.[98]
- Yellow perch, which were introduced illegally as live bait, have been confirmed in 59 lakes or ponds and 19 streams, including within the Lower and middle Fraser River and South Thompson River watersheds. Although yellow perch are potentially an important predator on and competitor with sockeye salmon in the Fraser River system, the researchers concluded that "the available information provides little support for the hypothesis that yellow perch were a major factor for sockeye survival trends over the last three decades."[99]

Climate change

The authors of Technical Report 9, Climate Change, Dr. Hinch and Dr. Martins, testified that scientists have identified water temperature as the master biological variable for fish.[100] Temperature directly affects metabolism, physiology, behaviour, and feeding, and indirectly can affect suitable habitat.[101] Metabolic scope defines the oxygen available for activities other than routine metabolism and is temperature-dependent.[102] Dr. Hinch and Dr. Martins reported that survival of sockeye salmon fry decreases when exposed to warm temperatures in the laboratory, although the direct effects of temperature are unlikely to cause mortality in the wild, as fry are able to move to cooler lake depths to avoid stressful temperatures. Several laboratory studies have shown that fry predation increases with higher water temperatures, and a 1985 study showed that sockeye inoculated with a parasite had higher mortality rates when held at 13°C than at 5°C.[103]

The warming trends discussed earlier in relation to eggs and alevins have also been associated with changes in sockeye nursery lakes. For example, since the 1960s Lake Washington has warmed up by as much as 1.5°C, particularly in the upper water layer. As a result of warming of Fraser River watershed nursery lakes, the timing of spring ice breakup has occurred up to 40 days earlier, and the timing of thermal stratification up to 27 days earlier.[104]

The researchers concluded that if water temperatures in Fraser River rearing lakes have paralleled warming trends of the river in the summer, then fry now experience temperatures approximately 1°C warmer than 20 years ago, and their survival has possibly decreased. However, warming is not homogenous throughout the lake volume. Since fry are able to move to cooler depths of lakes to avoid otherwise lethal temperatures at the surface, the researchers believe that warmer lake waters may not have directly affected survival of fry. They hypothesized that warmer waters may have enhanced fry mortality indirectly through increased predation rates, although the authors of Technical Report 8, Predation, provided no evidence of this type of predation.[105]

Other freshwater stressors

As discussed earlier, the authors of Technical Report 3, Freshwater Ecology, Nelitz and others, sought to understand the potential role of freshwater stressors in recent Fraser River sockeye declines by compiling and analyzing the best available data describing six categories of human activities that have the potential to affect sockeye salmon – forestry, mining, hydroelectric projects, urbanization upstream of Hope, agriculture, and water use. These activities have the potential to affect sockeye salmon during freshwater life stages, in particular by having effects on the quality and quantity of spawning habitats, on the productivity of nursery lakes for rearing juveniles, and on habitat conditions associated with smolt outmigration and adult migration. Regulation of these activities is discussed in Volume 1, Chapter 6, Habitat management. The researchers' examinations and conclusions in relation to both the incubation and nursery lake–rearing phases of the life cycle were discussed above (Incubation).

Pulp and paper

Pulp and paper mills were historically a large point source of dioxins and furans in British Columbia.[106] Toxic even in small amounts, dioxins and furans were formed as by-products in the chlorine-bleaching process used in the pulp and paper industry.[107] Dioxins and furans also have a strong tendency to adsorb to sediments and to bioaccumulate and biomagnify up the food chain.[108] The Commission's Technical Report 2, Contaminants, provides a comprehensive list of contaminants of greatest concern found in pulp and paper effluents.[109]

At the time of the hearings, seven pulp and paper mills operated in the Fraser River basin.[110] Two mills are located near Prince George, two near Quesnel, one near Kamloops, and two near Vancouver.[111] Although all seven mills are located along the migration corridor of Fraser River sockeye, Janice Boyd, a program scientist with Environment Canada, testified that, as far as she knows, none of these mills discharges into rearing lakes for Fraser River sockeye.[112] However, I was told that the Domtar Products mill near Kamloops discharges into the Thompson River, which flows into Kamloops Lake, where sockeye rear.[113]

Metal mining

Mines, and metal mines in particular, have the potential to adversely affect water quality conditions in receiving water systems (areas subject to discharges).[114] Intentional and unintentional releases from mines include the following types of contaminants:

- conventional variables (e.g., alkalinity, conductivity, hardness, pH, and total suspended solids);
- microbiological variables (e.g., fecal coliforms and enterococci);
- major ions (potassium, sodium, and sulphate);
- nutrients (e.g., nitrate, nitrite, ammonia, and phosphorus);
- metals (aluminum, arsenic, boron, barium, cadmium, copper, chromium, iron, lead, mercury, manganese, molybdenum, nickel, antimony, selenium, strontium, silver, and zinc);
- cyanides (strong acid dissociable and weak acid dissociable);
- petroleum hydrocarbons (oil and grease, alkanes, and diesel-range organics);
- monoaromatic hydrocarbons (e.g., benzene, toluene, ethylbenzene, and xylene); and
- polycyclic aromatic hydrocarbons (e.g., parent PAHs, alkylated PAHs, and total PAHs).[115]

At the time of the hearings, there were seven active metal mines in the Fraser River watershed: Endako (Prince George area), Huckleberry (Houston area), Gibraltar (between Williams Lake and Quesnel), Mount Polley (near Williams Lake), Quesnel River (near Quesnel), Highland Valley (near Kamloops), and Bralorne (Bridge River area).[116] The first six of these conduct open-pit mining while Bralorne is an underground gold mine.[117] The Endako mine discharges into a creek that drains into François Lake (a sockeye-rearing lake) and into the Endako River, which drains into Fraser Lake.[118] The Huckleberry mine discharges into the Tahtsa Reach on the Nechako Reservoir, which has two discharge points, making it unclear how much, if any, discharge ultimately enters the Fraser River.[119]

There are also closed or abandoned mines in the Fraser River watershed, not all of them known to Environment Canada or the province.[120] However, Michael Hagen, program scientist, Natural Resources Sector Unit, Environmental Protection Operations, Environment Canada, testified that a fair bit is known about most of the closed mines and, although some of these mines could be discharging into the Fraser River system, problems have been addressed where identified.[121]

Infectious diseases

The author of Technical Report 1, Infectious Diseases, Dr. Michael Kent, documented and evaluated the potential effects of diseases and parasites on Fraser River sockeye salmon during both the freshwater and the marine life stages. I summarize his findings on the freshwater period, including the incubation and fry phases.

In a confined environment, fish drink and eat in the same water in which they urinate and defecate. Pathogens can be transmitted among fish in the water environment, and the degree of transmission is greatly influenced by density of fish in water. This transmission may not be an important concern in the ocean or within large rivers, but it can come into play in small rivers, spawning channels, and hatcheries. Thus, infectious agents in particular are transmitted from fish to fish before and during spawning, or as fry.[122]

Several environmental factors can influence the impact of pathogens on salmon. For example, since fish are cold-blooded, both pathogens and hosts are strongly affected by water temperature. High water temperature has been documented to cause stress in fish, to reduce general immune status in fish, and to dramatically increase the replication rate of parasites – all of which lead to increased susceptibility to disease, especially in freshwater. Also, pollution can cause reductions in the immunocompetence of the fish host, and the addition of contaminants through fertilizers and sewage to the freshwater system can influence some fish pathogens.[123]

Dr. Kent identified the following specific pathogens that are either high or moderate risk to Fraser River sockeye juveniles.

Viruses. The infectious hematopoietic necrosis (IHN) virus often causes severe, acute systemic disease in juvenile salmonids, and one strain has been documented to cause high mortality in sockeye fry in many populations. For example, a 1989 study documented 50 percent mortality in the Weaver Creek spawning channel, in a population of about 17 million fish.[124] Dr. Kent concluded that the risk was high, adding that the virus "is deadly to fry and juvenile sockeye salmon. Sockeye in seawater are susceptible, but the virus at this stage is less virulent as older and larger fish show fewer mortalities when they become infected."[125]

Bacteria. The *Renibacterium salmoninarum* bacterium causes bacterial kidney disease (BKD) in salmonids. The infection results in acute to chronic, severe systemic disease, and fish die within a few weeks to months following infection. Infections are contracted and spread in freshwater as well as marine areas, apparently by oral-fecal transmission. Sockeye salmon are highly susceptible, and the bacterium is prevalent in British Columbia, leading Dr. Kent to rate the risk as high. *Aeromonas salmonicida* infection occurs in both wild and cultured fish in British Columbia, and can result in an acute, severe disease with high mortality. All salmonids are susceptible to it. Because the bacterium has the potential to be lethal to juvenile and adult sockeye salmon in both freshwater and seawater, Dr. Kent rated the risk as high.[126] Several members of the *Flavobacterium* genus cause disease in fish in freshwater as well as in the marine environment. Most are considered opportunists that cause significant disease only when fish are compromised by suboptimal environmental conditions. Dr. Kent rated the risk as moderate, explaining that these infections "are generally considered to cause disease mostly in hatcheries, but should not be excluded as a cause of disease in wild sockeye if water conditions are poor. There is no evidence that infections and associated mortality have increased in the Fraser River in recent times."[127]

Protozoa. Ichthyophthirius multifiliis, a ciliate protozoan, is a recognized serious pathogen, infecting a wide variety of freshwater fish. The parasites cause severe damage to the skin and gills, often killing fish by asphyxiation as a result of the tissue's reaction to the parasite in the gills. Heavy infections can cause high mortality in salmonids, including wild stocks of sockeye in the Fraser River system. Dr. Kent rated the risk as high, noting that severity would increase with increased water temperature and reduced water flows. The blood flagellate *Cryptobia salmositica* is common in salmonids from freshwater throughout the Pacific Northwest. Juveniles as well as adults are susceptible to the infection, and the parasite can persist in fish after they enter seawater. Infections in wild salmonids, both adults and juveniles, are often lethal. Numerous reports of the infection of sockeye from British Columbia lead Dr. Kent to rate the risk as moderate. He noted that, although the pathogen is capable of causing severe disease, there are no reports on the prevalence in Fraser River sockeye salmon.[128]

Mortality-related genomic signature

Dr. Kristina Miller is head of the Molecular Genetics Section, Salmon and Freshwater Ecosystems Division, Science Branch, DFO. I qualified her as an expert in molecular genetics, immunogenetics, and functional genetics, with a specialty in salmon.[129] She testified respecting the results of her recent investigations into a mortality-related genomic signature (explained below) identified in Fraser River sockeye salmon, some of which were reported in the journal *Science* in 2011.[130] Her research involved sampling returning adults approaching and in the Fraser River, as well as smolts before they left the Fraser River on their outbound migration.
I summarize both aspects of her research here.

In 2006, sockeye salmon returning to the Fraser River to spawn were sampled at three locations – in the marine environment up to 200 km before they entered the river, in the Lower Fraser River, and at the spawning grounds. Researchers took tissue samples from the gills and inserted a transmitter in each migrating fish so that they could determine which fish made it to the spawning grounds and which ones successfully spawned. The gill tissue samples were subjected to microarray technology, through which thousands of genes are examined at once, to determine which genes are turned on and which ones are turned off. This sampling yields information about the physiological condition of the tissue; and that condition may be expressed as a pattern, known as a genomic profile or a genomic signature. The researchers also did genetic stock identification in order to look at stock-specific differences.[131]

Dr. Miller stated that, in all three tagging studies, the same genomic signature was associated with poor spawning success, whether the fish were tagged in the marine environment, in the lower river, or on the spawning grounds. In the marine environment, when fish carry this mortality-related signature, they had a 13.5 times lower probability of spawning. A similar pattern was found for returning adults tagged in the lower river and on the spawning grounds, although with not as high a difference in probability of spawning success between fish with and without the mortality-related signature.[132]

Dr. Miller also testified that in the 2006 study she found an association of the mortality-related signature with more rapid entry into the river and faster migration to the spawning grounds.[133] In a paper prepared for the June 2010 Pacific Salmon Commission (PSC) workshop (PSC workshop paper), she reported that approximately 50 percent of the returning adults tested in 2006 carried this mortality-related signature.[134] Salmon with the signature in the ocean carried a four-times-lower probability of reaching the spawning grounds, while those carrying the signature at the spawning grounds were twice as likely to die prematurely as those without this signature.[135] Dr. Miller's paper concluded:

> This study showed unequivocally that Fraser River sockeye salmon are entering the river in a compromised state, that survivorship was somewhat predictable based on gene expression [greater than] 200 km before salmon reach the river, that stocks may be affected differently, and that the freshwater environment alone may not be the sole source of the highly fluctuating mortalities of salmon in the river.[136]

This PSC workshop paper also reported that Dr. Miller's team has since observed this same mortality-related signature in brain, liver, and gill tissue (but not muscle) of adult sockeye in all years over the past decade where available (2003, 2005–2009), with the proportion of affected fish varying in different years.[137]

On the subject of smolts leaving the Fraser River, Dr. Miller's PSC workshop paper reported that the same mortality-related signature was observed in all years where samples are available (2007, 2008, and 2009). In 2008, 60 percent of smolts left the river with the unhealthy signature in the brain, and 40 percent with the signature in the liver. Overall, 82 percent of fish were affected in at least one tissue. There was a 30 percent reduction in brain prevalence of the signature from summer to fall in the ocean, and a 50 percent reduction in the liver. Overall, there were 2.4 times as many fish with the signature in the fall as in the summer. The paper concluded: "If these decreases in prevalence were due to mortality, and if we assume that 120 million smolts left the river in 2008 (there may have been more), we could account for the loss of [more than] 27 million salmon in 2008 associated with the unhealthy signature alone."[138]

Dr. Miller testified that 82 percent of outmigrating smolts have the mortality-related signature in at least one tissue, while the proportion of returning adults affected is much less, for the two years of available data.[139]

In an April 15, 2011, update to DFO scientists, Dr. Miller reported that, in June 2007 and June 2008, smolts were sampled in the marine environment.[140] Nine out of 10 from 2007 contained this mortality-related signature in liver tissue, whereas in 2008 only 40 percent of liver tissues contained it.[141] She testified that "[w]here we're looking to go is to establish whether or not it's simply the prevalence of the signature in the ocean, or whether it's the shift in prevalence that we observe over time that's more important in terms of being a predictor."[142] Dr. Miller speculated that if fish enter the ocean in poor condition, and the ocean is additionally stressed, those factors may have a more profound effect on their survivorship than if they enter, in good condition, an ocean that is in good condition.[143]

Dr. Miller stated that when a genomic signature is obtained, one can then compare the similarities with signatures observed in other controlled studies.[144] From this kind of functional analysis, the most likely explanation for this signature is that it is virally mediated (i.e., it is a response to a viral infection).[145] In addition, the fact that the signature was found in other tissues fits well with a pathogen model, but does not fit well with a general stressor or toxicant exposure.[146] In the 2011 *Science* article, Dr. Miller and her colleagues stated their hypothesis "that the genomic signal associated with elevated mortality is in response to a virus infecting fish before river entry that persists to the spawning areas."[147]

Dr. Miller stated that her finding that the fish are already conditionally challenged before they enter the river during the return migration is consistent with work done by her colleagues Dr. Scott Hinch and Dr. Tony Farrell into stress and osmoregulation.[148] She said those studies were unable to propose a mechanism for why some returning fish were more ready for freshwater and why there were so many stress indicators.[149] Genomics tries to provide a deeper level of understanding of the mechanisms that might create the kinds of patterns being observed.[150] Dr. Miller's study showed a pattern of osmoregulatory preparedness for freshwater when the returning fish were 200 km from the river – they were probably very uncomfortable in the marine environment.[151]

Dr. Kyle Garver leads the Virology Research Program in the Aquatic Animal Health Section, Salmon and Freshwater Ecosystems Division, Science Branch, DFO Pacific Region. I qualified him as an expert in molecular virology, with a specialty in viruses affecting salmon.[152] He testified that he suggested to Dr. Miller, and tried himself, several diagnostic methods to determine if there was a virus in these tissues that have the mortality-related signature.[153] He tried first a traditional virological approach in which the sample is placed onto artificially grown fish cells, and one observes these cells for virus infectivity.[154] Various lines of fish cells were tried, but Dr. Garver was unable to culture any virus. He told me that this is a broad technique and that many viruses cannot be detected using this method.[155]

Dr. Garver then tried microarray technology, using a ViroChip. The ViroChip contains bits of genetic material representing all known viruses and is used to detect the presence of virus in a sample.[156] He testified that after testing samples with the mortality-related signature using the ViroChip, he did not see any conclusive viral signature; in other words, there was no significant difference in the ViroChip results between samples with the mortality-related signature and samples without it.[157]

Dr. Miller told me that she later "background corrected" the samples and was able to report to the Pacific Salmon Commission workshop as follows:*

> A VIRAL PATHOGEN? In collaboration with BC Centre for Disease Control, we ran both healthy and unhealthy tissue RNA on a Viral Array (used to identify viral strains in humans and agricultural animals), and found the unhealthy tissue gave 6X higher intensity binding to the array than healthy tissue. There was a 3-fold over-representation of Retroviral family DNA.[158]

Dr. Miller agreed that in a meeting of DFO scientists she distributed a paper entitled "Epidemic of a novel, cancer-causing viral disease may be associated with wild salmon declines in B.C."[159] This paper was based on literature relating to the salmon leukemia virus, which was thought to involve optic tumours. Samples she examined carried very heavy vascularization on the outside of the optic lobe, but subsequent analysis showed these to be hemorrhages, not tumours.[160]

Dr. Miller said that she and Dr. Garver subsequently attempted to isolate viral material from tissues that contain the mortality-related signature. Using a sucrose gradient method, they were able to isolate DNA from tissue and found that the sequence of this DNA showed a high probability of being a parvovirus. She described her results as "a very, very powerful positive for a parvovirus."[161] Dr. Miller told me that she has observed the parvovirus sequence in tissues positive for the mortality-related signature, but not in liver samples that were negative for the mortality-related signature. At the time of the hearings in August 2011, she and Dr. Garver were in the process of testing other tissue samples, negative for the mortality-related signature, to determine if they contained parvovirus sequences or not."[162] In addition, they planned experiments to isolate the viral particle, to test the infectivity of the parvovirus, and to determine whether the parvovirus is associated with disease.[163]

Dr. Miller testified that one of the most interesting things about parvoviruses is that they require rapidly dividing cells to facilitate their own reproduction, and one can induce the proliferation of parvoviruses by stressing the cells.[164] She is interested in whether the stress associated with transitioning between freshwater and saltwater could make this virus more active and elicit more disease, although this idea is speculative.[165] She added that if it is established that there is a parvovirus, it will be the first time a parvovirus has been identified in a fish.[166]

* Background correction is a step that is not found in the ViroChip maker's protocol, which is Exhibit 1514.

Dr. Miller was asked whether it would be fair to suggest that this particular mortality-related signature, if it turned out to be the virus and if it turned out to have the mortality that she speculated about, could be a very significant explanation for the low return in 2009. She responded that "there is certainly the potential that this virus could have a major impact on salmon declines," and that "[i]t could be the smoking gun" for the 2009 low return. [167]

Dr. Miller added that she had some level of confidence that she and Dr. Garver will find disease with this virus.[168]

Dr. Miller testified that the earliest in the life cycle that she and Dr. Garver have identified this mortality-related signature was in November, before fish were going to smolt, in their natal rearing areas.[169] She added that she has no data on whether a parvovirus could be transmitted vertically (i.e., from adult fish to offspring), so it would be pure speculation.[170] Dr. Garver added that a parvovirus could be in other species in a lake and could, therefore, be transmitted horizontally (i.e., between fish of the same generation), but that is also pure speculation because it is unknown whether the parvovirus sequence is linked to disease, or how it is transmitted.[171]

In August 2011, Dr. Miller testified that industry representatives from BC Atlantic salmon farms had recently agreed to have their fish tested for the presence of parvovirus.[172] She had observed the mortality-related signature and suspected parvovirus in sockeye and chinook salmon, but she did not yet have any Atlantic salmon to test.[173] In December 2011, however, Dr. Miller explained that, shortly after testifying in August, she and Mary Ellen Walling, executive director of the B.C. Salmon Farmers Association, disagreed on when and how Atlantic salmon would be tested.[174] The result was that Dr. Miller no longer had an agreement with the salmon-farming industry to obtain Atlantic salmon samples to test for the parvovirus. She explained:

> I did not feel that what they proposed was what we originally had talked about and what I had said that we were going to do in the Cohen Inquiry and I did feel that there was no need to move forward. I didn't need them to run sockeye salmon, I needed them to provide Atlantic salmon to test.[175]

Dr. Miller rejected the proposal to have sockeye salmon tested with industry as a collaborator.[176]

Life stage 2: smolt outmigration

In about May, approximately 20 months after spawning, when the fry are about 8 cm, they begin a process called "smoltification," a physiological change facilitating the transition from life in freshwater to life in seawater. They cease their movement between shallower and deeper parts of the lake, begin to gather into schools of fish, take on a silvery body coloration, and develop an ability called "compass orientation" that aids their navigation out of the lake and downstream.[177]

Given the magnitude of the Fraser River watershed, some sockeye stocks face a daunting downstream migration. For example, smolts resident in Takla and Stuart lakes, north of Fort St. James, must cover approximately 1,200 km before reaching the ocean.[178]

Mr. Lapointe testified that while approximately 420 fry survive out of a brood of 3,000 eggs, nearly 300 of those fry will die, leaving about only 120 smolts.* This fry mortality usually occurs within the nursery lakes. I understand that these numbers are, at best, estimates. Long-term time series data exist only for two fry populations (Quesnel and Shuswap lakes) and for two smolt potpulations (Chilko and Cultus lakes). Once smolts leave their nursery lake, there was, at the time of the hearings, no standardized assessment of them during or at the end of their downstream migration.[179]

Several of the Commission's technical reports examined, and witnesses testified about, the stressors facing smolts during their downstream migration which may have caused or contributed to the recent decline.

Predation

During the marine ecology hearings, Dr. David Welch, president and CEO, Kintama Research Services, testified that tagging of smolts in Chilko and Cultus lakes showed that most of the

* In a study of Chilko salmon, Dr. Jim Irvine calculated fry-to-smolt mortality at 87.5 percent. See Exhibit 1352.

outmigration mortality occurred between release in the lake and entry into the mainstem of the Fraser River. It occurred during passage through clear river water and was possibly due to predation.[180] In Technical Report 8, Predation, Dr. Christensen and Dr. Trites reported that, although several endemic and introduced fish species are known to feed on salmonid smolts, little information is available on abundance and trend. The researchers' opinion was that none of these species is abundant enough to have had a major influence on the recent Fraser River sockeye salmon decline.[181]

As for predation by birds, the main source of bird abundance information for British Columbia is the Christmas Bird Count, conducted annually between mid-December and early January. The researchers said that the count gives information that is standardized for observer effort, which means that it can be used to evaluate trends in abundance. However, it provides no information about notable bird species that do not overwinter in British Columbia.[182]

The common merganser is an important predator on juvenile salmon during the seaward migration, as is the double-crested cormorant. The Caspian tern has recently begun breeding in British Columbia. A 2003 study estimated that, in 1998, Caspian terns consumed 12.4 million salmon smolts in the Columbia River estuary.[183] However, the researchers concluded that since there is no indication that these three species have increased in abundance in recent decades, it is therefore unlikely they have played a major role in the decline.[184] Because osprey migrate south for the winter, trend data are not available. The researchers concluded that it is unlikely that the osprey has a major predation impact on Fraser River sockeye.

The harbour seal is the only marine mammal known to occur in British Columbia that has been documented feeding on salmon smolts in freshwater and estuarine habitats. However, direct observations of feeding showed predation on chum, coho, and chinook, but not on sockeye.[185] The researchers concluded:

> Despite the shortcomings of the data, they are the best that are available and show no indications that harbour seals are a significant predator of sockeye salmon smolts … Harbour seal numbers increased during the 1980s and 1990s, but have been relatively constant for the past decade. Harbour seals should therefore have not posed an increasing threat to sockeye survival over the past decade.[186]

Climate change

The authors of Technical Report 9, Climate Change, Dr. Hinch and Dr. Martins, did not specifically address the impact of warmer river temperatures on Fraser River sockeye salmon smolts during their downstream migration, other than to observe that the Fraser River watershed has likely warmed at the highest rates during winter and spring because that is when the province's climate has warmed the most.[187]

Infectious diseases

In Technical Report 1, Infectious Diseases, Dr. Kent pointed to numerous reports of a high prevalence of the infection of the *Parvicapsula minibicornis* parasite in outmigrating Fraser River sockeye smolts as well as in adults. The chronic infection targets the kidneys and can also reduce swimming ability. Given the high prevalence in Fraser River sockeye salmon, Dr. Kent rated the risk as high.[188]

Other freshwater stressors

The authors of Technical Report 3, Freshwater Ecology, Nelitz and others, sought to understand the potential role in recent Fraser River sockeye declines of six categories of human activities that have the potential to affect sockeye salmon: forestry, mining, hydroelectric projects, urbanization upstream of Hope, agriculture, and water use. The regulation of these activities is discussed in Volume 1, Chapter 6, Habitat management.

Although most of these stressors have an impact on the incubation and nursery lakes phases of the Fraser River sockeye salmon life cycle, several are relevant to the smolt downstream migration.

Log storage / handling in the Fraser River estuary. Port Metro Vancouver estimates that 48 different tenants are distributed across 256 log storage leases and permits, covering 862 hectares within the Fraser River estuary. Logs can compact, scour, and shade nearshore habitats and smother marine plants. The reduction in primary production and growth can reduce food availability for juvenile salmon. Wood and bark debris can accumulate beneath storage areas, potentially altering the composition of food sources, smothering emergent vegetation, increasing biological oxygen demand, and increasing concentrations of potentially toxic log leachates. Studies on the effect of Fraser River estuary log storage on salmon are limited, but the researchers reported that studies in the 1980s revealed that densities of juvenile salmon (chinook, pink, and chum) and amphipods (a food source) did not differ between a large log storage site and nearby marsh areas.[189]

Hydroelectric projects. Large-scale hydroelectric projects can cause direct mortality of smolts that pass through hydro turbines or over spillways. The researchers reported that the Bridge River–Seton power project has the potential to affect Seton and Anderson Lake sockeye Conservation Units during the smolt downstream migration. A 1995 study indicated that more than 90 percent of sockeye smolts were being entrained into the power canal, with the smolt mortality rate estimated at 17 percent when the plant was fully operational.[190] A 2006 study estimated that the average number of smolts lost at the canal was approximately 200,000. However, mitigation measures introduced since 2006 have reduced smolt mortality rates to as low as 1.7 percent.[191] The researchers also concluded that, given the small number of projects in proximity to migration corridors, independent power projects have not had a significant impact on sockeye salmon populations during the downstream migration.[192] During the hearings, two witnesses testified that they were not aware of any independent power projects in the Fraser River watershed that are affecting sockeye salmon or their habitat.[193] However, a third witness cautioned that it is very difficult to assess the impacts of independent power projects because of the absence of a planning process, public input on siting, and transparency within the monitoring program, and the fact that the impacts are not well understood.[194]

Agriculture. The researchers observed that, because of the concentration of agricultural lands along the Fraser River mainstem in the Cariboo-Chilcotin, agriculture has its greatest interaction with migration corridors. The researchers found that data on type and intensity of pressure on lands and streams associated with livestock production were generally lacking.[195]

Urbanization upstream of Hope. Residential, business, and industrial development, as well as related road construction, can increase the amount of impervious surfaces in urban watersheds, which affects rates of interception, patterns of runoff, and, in turn, the magnitude and timing of instream flows. Also, roads, stormwater runoff, and municipal and industrial effluents have been known to alter water quality in watercourses across the Fraser River basin.[196]

Lower Fraser River habitat use

One technical report focused exclusively on stressors in the Lower Fraser River. In Technical Report 12, Lower Fraser Habitat, authors Johannes and others summarized potential human development–related impacts from 1990 to 2010, and qualitatively examined potential interactions between human development and activities in the Lower Fraser River (from Hope to the estuary) for sockeye salmon habitats. In testimony, several witnesses challenged some of the evidence contained in Technical Report 12. Where applicable, I set out below the contradictory evidence.

Sockeye salmon freshwater distribution in the Lower Fraser River extends to four major watersheds: the Harrison, Lillooet, Chilliwack, and Pitt rivers. Spawning, incubation, and juvenile rearing occur in these watersheds, including Cultus Lake. Residence periods extend for between four and six months for river-type sockeye such as Harrison River stocks, and one or two years for lake-type sockeye.

This 160-km portion of the Lower Fraser River and estuary is used as a migratory pathway for smolts, with a residence period of often less than seven to 10 days. Harrison River sockeye fry are an exception, using various sloughs and off-channel areas in the Lower Fraser River and estuary for

Restored salmon habitat, South Alouette River, BC, 2010

rearing over a period of two to six months. Feeding in the Lower Fraser River by Harrison fry is likely to be in micro-habitats that are attached to the main channel, where water clarity is better and where access to planktonic prey items may be better than what is available in the main channel. Disruptions or losses to these habitats may therefore have greater impact on these sockeye than disruptions to the deeper portions of the riverbed (such as through navigational dredging), because sockeye do not bottom feed.

The researchers selected seven factors as metrics to express changes over space and time in human activities and development in the Lower Fraser River between at least 1990 and 2010. They were considered potential stressors that could illustrate effects and interactions of human activities and development on the environment and show relevance for possible interaction with sockeye habitats.

Population. Population size and density provide a broad metric of potential stress on the environment and allow a generic estimate of human activities that could result in changes in land and marine areas through urban, rural, and industrial development. The researchers reported that population size and density in most regional districts and in all municipalities in the Lower Mainland increased by 150 percent over the past 20 years. Human activities related to population size and density may affect sockeye habitats through direct habitat loss and through non–point source effects associated with change in water quality and quantity.[197]

Land use. Development of residential, recreational, and industrial lands and transportation corridors in the Lower Fraser River has removed and degraded habitat areas and natural environments over the past century. Such development leads to higher levels of water pollution, nutrients, and contaminants from wastewater and stormwater runoff. Reduced natural forest, riparian, wetland, watercourse, and water body areas limit the natural capacity of landscapes to filter and buffer surface water runoff and recharge groundwater sources. The researchers observed that agricultural and forestry land use have remained stable in many regional districts, although in urban areas more than 3,000 hectares of forest and agricultural land were lost and replaced over the past two decades.[198]

Large industrial and infrastructure sites and projects. Between 1990 and 2010, 70 large industrial sites and infrastructure projects were constructed in or near the Lower Fraser River and Strait of Georgia. Thirty-six such sites or projects had potential overlap with aquatic habitat, but the researchers considered the overlap with sockeye habitats to be minimal for many of them.[199]

Waste. An estimated 80 percent of marine pollution is derived from land-based activities through liquid and solid waste. Programs to reduce the amount of solid waste disposed of were adopted in British Columbia and Metro Vancouver less than 20 years ago. Owing in part to improved best practices such as recycling and secondary or better sewage treatment, solid and liquid waste volumes, despite population growth, have not increased across the region over the past 20 years. (This last point was an assumption, not based on any analysis.) Don MacDonald, the principal author of Technical Report 2, Contaminants, gave contrary expert evidence.* He testified that the volume of discharges from wastewater treatment plants has increased over the past 20 years.[200] Johannes and others reported in Technical Report 12, Lower Fraser Habitat, that the proportion of municipalities using secondary or tertiary wastewater treatment has increased over the past 20 years – a change that has led to reduced tonnage of biological oxygen demand and total suspended solids being discharged into the environment from municipal wastewater, despite population growth.[201]

Dredging and diking activities. Fraser Valley urban areas and cities are protected by more than 400 km of dikes, built during the first half of the 20th century. No new dikes have been constructed in the past two decades, and in some cases dikes have been removed or replaced to create opportunities for salmon habitat restoration. The volume of material dredged from the Lower Fraser River has declined since the 1990s and is timed to occur outside the migration period.[202]

Contaminated materials. Contaminants such as metals and organic pollutants show a general decreasing trend over time in many organisms, presumably as a result of decreases associated with effluent discharge regulations, improved treatment, and remediation of contaminated sites. In contrast, there appears to be an increase in polybrominated diphenylethers (PBDEs, which are fire retardants found in a wide array of products) associated with increased use over the past two decades and an apparent increase in contaminants associated with personal care and pharmaceutical products. The latter may be increasing in the environment because conventional municipal wastewater treatment systems do not remove them.[203] (See Freshwater and marine contaminants, below.)

Non-indigenous species. More than 117 terrestrial and aquatic non-indigenous plant and animal species have established populations in the Lower Fraser River and Strait of Georgia. Among the nine fish species introduced into freshwater areas are the smallmouth bass and yellow perch, which are predators with the potential to directly affect sockeye survival during early life history growth in nursery habitats. However, the number of non-indigenous freshwater species has remained stable from 1990 to 2010.[204] (See Predation, above.)

The researchers noted that few data are available for quantitative evaluation and review of the amount of sockeye habitat change over time in the Lower Fraser River relative to human activities. Consequently, the potential effects from human activities on sockeye habitats were reviewed qualitatively through a hierarchical classification and ranking method that shows the substantial potential overlap with the activity and sockeye habitat, and the potential level of interaction. The researchers concluded that only one human activity, land use in Lower Fraser River watersheds, constituted a moderate risk of loss or degradation of sockeye habitats. All other human activities were ranked as low or nil risk of loss or degradation.[205]

Pathogens from salmonid enhancement facilities

In Technical Report 1A, Enhancement Facility Diseases, authors Dr. Craig Stephen and others were commissioned to evaluate the impacts of hatchery and spawning-channel diseases on wild Fraser River sockeye salmon and to determine their potential role in reduced productivity. (For detailed discussions of wild–enhanced salmon interactions and management aspects of salmon enhancement, see Volume 1, chapters 6, Habitat management, and 9, Fish health management. The British Columbia Salmonid Enhancement Program was established in 1977. As of the hearings in May 2011, there were 23 major enhancement facilities and spawning channels managed by government employees, 21 community hatcheries operated as part of the Community Economic Development Program, and about 350 public involvement projects supported by 18 DFO community advisers.[206]

* Mr. MacDonald was qualified as an expert in environmental toxicology and chemistry with particular expertise in ecological risk assessment and ecosystem-based management; water quality and water use interactions; the design and evaluation of contaminated sediments on ecology receptors, including fish; and the design and implementation of environmental quality monitoring programs. Transcript, May 9, 2011, pp. 9–10; Exhibit 828.

Weaver Creek Spawning Channel, BC, 2010

Four sockeye salmon spawning channels have been created in the Fraser River drainage. They are located in Weaver Creek, Nadina River, Horsefly River, and Gates Creek. There are also two hatchery programs for the Upper Pitt River and Cultus Lake stocks. Two spawning channels are responsible for more than 80 percent of the sockeye salmon produced in enhancement facilities – Weaver Creek (67 percent) and Nadina River (14 percent). Between 2005 and 2009, an average of 46 million sockeye salmon were released each year from enhancement facilities in British Columbia.* During that same period, approximately 97 percent of all enhanced populations of sockeye salmon released from program facilities originated in spawning channels.[207]

Movements of fish create the risk of pathogen movements. Three types of movements are relevant:

- *The movement of fish after release from hatcheries or spawning channels.* DFO has the practice of acclimating salmonids other than sockeye to seawater by short-term holding in net pens. DFO records indicated that six major facilities and 21 community facilities or sites use seawater or brackish water pens in British Columbia.
- *The transportation of fish from a hatchery to a distant receiving water body.* For example, the Freshwater Fisheries Society of BC stocks nearly 900 provincial lakes with fish produced from five facilities.
- *The transfer of fish between enhancement facilities.* No pathogen screening of fish being transferred from one enhancement facility to another takes place if both are within the same region. For these purposes, the entire Fraser River basin is one region.[208]

Another plausible exposure route occurs with the release of water or wastes contaminated with pathogens from hatcheries and spawning channels into streams, rivers, and other fish-bearing waters. The survival of fish pathogens in water can vary with environmental conditions, ranging from days to weeks and even months.[209]

The researchers reported that neither federal nor provincial regimes have been designed or funded to be a surveillance or monitoring program. Rather, they offer diagnostic support in response to active disease concerns in hatcheries. The data collected can best be used to describe the types of problems causing increased disease frequency and mortality in hatcheries but do not reflect the infection status of the hatchery population as a whole or allow the generation of information on rates of disease.[210] The quality of the data is not audited or systematically evaluated. Diagnostic laboratory records would not detect all disease events or pathogens found in an enhancement facility because the criteria used to encourage submissions to the laboratory reduce the likelihood that diseases which are endemic and familiar to the hatchery workers would be submitted, and diseases causing sporadic or a low level of mortality would not be subject to laboratory investigation.[211]

Dr. Christine MacWilliams, fish health veterinarian, Salmonid Enhancement Program, DFO, qualified as an expert on veterinary sciences with a specialty in fish health, testified that the level of screening of enhancement facilities is sufficient and that DFO "probably" does not miss

* During the habitat enhancement and restoration hearings, the evidence of Greg Savard (Exhibit 758) was that, between 2006 and 2009, the average number of Fraser River sockeye produced annually from hatcheries and spawning channels was approximately 40 million. About 90 percent of these fish were from spawning channels.

any disease outbreaks.[212] (Dr. MacWilliams's evidence on the management of enhancement facilities is summarized in Volume 1, Chapter 9, Fish health management.)

The researchers' review of hatchery records found 17 reports of fish being placed into fish-bearing waters (released into streams or rivers, or moved to lake or sea pens) with known infectious diseases, suspected infections, or clinical signs of undiagnosed disease. In some cases the fish were given a chemical treatment and released three to 10 days later, without records verifying that the treatment was effective. Most often, these releases involved myxobacterial infections or fish with symptoms consistent with myxobacteriosis. One case involved suspected but unconfirmed furunculosis.[213]

In Technical Report 1A, Enhancement Facility Diseases, Stephen and others showed that the seasonal timing of salmonid releases from enhancement facilities overlaps with the migration timing of wild fish, a practice designed to optimize survival of enhancement fish and one that creates opportunities for interactions with wild fish. However, no data were found on niche or habitat overlaps between wild sockeye salmon and enhanced salmon, or on whether the temporal co-occurrence in the same waters is sufficient to result in the exchange of pathogens between wild sockeye salmon and enhanced fish.[214]

The researchers undertook an exposure assessment to estimate the probability that Fraser River sockeye salmon are exposed to the hazards of concern. They concluded:

> Fraser River sockeye salmon reared in enhancement facilities have the most likely route of exposure to diseases present in hatcheries or spawning channels. Exposure of other Fraser River sockeye to infected enhanced fish, sockeye salmon or otherwise, has not been proven or disproven. Biologically plausible routes of exposure exist, but none have been measured. Generally, there are three variables that affect the probability of exposure; the geographic distribution of the escaped pathogen, the abundance of the pathogen in the receiving environment and the frequency with which the fish are involved in an exposure that results in transmission of the pathogen. As data are lacking for these three variables, exposure assessment is not possible.[215]

Stephen and others were also unable to clarify what effect, if any, a pathogen of enhancement facility origin might have on Fraser River sockeye salmon productivity. They stated:

> The risk assessment did establish that known fish pathogens do occur in salmonid hatcheries and spawning channels and that biologically plausible routes of exposure exist, but there was no monitoring or follow-up to establish that pathogens were transferred to sockeye salmon outside of sockeye salmon enhancement facilities and that the transfer impacted the population.[216]

The researchers concluded that the data available for the review could not prove or disprove that diseases associated with salmonid enhancement facilities have been transmitted to Fraser River sockeye salmon and, in turn, have affected their production. The portion of the Fraser River sockeye salmon population that is reared in spawning channels or hatcheries has, at times, been exposed to infectious diseases while within the enhancement operation, but there was no evidence that this exposure has medium- to long-term population-regulating effects. It could not be established whether Fraser River sockeye salmon not reared in enhancement facilities had or had not been exposed to infectious agents of enhancement facility origin.[217]

During the evidentiary hearings, Dr. Stephen agreed that the most important conclusion in his report was the following:

> 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.[218]

Freshwater and marine contaminants

Overview

A "contaminant" is a substance that can be detected, while a "pollutant" is a contaminant that has been shown to have an adverse biological effect on the environment.[219] Contaminants in the Fraser River and marine environments originate from both natural and anthropogenic sources. Natural sources include weathering and erosion of terrestrial soils, bacterial decomposition of vegetation and animal matter, and long-range transport of substances from natural combustion sources including wildfires.[220]

Anthropogenic contaminants enter the environment through a number of sources, which are discussed below. Contaminant research also shows that Pacific salmon accumulating persistent, bioaccumulative, and toxic contaminants (PBTs)* in their marine life stage transport these contaminants into spawning and lake environments.[221] These chemicals are fat-soluble, meaning they accumulate in fatty tissues and so readily accumulate in aquatic food chains and can reach relatively high concentrations in fish.[222]

Contaminant effects on sockeye can be lethal (i.e., result in an immediate fish kill), but more commonly the effects are sublethal and may cause sockeye to be more susceptible to disease, parasites, or predators.[223] Both lethal and non-lethal effects can be enhanced when fish are challenged by other environmental factors such as high temperatures, disease, or nutritional stress.[224]

DFO has acknowledged that contaminants such as pesticides and other pollutants may potentially affect Fraser River salmon.[225] Many contaminants enter sockeye habitats, and exposure to contaminants can occur at any stage of the sockeye life cycle through digestion, gills, skin absorption, or sensory exposure.[226]

Dr. Peter Ross, research scientist, Marine Environmental Quality Section, Institute of Ocean Sciences, Science Branch, testified as an expert in aquatic toxicology.[227] He explained that marine fish and fish habitat, including Fraser River sockeye habitat, can be affected by chronic low-level releases of contaminants.[228] There are two types of impacts due to exposure to two general classes of contaminants:

- *Deferred ("carry the risk") effects.* In this category, sockeye are exposed as eggs in their spawning habitat; smolts in freshwater, estuarine, or coastal habitats; or juveniles in coastal or oceanic habitat.†
- *More immediate ("gauntlet") effects.* In this category, sockeye are exposed as they transit from lake to ocean and back to lake.[229]

At the Pacific Salmon Commission's June 2010 workshop on the decline of Fraser River sockeye salmon, the Expert Advisory Panel concluded that the relative likelihood of contaminants in the Fraser River causing the 2009 decline was possible, but unlikely or very unlikely.[230] In terms of the long-term trend in declining productivity, the Expert Advisory Panel considered Fraser River contaminants and habitat conditions unlikely or very unlikely contributors to the decline.[231] However, limited site-specific data on contaminants and the often complex nature of environmental toxicological processes make any conclusion about the role of contaminants highly uncertain.[232]

In contrast to the conclusions of the Expert Advisory Panel, DFO Science contaminant researchers who participated in the 2010 PSC workshop concluded that it was plausible that contaminants were a secondary contributor to reduced productivity of Fraser River sockeye, but that direct evidence is lacking and, further, that the monitoring or assessment studies to assess any impacts are lacking.[233] Moreover, these researchers also noted that chemicals are likely to fall into the category of sockeye stressors that we can actually control.[234]

Dr. Ross told the Commission that DFO is in a very poor position to be able to rule out the effect of contaminants on the decline of Fraser River sockeye, largely because of the absence of data:

* PBTs include many well-known chemicals such as dioxins, furans, polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), polycyclic aromatic hydrocarbons (PAHs), and dichlorodiphenyltrichloroethane (DDT). See PPR 14, pp. 48–49.

† Fish, including sockeye, do not easily metabolize PBTs, so they can "carry the risk" of these contaminants with them through their entire life cycle. But as sockeye migrate home from the sea they use their fat reserves, so these chemicals can then be transferred to their reproductive tissues. See Exhibit 573, p. 31; Exhibit 73, pp. 75–76.

> An absence of data, or an absence of evidence to me is not evidence of absence, and I think it's a little bit dangerous to use an absence of data or an absence of evidence to suggest that contaminants play no role whatsoever or are indeed unlikely to play a role.
>
> …
>
> I think it gives short shrift to the examples we have from other parts of Canada with salmon that have been dramatically impacted by acid rain in Eastern Canada, and aluminum and copper and pesticides in New Brunswick. It gives short shrift to the evidence we have from our colleagues, our federal colleagues to the south of us where we see Chinook salmon returning to Puget Sound that are being affected by urban contaminants.
>
> …
>
> So these are some specific examples. Other scientists, other toxicologists might have a slightly different view, but clearly we're data deficient in terms of our current capacity to understand what's happening with the sockeye situation.[235]

Further, according to Dr. Ross, contaminants very likely contributed to the long-term decline in the sense that they may have contributed through small incidents here and there (i.e., "death by a thousand cuts") or they may have weakened the fish over time, such that when they went to sea they may have been more vulnerable.[236]

Technical Report 2: Contaminants

In Technical Report 2, Contaminants, authors MacDonald and others developed an inventory of aquatic contaminants for the Fraser River basin and evaluated the potential effects of those contaminants on Fraser River sockeye salmon. The greatest potential impact of these contaminants occurs during the downstream migration of sockeye salmon smolts. During the evidentiary hearings, Mr. MacDonald testified that virtually no data are available on spawning and rearing areas.[237] He added that he and his co-authors did not expect to see a lot of contaminated sediments within these areas, because sockeye spawn largely in headwater systems or mainstem areas farther up the Fraser River. These areas are spatially separated from the source releases of contaminants into the system.[238]

The researchers identified 15 key exposure areas within the Fraser River basin.[239] To determine if exposure to contaminants represents a causative or contributing factor in the decline, it was necessary to compare recent conditions in the watershed with those that have existed historically in the Fraser River and its tributary watersheds.[240] The temporal scope of this study was broadly defined to include the years 1965 through 2010, the period of record for which reliable water quality data are available.[241] Mr. MacDonald testified that, because of data gaps in this time period, the researchers sometimes had to make assumptions that the water quality data for river water downstream of a nursery lake were the same as for the lake water itself.[242]

The researchers identified 11 point sources (discharge of substantial volumes of wastewater from identifiable locations into receiving waters within the Fraser River basin) of contaminants.

Pulp and paper mills. Ten pulp and paper mills are located between Prince George and Greater Vancouver.[243] The researchers identified 12 categories of substances of greatest concern relative to contamination of aquatic habitats by pulp mill effluents. Several of the specific substances identified are ammonia, chlorides, mercury, benzene, toluene, and chlorophenols.[244]

Sawmills, plywood mills, and particle board mills. From the numerous mills throughout the Fraser River basin, the researchers identified nine categories of substances of greatest concern. Several of the specific substances identified are ammonia, phosphorus, sulphides, sulphates, and formaldehyde.[245]

Wood preservation facilities. At least 15 operating wood preservation facilities are located within the Fraser River basin. Among the highest-priority wood preservation chemicals are creosote and chromated copper arsenate.[246]

Cement and concrete plants. There are 17 plants operating in the basin, most in the Lower Fraser River. The contaminants of greatest concern include pH, total suspended solids, sodium, potassium, chlorine, sulphates, oil and grease, and metals such as aluminum, arsenic, copper, chromium, lead, and zinc.[247]

Seafood-processing facilities. At least 10 seafood-processing facilities are permitted to discharge effluent into the Lower Fraser River. In addition to temperature and pH, the priority contaminants include total suspended solids, residual chlorine, oil and grease, and nutrients such as nitrate, nitrite, and ammonia.[248]

Operating and abandoned mines. There are 28 operating metal and mineral mines within the Fraser River basin. These have the potential to influence water quality conditions in receiving water systems as a result of construction and operation of mine components such as camp facilities, sewage and wastewater treatment facilities, tailings containment areas, open pits, waste rock piles, roads and storage yards, airstrips, and quarries.[249] Abandoned mines may also release metals into receiving water systems in the Fraser River basin.

Bulk storage and shipping facilities. There are 24 facilities located within the Fraser River basin, most in the Lower Fraser River. Contaminants such as metals and petroleum hydrocarbons could be released through oil spills, fuel spills, or sloughing of anti-fouling paints.[250]

Other manufacturing facilities. A wide range of manufacturing facilities and operations are located throughout the Fraser River basin, including foundries and those dealing with wood pellets, rubber products, chemicals, food products, packaging, boat-building, gypsum products, cleaning compounds, and asphalt paving.[251] The contaminants of greatest interest include metals, nutrients, petroleum hydrocarbons, polymers, solvents, resins, chemical additives, volatile organic compounds, and cyanide.[252]

Contaminated sites. About 5,000 contaminated sites within the basin are registered with the provincial Land Remediation Branch. These sites include those with spills of raw or partially treated sewage as well as gasoline, oil, diesel, and other fuels.[253] Mr. MacDonald testified that there may be an additional 4,000 sites.[254]

Municipal wastewater treatment facilities. There are 31 facilities in the Fraser River basin. Eleven in the Lower Fraser River and on Iona Island account for 97 percent of volume (3.0 million cubic metres per day). A 1998 study of concentrations upstream and downstream of the Annacis Island wastewater treatment plant determined that levels of chromium, copper, iron, zinc, and PCBs downstream of the plant exceeded water quality guidelines. Effluents from wastewater treatment plants are also known to contain a variety of other substances, including pharmaceuticals, fire retardants, steroids, personal care products, and disinfectants.[255] Mr. MacDonald testified that the volume of discharges from wastewater treatment plants has increased over the past 20 years.[256] The data to evaluate them are not available, but it is assumed that the concentrations of these contaminants are increasing.[257]

Salmonid enhancement facilities. At least 37 facilities are located in the Fraser River basin, all of them generating wastewater that is discharged into receiving water systems. The highest-priority contaminants are bromine, chlorine, formalin, and formaldehyde.[258]

The researchers also identified several non-point sources (diffuse discharges of runoff from a variety of areas) and atmospheric sources of contaminants.

Runoff from forest management areas. Road building, road maintenance, and clear-cut logging can cause losses of fine sediment as a result of accelerated erosion.[259] Fertilizers, pesticides, herbicides, and insecticides applied to enhance production of timber can be lost through runoff into receiving waters. Mr. MacDonald testified that pine beetle salvage logging leads to deforestation, which in turn leads to erosion and the release of fine sediments into the receiving water systems.[260] When carried along in the flow, these suspended solids get into fish gills, causing toxicity. If they are deposited in the stream substrate, the suspended solids can create a layer on the bottom that can suffocate eggs.[261]

Runoff from agricultural operations. Cattle ranching, feed lots, chicken farms, dairy operations, and tree fruit and vegetable crops result in a wide range of herbcides, insecticides, and fungicides entering receiving waters.[262]

Runoff from municipal stormwater. Contaminants associated with this type of runoff include road salts, metals, polycyclic aromatic hydrocarbons, oil and grease, total suspended solids, nutrients, and pesticides.[263]

Runoff from linear developments. Releases of contaminants can occur during construction, maintenance, or decommissioning of roads, railways, and electrical transmission lines. The substances of greatest concern include chloride, nitrates, ammonia, arsenic, lead, mercury, petroleum hydrocarbons, and herbicides.[264]

Atmospheric sources of contaminants. These include natural sources such as forest fires (e.g., carbon monoxide, benzene) and volcanoes (e.g., silica, aluminum, potassium, sodium, iron, sulphate, and hydrochloric and sulphuric acid); human-caused sources such as vehicle, industrial, and agricultural emissions; and long-range transport of atmospheric pollutants.[265]

From this review, the researchers developed an Inventory of Aquatic Contaminants that included more than 200 substances which may be released into aquatic ecosystems in the Fraser River basin from the various land uses identified. They went on to identify which of those substances occur in surface water or sediment at concentrations sufficient to pose potential risks to aquatic organisms, including sockeye salmon. Based on water quality data from 12 of the 15 geographical areas examined, the researchers identified 23 chemicals of potential concern measured in surface water at concentrations sufficient to pose potential risks to sockeye salmon eggs, alevins, fry, smolts, or adults.[266] Data on sediment quality conditions were available for only four geographical areas in the watershed, and the researchers identified 11 substances posing potential hazards to sockeye salmon.[267]

The researchers then went on to determine if one or more of these contaminants of concern occur at concentrations sufficient to cause or substantially contribute to adverse effects on the survival, growth, or reproduction of sockeye salmon in the Fraser River basin. They refined the list of contaminants to 17 substances in surface water, five substances in sediment, and several others with the potential to accumulate in the tissues of sockeye salmon.[268] They found that water quality conditions in spawning, incubation, and rearing habitats did not exhibit any significant trend. For the migration corridors, water quality conditions generally showed a downward trend between 1965 and 1990, were consistent between 1990 and 2003, and showed improvements thereafter (although the researchers acknowledged that the reliability of post-2003 data was uncertain).[269]

The researchers concluded that the available limited data do not implicate water quality conditions (as measured by standard water quality parameters) as a major factor influencing recent trends in sockeye salmon abundance in the Fraser River basin.[270] However, numerous contaminants of concern occur in one or more habitats at concentrations sufficient to adversely affect the survival, growth, or reproduction of sockeye. These contaminants include total suspended solids, six metals (aluminum, chromium, copper, iron, mercury, and silver), and phenols. The researchers also cautioned that bioaccumulation of contaminants in fish tissues has the potential to adversely affect the productivity of sockeye salmon, although the magnitude and extent of such effects could not be determined with the available data.[271]

MacDonald and others then undertook a qualitative evaluation of the potential effects of endocrine-disrupting compounds. Many of the substances released into the environment as a result of human activities have the potential to modulate or disrupt the endocrine system of aquatic organisms. These chemicals interfere with the natural hormones responsible for the maintenance of homeostasis (metabolic equilibrium), reproduction, development, and behaviour. Exposure has the potential to cause a variety of adverse effects in fish, including abnormal thyroid function, decreased fertility, decreased hatching success, de-masculinization and feminization, defeminization and masculinization, and alteration of immune function (see below).[272]

Endocrine-disrupting chemicals include a wide variety of substances that are released into the environment from natural and human-caused sources, including:

- pharmaceutical and personal care products, including synthetic hormones, and ingredients found in cosmetics, toiletries, detergents, and cleaning products;
- industrial chemicals, including PCBs, PBDEs, ethers, esters, and bisphenol A;

- pesticides, including DDT, organophosphate pesticides, insecticides, herbicides, and fungicides;
- inorganic and organometallic compounds, including methyl mercury; and
- biogenic compounds, including several estrogen-like compounds.[273]

The researchers identified three types of effluents in which endocrine-disrupting compounds are most likely to be observed.

Municipal wastewater treatment plant effluents. For incubating sockeye eggs and alevins, exposure to wastewater treatment plant effluent is likely to be negligible for most Conservation Units. Two exceptions may be Harrison River sockeye spawning downstream of the treatment plant located at Harrison Hot Springs, and Salmon River stocks that may be exposed to diluted wastewater treatment plant effluent during incubation. No evidence was found indicating that treatment plants discharge directly into nursery lakes used for early rearing, so exposure to effluent during this phase of the life cycle is negligible for all stocks, except for the Harrison River stocks, which rear in the backwater areas and sloughs within the Lower Fraser River. However, there are numerous wastewater treatment plants located along the migration corridors. The magnitude and duration of exposure to endocrine-disrupting compounds is a function of several factors, including the level of effluent treatment used, the volume of effluent discharged, dilution capacity of receiving waters, distance travelled during downstream migration, and sockeye residence times in areas with significant effluent discharges. Since residence times are unknown, the researchers assumed that the magnitude and duration of exposure are highest for upriver stocks with the longest migration distances.[274] During the hearings on municipal wastewater treatment, three witnesses agreed that municipal wastewater potentially has harmful effects on Fraser River sockeye, in particular sublethal effects, and that it cannot be ruled out as a contributing factor to the long-term decline.[275] Dr. Ross referred to the cumulative, sublethal exposure to chemicals of concern, in particular persistent chemicals that do not break down, such as dioxins, PCBs, organic chlorine pesticides, and PBDEs.[276]

Pulp and paper mill effluents. Exposure of sockeye eggs and alevins to pulp and paper effluent is likely to be negligible during the incubation period and, with one exception, during nursery lake rearing, because none of the mills discharges into spawning streams or nursery lakes.* However, all 10 pulp and paper mills are located along the migratory corridors, and the magnitude and duration of exposure are functions of several processes, similar to those noted earlier. Since residence times are unknown for most stocks, the researchers assumed that the magnitude and duration of exposure are highest for upriver stocks with the longest migration distances.[277]

Areas with high industrial activity / chemical contamination. Exposure is likely to be negligible for salmon eggs and alevins in most Conservation Units. No information was located indicating the presence of point source industrial or other discharges into nursery lakes used for early rearing (except possibly Fraser Lake) and, accordingly, exposure during early rearing is considered to be negligible, except for Harrison River stocks. However, there are numerous point and non–point source discharges along the migration corridor. Because loadings of endocrine-disrupting compounds to the watershed from these discharges are virtually unknown, the researchers assumed that the magnitude and duration of exposure are highest for upriver stocks with the longest migration distances.[278]

The researchers concluded that exposure of smolts to endocrine-disrupting compounds at levels at or above those likely to be observed in the Fraser River basin has the potential to adversely affect adult reproduction.[279] However, it is unlikely that reproductive effects associated

* The one exception is the Harrison River stocks, which rear in backwater areas and sloughs within the Lower Fraser River. However, during the hearings on pulp and paper effluent, Robert Grace, environmental impact assessment biologist, BC Ministry of Environment, testified that there is some rearing of sockeye in Kamloops Lake and that one mill near Kamloops discharges into the Thompson River, which flows into Kamloops Lake. See Transcript, June 13, 2011, p. 49.

with endocrine-disrupting compound exposure are sufficient to explain the declines in Fraser River sockeye salmon abundance over the past two decades, or the poor returns in 2009, for several reasons: exposure to such compounds in pulp and paper mill effluents has likely decreased; exposure durations during downstream migration may be insufficient to elicit significant reproductive effects; and there is little evidence for differential response among stocks that possibly receive different exposures to such compounds.[280] However, exposure may come from other sources, such as municipal wastewater discharges, which have increased.[281]

MacDonald and others cautioned that it is nevertheless possible that exposure to endocrine-disrupting compounds is causing other types of effects that could be sufficient to adversely affect the survival, growth, or reproduction of sockeye, through compromise of the immune system. They stated:

> Collectively, the results of studies on immunosuppression indicates that exposure to endocrine disrupting compounds has the potential to adversely affect salmon during their transition to the marine environment. If the concentrations of endocrine-disrupting compounds were sufficient to elicit these types of effects in the Fraser River, then the resultant mortality of smolts during transition to the marine environment could have contributed to long-term declines in sockeye salmon abundance.[282]

Finally, the researchers undertook a qualitative evaluation of the potential effects of contaminants of emerging concern – this term describes a broad group of chemicals that were previously unknown or not previously recognized as being of concern relative to human or environmental health.[283] Contaminants of emerging concern in the Fraser River basin are likely to include veterinary and human antibiotics, prescription and non-prescription drugs, industrial and household waste products, sex and steroidal hormones, herbicides, fungicides, wood preservatives, and polychlorinated paraffins.[284] The sources for these contaminants include municipal wastewater treatment plants; and runoff from feedlots, industrial and manufacturing facilities, and wood preservation facilities.[285]

According to the researchers, exposure is likely to be negligible for most stocks of sockeye eggs and alevins, and during early rearing. Contaminants of emerging concern are most likely to be released along migratory corridors. However, during the urbanization hearings, Dr. Robie Macdonald, section head, Marine Environmental Quality, Institute of Ocean Sciences, Science Branch, testified that salmon can accumulate concentrations of fat-soluble contaminants such as PCBs which, when the salmon reach their spawning lakes or rivers, are many times higher than the water systems.[286] These contaminants can then be transferred into the watershed when the returning sockeye die. Owing to the paucity of toxicity and exposure data, it is difficult to evaluate the risks to sockeye.[287] Nevertheless, the researchers concluded that contaminants of emerging concern are a significant environmental issue that needs to be addressed and could be causing, or substantially contributing to, the decline of Fraser River sockeye observed over the past two decades.[288]

Overall, the researchers concluded:

- Exposure to measured contaminants in surface water, sediments, and fish tissues is not a primary factor influencing the productivity or abundance of Fraser River sockeye salmon over the past 20 years or in 2009.[289]
- 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.[290]

In his testimony, Don MacDonald agreed that his report did not address contaminants in the marine environment; synergistic effects between and among contaminants; or interactive effects of temperature, disease, and contaminants.[291]

Testifying on freshwater urbanization, Dr. Robie Macdonald stated that water quality monitoring of the Fraser River provides information about general river functioning (e.g., temperature and nutrient work), but provides no information on pesticide exposure, mercury uptake, pharmaceuticals, or biomagnifying accumulating contaminants (e.g., PCBs).[292] The monitoring done is not intended to assess receiving water quality for Fraser River sockeye salmon.[293]

Specific freshwater and marine contaminant sources

Municipal wastewater

Dr. Peter Ross, Graham van Aggelen, and Dr. Ken Ashley all provided their opinion on the potential effects of wastewater effluent on Fraser River sockeye.* All agreed that municipal wastewater potentially has harmful effects, in particular sublethal effects, on Fraser River sockeye and cannot be ruled out as a contributing factor to the long-term decline of Fraser River sockeye (but is likely not the "smoking gun" concerning the poor returns in 2009).[294]

Dr. Ross explained that a number of chemicals of concern involving Fraser River sockeye are in wastewater.† In support of this view, he pointed to research in other jurisdictions that has shown effects on fish from chemicals in wastewater.[295] According to Dr. Ross, there are 90 wastewater treatment plants in the Fraser River valley. He was concerned about the cumulative, sublethal exposure to chemicals of concern – in particular, persistent chemicals that do not break down, such as dioxins, PCBs, organic chlorine pesticides, and PBDEs – by Fraser River sockeye throughout their early life and on their return migration.[296]

Mr. van Aggelen described how chemicals of emerging concern in wastewater can be present at very low levels that can cause endocrine disruption. Many municipal wastewater systems do not, or cannot, remove or treat these chemicals, and traditional fish health bioassays cannot detect them.[297] He agreed with Dr. Ross that of particular concern is the persistent, low-level continuous exposure that can have a cumulative, sublethal effect on Fraser River sockeye.[298]

Dr. Ashley agreed with Dr. Ross in expressing concern about sublethal endocrine-disrupting chemicals. He also described a potential acute toxicity issue for sockeye with some of the high concentrations of ammonia, which can be acutely lethal depending on pH and temperature discharged from the Annacis Island and Lulu Island wastewater treatment plants.[299] He said that the design of the plants at Annacis and Lulu islands are not particularly effective at converting ammonia to a non-toxic form, so they discharge it at fairly high concentrations into the effluent stream, assuming that the ammonia will be diluted to the point where it is non-toxic to salmonids.[300] Despite his concern, Dr. Ashley was not aware of any evidence that links harmful effects from ammonia from Annacis and Lulu islands to Fraser River sockeye.[301]

In the Pacific Region, DFO is not involved in monitoring or researching the impacts of municipal wastewater on salmon or Fraser River sockeye,[302] nor is anyone from Environment Canada tasked with assessing the impacts of municipal wastewater on salmon.[303] Dr. Ross testified that the lack of research on the effects of chemicals in wastewater on Fraser River sockeye makes it difficult to speak with certainty about potential effects on these fish stocks.[304]

On the related issue of stormwater, this runoff contains oil, gas, metals, PCBs, grease, antifreeze, solvents, pesticides, herbicides, fertilizer, paint, detergents, road salt, and animal feces.[305] The Commission's Technical Report 2, Contaminants, summarizes the contaminants most commonly associated with runoff of stormwater from urban centres:

- total suspended solids;
- major ions (chlorides);
- metals (arsenic, cadmium, copper, chromium, lead, mercury, nickel, and zinc);
- monoaromatic hydrocarbons;
- polycyclic aromatic hydrocarbons;
- petroleum hydrocarbons (e.g., oil and grease);
- polychlorinated biphenyls;
- organochlorine pesticides (e.g., DDT); and
- pesticides.[306]

* I qualified all three witnesses as experts in their fields. Specifically, Mr. van Aggelen, head, Environmental Toxicology Section, Pacific Environmental Sciences Centre, Environment Canada, was qualified as an expert in toxicology and toxicogenomics (Transcript, June 14, 2011, p. 3; Exhibit 1044). Dr. Ashley, senior scientist, Northwest Hydraulic Consultants, was qualified as an expert in environmental engineering, aquatic ecology, and limnology (Transcript, November 4, 2011, p. 3; Exhibit 1045). For Dr. Ross's duties and expert qualifications, see the Freshwater and marine contaminants overview, above.

† "Chemicals of concern" and "chemicals of emerging concern," as used by some witnesses, may not match exactly to the use of the terms in Technical Report 2, Contaminants. See Exhibit 826, in particular Tables 3.16 and 3.17, for a list of chemicals frequently found in municipal wastewater (pp. T-48–T-50) and a list of contaminants of emerging concern commonly present at elevated levels in wastewater treatment plant effluents (pp. T-51–T-52).

In some communities, such as Vancouver, combined systems are connected to wastewater treatment facilities, where both stormwater and sanitary sewage receive treatment.[307] One disadvantage with combined systems is that, during periods of heavy precipitation, they can become overloaded and wastewater is typically directed to combined sewer overflows (CSOs), allowing raw sewage and untreated stormwater to overflow at many exit points upstream of the treatment facility and to enter receiving waters directly without any treatment.[308] Municipalities with combined sewer systems typically experience tens of overflows of CSOs annually.[309]

Dr. Ashley testified that overflows from combined sewage and stormwater sewer systems have the potential to harm Fraser River sockeye depending on the timing and magnitude of the discharge event.[310] He stated that there is a risk of acute and chronic toxicity and accumulation of persistent contaminants in the Fraser River.[311] Dr. Ross added that research in Puget Sound, Washington, has shown that runoff from CSOs has created problems for salmon.[312]

Pesticides

The broad application of pesticides to crops, lawns, and forests results in mostly non–point source pollution in the form of runoff.[313] Pesticides can also get into surface waters from overspraying, erosion of contaminated soils, and contaminated groundwater.[314] Mr. MacDonald, lead author of Technical Report 2, Contaminants, testified that the forestry sector's use of pesticides may be one of the greatest concerns for Fraser River sockeye.[315] A 2003 Environment Canada study on pesticide use in Canada states that the majority of pesticides sold and used in British Columbia were used by the forestry sector.[316] This report also says that a number of pesticide active ingredients were used exclusively in the agriculture sector and accounted for 63 percent of total sales.[317] I also heard from Dr. Ross that agriculture and forestry pesticides are of concern with respect to Fraser River sockeye.[318] Technical Report 2 describes a number of water quality concerns associated with agriculture.[319]

Greywater

Greywater is wastewater originating from showers, baths, bathroom sinks, kitchen sinks, pools, spas, and laundry.[320] (See Volume 1, Chapter 6, Habitat management.) It gets into the environment through municipal wastewater systems, septic systems, and discharge from vessels. It can contain nutrients, bacteria, viruses, and a variety of chemicals, including endocrine disruptors associated with detergents and personal care products.[321] According to the province, the cumulative effects of multiple vessels discharging greywater may result in the long-term disruption of natural nutrient levels and subsequent impacts on the natural ecology of a water body like Shuswap Lake.[322]

Gravel removal in the Lower Fraser River

On the topic of potential gravel removal impacts on Fraser River sockeye, I heard from two witnesses qualified as experts in freshwater fish habitat in flowing waters and rivers, with an emphasis on the Lower Fraser River (for management of the potential impacts of gravel removal, see Volume 1, Chapter 6, Habitat management).[323]

Dr. Laura Rempel, a habitat biologist within OHEB, described the potential impacts to fish habitat generally resulting from gravel removal, most of which can be mitigated through planning, best practice, and due diligence (having contractors remove the gravel, and in the design of the removal itself).[324]

For most Fraser River sockeye salmon, the Lower Fraser River gravel reach appears to provide habitat during only relatively brief periods of migration. Sockeye salmon are not known to spawn regularly in the gravel reach, but at least one population has spawned sporadically in a slough habitat toward the top end of the area (Maria Slough).[325] Dr. Rempel described the occurrence of sockeye found in the gravel reach in beach seines she carried out over three years. Out of a total of more than 40,000 fish caught in these seines, on average only 0.8 percent were juvenile sockeye.[326] Dr. Rempel stated that the juvenile sockeye caught in her beach seines may have been river-type sockeye or strays from a lake-type population, but without genetic analysis there is no way to be sure which they might be.[327]

The other expert, Dr. Marvin Rosenau, is an instructor of fish wildlife and recreation technology at the British Columbia Institute of Technology.

He described the results from two single-day surveys on the gravel reach, in 2007 and in 2010.[328] Some juvenile sockeye – not outmigrating smolts – were found at two locations in 2007.[329] Juvenile sockeye were found in one of the locations in 2010 as well.[330]

Dr. Rosenau also described information on sockeye that arose out of projects by his students.[331] These projects found that sockeye were present in the winter in some isolated ponds off the mainstem of the Fraser River.[332] He summarized these findings:

> So with respect to sockeye, we're seeing this behaviour, as the floodwaters increase and then decrease, of fish moving out into the sides, the perimeters of the river, and then moving back out, in some cases clearly onto gravel bars.[333]

Dr. Rempel testified that the sites surveyed by Dr. Rosenau's students are located outside the area of gravel removal.[334] In response, Dr. Rosenau stated that one of his study sites was a gravel removal site in the 1980s. He explained that, in any event, the key piece of information is the ubiquity of sockeye throughout the flood plain and their movements during the high-discharge periods, which indicate that we do not yet understand what the fish are doing in these habitats.[335]

I also heard from Mr. Hwang that gravel removal has significantly less potential to affect sockeye than other habitat impacts such as changes to the watershed due to the mountain pine beetle, water diversions, and cumulative impacts of accelerated and high rates of foreshore and recreational property development.[336]

Both Dr. Rempel and Mr. Hwang stated that gravel removal probably has a very small potential to affect sockeye and sockeye habitat.[337] Dr. Rempel stated that DFO has adequate information to appreciate the relative use by sockeye of the gravel reach habitats.[338] However, I also heard from both Dr. Rempel and Dr. Rosenau that there are limitations to DFO's understanding of the ways that sockeye use this area.[339] Dr. Rosenau testified that the presence of juvenile sockeye in ponds that develop periodically over a number of years suggests that a lot more juvenile sockeye are in the river during high-discharge periods than previously thought.[340] He added that we need to know more about these sockeye that were found to be predominantly Late Stuart and Stellako stocks, both of which are lake-type sockeye.[341] He concluded that, in his view, we do not yet understand the role of the gravel reach with respect to sockeye salmon.[342]

Life stage 3: coastal migration

Strait of Georgia and Juan de Fuca Strait

After leaving the river, it is believed that most Fraser River sockeye juveniles turn north and migrate through the Strait of Georgia, Johnstone Strait, and Queen Charlotte Strait and into Queen Charlotte Sound.

There is some evidence that the Harrison River population, and perhaps other populations, are exceptions to this migratory pattern. For example, it appears that the Harrison River population spends the remainder of its outward migration year in the Strait of Georgia and then migrates south of Vancouver Island through Juan de Fuca Strait to the west coast of Vancouver Island.[343]

Several of the Commission's technical reports examined, and witnesses testified about, the stressors that may have caused or contributed to the recent decline during this life stage. I summarize these discussions below.

Predation

The authors of Technical Report 8, Predation, Dr. Christensen and Dr. Trites, reported that the mortality of salmonids in the ocean can be substantial – a 1968 study found early mortality of pink salmon fry to be between 2 and 4 percent per day for the first 40 days.[344] The researchers considered two categories of potential predators relevant to the postsmolt migration through the Strait of Georgia, which I will discuss in turn.

Fish

A 1991 study estimated that river lamprey in the Strait of Georgia were a major predator on postsmolt salmon, consuming an estimated 65 percent of coho and 25 percent of chinook salmon, but only 2.3 percent of sockeye production. Dr. Christensen and Dr. Trites concluded that the river lamprey may be an important predator on sockeye postsmolts; however, in the absence of estimates for trends in abundance, it is not possible to quantify the effect.[345]

Although ecosystem modelling conducted in 2001 suggested that spiny dogfish consumed approximately 145 tonnes of juvenile sockeye and pink salmon in the Strait of Georgia, there is no evidence of any clear changes in dogfish abundance between 1980 and 2005.[346] Similarly, a 2001 study estimated that, if sockeye postsmolts constituted 0.5 percent of the diet of chinook salmon in the Strait of Georgia, those chinook could consume 345 tonnes of postsmolts, or 35 million fish, per year. However, the researchers concluded that it is unlikely that chinook is of importance for the decline of Fraser River sockeye salmon, given the considerable decline in chinook abundance in the Strait of Georgia over the past decades. They reached a similar conclusion in relation to predation by coho salmon.[347]

During the evidentiary hearings, Gordon McFarlane, former head, Marine Fish Population Dynamics, Pacific Biological Station, Science Branch, testified that he agreed with the researchers' final conclusions that marine fish probably were not a major factor in the 2009 reduced returns.[348] He would, however, spend more time studying the dogfish shark.[349]

Birds

Common murres are seabirds that come ashore in summer to breed, and the Strait of Georgia has major concentrations in the late summer and the fall. They actively feed on smolts during release periods of hatcheries. However, data from the Christmas Bird Counts do not indicate any increasing trend over time. Based on this observation, the researchers concluded that the common murre may not be an important factor for the decline in survival of Fraser River sockeye salmon.[350] They also discounted the pelagic cormorant, Brandt's cormorant, and the glaucous-winged gull, given their recent declines in abundance.[351]

During the evidentiary hearings, Mr. McFarlane testified that the most vulnerable phase of marine life to predation is the first four or five weeks after entering saltwater.[352] The year 2007 saw very low productivity in the Strait of Georgia, and smolts had the lowest length:weight ratio on record – an occurrence that, over the next weeks or months, could have increased mortality and vulnerability to predation.[353]

Sockeye habitat use in the Strait of Georgia

In Technical Report 12, Lower Fraser Habitat, authors Johannes and others summarized potential human development–related impacts over the recent 1990–2010 period and examined potential interactions between human development and activities in the Lower Fraser River (from Hope to the estuary) for sockeye salmon habitats. Some witnesses challenged the evidence contained in Technical Report 12, and I set out the conflicting evidence below. The researchers addressed stressors and marine conditions specific to the Strait of Georgia, including land use, shipping and vessel traffic, and water and biological properties.

Land use. Development of residential, recreational, and industrial lands and transportation corridors in the Strait of Georgia has removed and degraded habitat areas and natural environments over the past century. Larger population size and density lead to higher levels of water pollution, nutrients, and contaminants from wastewater and stormwater runoff.[354]

Shipping and vessel traffic. Shipping and marine vessels are a source of noise, contaminants, accidental spills, and non-indigenous species into the marine areas of the Strait of Georgia through hull fouling and ballast water exchange. However, port vessel traffic and ferry traffic across the Strait of Georgia have remained relatively stable during the past two decades. Although cruise ship traffic has nearly tripled between 1990 and 2005, it remains a small proportion of total ship movements. The researchers concluded that shipping and vessel traffic have limited direct interaction with sockeye habitats.[355]

Strait of Georgia water properties. Water circulation and other properties in the Strait of

Georgia – such as sea surface temperature, sea surface salinity, and nutrient properties and distribution – are determined by a number of factors, primarily the seasonality of freshwater discharge from the Fraser River, variation and strength of prevailing winds and tidal mixing, and currents influenced by climate and Pacific Ocean conditions.[356] For example, freshwater discharge from the Fraser River controls local circulation and helps stratify the upper layers of the water column in the strait.[357] Time series of sea surface temperatures showed that Juan de Fuca Strait was cooler at all times than the Strait of Georgia, and that a gradual warming of waters has occurred. Such changes in the physical water properties in the strait, which are linked to biological production, have implications on the distribution, growth, and survival of sockeye salmon.[358]

Strait of Georgia biological properties. Biological conditions in the Strait of Georgia show a large range of variation over seasons and years. Phytoplankton primary production supports the marine ecosystem and food chain in the Strait of Georgia. The onset of the spring phytoplankton bloom (late February to early April) appears to be associated with changes in wind, solar radiation, and Fraser River discharge.[359] Harmful *Heterosigma* algal blooms can potentially cause mortality in various marine species, including salmon, through altered ability to uptake oxygen and diminished respiratory function. However, because sockeye smolt distribution, timing, and migration tend to be outside the nearshore coastal areas and time periods normally associated with the generation and spread of *Heterosigma* blooms, the researchers concluded that no observations are currently available to assert or reject causal links between sockeye mortality and harmful algal blooms.[360] (However, I heard expert testimony regarding the potential impact of harmful algal blooms on Fraser River sockeye during the marine ecology hearings that asserted otherwise [see below].) *Neocalanus*, a dominant zooplankton species and preferred prey for Fraser River sockeye smolts while migrating through the Strait of Georgia, started a large decline in abundance in the 1990s, with a further decline between 2003 and 2007 associated with a warming trend. It is a subarctic copepod, and during warming conditions it is unable to complete its life cycle. Other copepods have become more abundant in the food web with the decline of *Neocalanus*.[361]

The researchers found that few data are available to be used for quantitative evaluation and review on the amount of sockeye habitat change over time in the Strait of Georgia relative to human activities. Nevertheless, concerning the impact of major project development, the researchers concluded that there has been a net gain of habitat:

> The habitat protection strategies used in the lower Fraser River and Strait of Georgia appear to be effective at supporting sockeye habitat conservation during project review and project-related activities (e.g., construction impacts of a specific project). More broadly, a hypothesis that the declines in Fraser River sockeye production are the result of major (or even moderate and minor) project development is not supported by the likely net gains in habitat that have occurred over the period of review.
>
> Overall, the development of major projects and resource restoration efforts during the period 1990–2010 has resulted in a net gain of sockeye habitat and these gains have been substantially added to through efforts to restore historically lost or damaged fish habitats.[362]

The researchers' summary of potential links to Fraser River sockeye declines based on interaction and effects of human activities identified Strait of Georgia water properties as a moderate risk, and Strait of Georgia biological properties as a high risk. They concluded (without a quantitative analysis):

> Potential interactions between biophysical conditions in the Strait of Georgia and sockeye (habitat and habitat use) are suggested as representing moderate and high risk to sockeye in the data compiled here, but limits in existing studies and data prevent an analysis of the causality of these interactions. Our review suggests that there may be an association between changes in biophysical conditions (temperature and food availability and/or quality) in the Strait of Georgia, sockeye habitat use and potentially production. This observation is not supported by conclusive causal linkages, but is supported by other studies which suggest that

> Fraser sockeye production is expected to be higher when sockeye growth and condition are high, compared with poorer sockeye production in years where the sockeye have lower growth and condition. Cooler years in the Strait of Georgia are expected to result in habitats with higher abundance and availability of preferred sockeye prey and lower levels of competitors and predators … The observations of association in time and space between sockeye declines and water and biological conditions in the strait are unlikely to be solely responsible for the declines observed in sockeye populations. The cause is likely much more complex, although the observations do suggest that research in these areas is warranted.[363]

During the evidentiary hearings, Dr. Johannes testified that his conclusion regarding net habitat gains was really an assumption based on several conditions – the available literature, his own experience as part of a team working on environmental assessments and reviews, and his professional experience throughout his career.[364] The Harper and Quigley study he relied on for his conclusion of net gain in sockeye habitat dealt with habitat across all of Canada, not just Fraser River habitat, and that study found that a No Net Loss determination could not be made for 86 percent of the projects.[365]

Dr. Johannes said that when other species of salmon and other fish are taken into consideration, habitat is in fact being lost.[366] However, based on records of distribution, he stated: "I would say that in the Lower Fraser for those races and sub-populations of sockeye that might use the Lower Fraser, there's probably been no net loss."[367] Regarding the requirement to restore lost habitat on a two-for-one basis, Dr. Johannes said that he did not know the extent to which the 2:1 requirements for habitat replacement are complied with or completed: "Conceptually, I would say that … during the last time period, there is no net loss conceptually. If I had the opportunity to look at the compliance records and the audits and the detailed information, I don't know what the answer might be."[368] He agreed with the suggestion that one has to consistently monitor projects to ensure that developers are in fact doing a proper job when they say they are restoring habitat.[369]

Other witnesses disagreed with the conclusion that there has been no net loss in habitat. Patrice LeBlanc, director, Habitat Management Policy Branch, Program Policy Sector, testified that Canada is not achieving No Net Loss and that there is an inability to measure the losses occurring nationally.[370] Mr. Hwang testified that, at the operational level, all indications are that Canada is not meeting the No Net Loss principle.[371] Rebecca Reid, former regional director, OHEB, and, at the time of the hearings in April 2011, regional director, Fisheries and Aquaculture Management, agreed that Canada is probably not achieving No Net Loss, but there is insufficient information to know for sure.[372] Randy Nelson, regional director, Conservation and Protection, Pacific Region, said that, in his experience from working on the Fraser River for 20 years, there probably has been a loss of fish habitat in many areas.[373] (For a more detailed discussion of the No Net Loss principle, see Volume 1, Chapter 6, Habitat management.)

Climate change

The authors of Technical Report 9, Climate Change, Dr. Hinch and Dr. Martins, reported that sea surface temperature in the Strait of Georgia has increased at about 0.25°C per decade since the 1950s. Waters are now 1.5°C warmer than 60 years ago, and 0.5°C warmer than 20 years ago.[374]

Thermal conditions experienced by smolts during their first months of marine life are closely related to their first-year survival. Although warmer temperatures have been frequently associated with increased early marine survival in Alaskan sockeye, the same conditions have been associated with poor survival of Fraser River sockeye migrating along the British Columbia coast. Warm sea surface temperatures are associated with reduced upwelling and, hence, low food availability (zooplankton) for young sockeye. As well, the peak timing of the main zooplankter in the Strait of Georgia has advanced up to 30 days in the past decades, and the peak duration has shortened in response to warming. The observed advance in timing of the Fraser River spring freshet may also be contributing to an earlier peak in zooplankton density in the Strait of Georgia, which might mean that sockeye smolts miss the peak of zooplankton (their food) abundance.[375]

The researchers concluded that warm sea surface temperatures lead to high metabolic rates in sockeye salmon and can change food availability, an occurrence that can reduce early marine growth. Warm waters can increase the abundance of non-resident predatory fish and can also increase the metabolic rate of resident predator fish, leading to increased food consumption.[376] These changes suggest that survival of juvenile Fraser River sockeye salmon during their coastal migration has likely decreased in the past two decades, although there were no data for Fraser River sockeye on which to base the analysis.[377]

Marine ecology

In Technical Report 4, Marine Ecology, authors Dr. Stewart McKinnell and others referred to studies from the 1960s which found that the earliest sockeye migrants into the Strait of Georgia had the least diverse diets – copepods were the dominant prey in April, but their contribution to sockeye diet diminished in later months. *Neocalanus*, the dominant copepod in the Strait of Georgia, experienced an 87 percent decline in abundance between 2001 and 2006, and this decline was accompanied by longer-term declines in copepod zooplankton biomass in the strait. During the years of *Neocalanus* decline, the composition of the phytoplankton spring bloom varied annually among diatoms, flagellates, and dinoflagellates.[378]

A review of studies from the 1970s found that the average size of sockeye postsmolts caught in the Fraser River plume and in the Gulf Islands did not increase with time through April, May, and June, a conclusion that led to speculation that they spend too little time in the Strait of Georgia to allow them to increase significantly in size.[379] (However, a major problem with such a conclusion arises from the high probability of a variable composition of the catch – fish caught in June may not be from the same stock as those caught in April.) The researchers concluded that sockeye salmon emerging from rivers in the southern part of their range, such as the Fraser River, have lower growth rates and lower average marine survival than their counterparts in southeastern Alaska. It is therefore not unreasonable to consider the initial period of their postsmolt migration as a race northward to find better feeding conditions in coastal Alaska.[380]

In addressing the low 2009 return of Fraser River sockeye, the researchers examined conditions in the Strait of Georgia during mid-2007, when postsmolts that would return in 2009 were migrating north. The Fraser River creates a large plume of fresh and brackish nutrient-rich water that spreads thinly across the strait and is mixed with salty water below by tides, winds, and currents. The sun's radiant energy, which provides the most warmth at the surface layer, reinforces the density gradient. In the spring of 2007, the daily volumes of freshwater entering the Strait of Georgia were often in the upper quartile, but not extreme. Similarly, an analysis of daily sea surface temperatures and salinity at four stations in the Strait of Georgia indicates that 2007 was not extreme in the historical record.[381]

Phytoplankton and nitrate concentrations during the winter and spring of 2007 in the Strait of Georgia were found to be similar to what had been observed from 2002 to 2006. During the summer, phytoplankton concentrations were higher at most stations but then dropped during the autumn. Surface temperatures in the Strait of Georgia remained warmer than average or average through the sockeye outmigration in 2007 and 2008. However, the deep waters in the strait began cooling in mid-2007, a trend that continued and intensified into 2008.[382]

During the evidentiary hearings, the Government of Canada tendered four reports that considered juvenile Fraser River sockeye ecology in the Strait of Georgia and the adjacent marine areas of Queen Charlotte Sound and Hecate Strait. Those reports can be summarized as follows, based on the reports' abstracts.

Preikshot and others. Based on catches of juvenile Fraser River sockeye salmon in a trawl survey and smolt sampling, it was estimated that the average residence time of juveniles in the Strait of Georgia was 35 days.[383]

Beamish, Neville, and Sweeting. The synchronous poor early marine survival of virtually all the salmon species in the surface waters of the Strait of Georgia in the spring of 2007 indicates that there was a collapse of prey production for these species, resulting in the poor 2009 Fraser River sockeye returns. It is likely that climate and ocean conditions within the Strait of Georgia were responsible for the synchronous poor production of prey and resulting poor survival of Pacific salmon and herring.[384]

Beamish and others. Large abundances of juvenile Pacific salmon of all species enter the Strait of Georgia between late April and late May, but smaller abundances (e.g., Harrison River sockeye and South Thompson chinook populations) enter the strait six to eight weeks later. These late ocean-entry populations have higher productivity. Although the reasons for this higher productivity are not known, the researchers proposed that in recent years feeding conditions in the strait improved in July after many of the other juvenile Pacific salmon have emigrated or died.[385]

Thomson and others. The low Fraser River sockeye returns in 2009 indicated poor early marine survival of juvenile salmon in 2007, likely due to low food levels arising from unfavourable wind and river discharge conditions in the Strait of Georgia and the Queen Charlotte Sound–Hecate Strait region in the spring of 2007. Conversely, the high returns in 2010 were associated with a large smolt output from the Fraser River and good early marine survival in 2008, which was likely due to adequate food levels arising from favourable wind and runoff conditions in the spring of 2008. Even though the 2008 entry stocks were negatively influenced by the 2008–9 winter, the winter conditions in 2009–10 had a positive effect on these fish.[386]

During the evidentiary hearings, Dr. Richard Beamish, retired research scientist, Salmon and Freshwater Ecosystems, Pacific Biological Station, Science Branch, testified that his research indicated that Fraser River sockeye take about 35 days to migrate through the Strait of Georgia. He also described the Preikshot study, which concluded that the average residence time of juveniles in the Strait of Georgia was approximately 35 days.[387] In Dr. Beamish's view, this figure was consistent with several other estimates, although he agreed that there are still some uncertainties with this estimate.[388]

Dr. Welch testified that acoustically tagged smolts move about a body length a second, or 10 km a day.[389] On that basis, it takes a smolt 15–20 days to swim from the mouth of the Fraser River to the north end of the Strait of Georiga, and about the same time to reach the Queen Charlotte Sound.[390] He thought that the Preikshot estimate of 35 days to clear the Strait of Georgia (Exhibit 1305) was an overestimate.[391]

Dr. Beamish testified that in 2001 he and Dr. Connie Menken published an article (Exhibit 1308) espousing a critical size / critical period hypothesis:

> So in general, then, what we're saying is that juvenile salmon enter the ocean and have to grow quickly. There's large mortalities in that first up to six week period, and the fish that grow the fastest are the ones that are the larger ones, store energy and continue to store energy through the summer and survive the harsher conditions when feeding is less available, and prey are less available in the winter.[392]

Dr. Beamish also referred to his more recent study documenting a synchronous failure in juvenile Pacific salmon and herring production (Exhibit 1309). He said that during a 2007 trawl survey in the Strait of Georgia, he and his colleagues encountered extremely low abundances of herring and five salmon species (pink, sockeye, chinook, chum, and coho).[393] He could not think of another situation, anywhere, of such a synchronous failure in year-class strength.[394] They also found that coho and chinook had a high percentage of empty stomachs, although Dr. Beamish agreed that the sample sizes were small.[395] Dr. Beamish was directed to a study by Dr. Angelica Peña in which she stated that the distribution of phytoplankton and nitrate concentration during winter and spring of 2007 was similar to those observed in previous years.[396] He responded that he did not think that Dr. Peña, or any other scientist, was saying that phytoplankton production in the Strait of Georgia in 2007 was normal.[397]

Dr. Welch stated that his concern about focusing on the Strait of Georgia before establishing where the problem is means one may spend a great deal of energy on an area that is not the problem.[398] Dr. McKinnell agreed with the suggestion that we may never know what caused the 2009 decline.[499] Dr. Welch added that multiple explanations are still on the table.[400] Dr. Beamish said that sockeye entering the Strait of Georgia experienced very poor conditions for growth and survival, and then those conditions were exacerbated when they moved through Queen Charlotte Sound.[401]

Dr. McKinnell testified that, since completing his technical report, he has done further research showing that the British Columbia rivers which had the highest peak five-week discharge in the spring of 2007 were from Queen Charlotte Strait north.[402] The Fraser River was the 17th highest in the record.[403] He said he could use the term "extreme" for physical conditions in Queen Charlotte Strait and Sound, but not for anything he found when looking at the Strait of Georgia.[404]

Dr. Beamish also summarized Dr. Richard Thomson's study, which found extremely anomalous conditions in the Strait of Georgia in the spring of 2007: exceptional freshwater discharge, low surface salinity, a very shallow mixing layer depth, and winds blowing up the strait retaining the freshwater.[405] Dr. Beamish testified that these conditions match perfectly with what would affect prey production and result in the very poor survival that he and his co-authors had identified.[406] Conditions in Queen Charlotte Sound were also anomalous in 2007, an occurrence which resulted in Dr. Beamish's interpretation that juvenile sockeye entering the Strait of Georgia experienced very poor conditions for growth and survival, and that those conditions were exacerbated when the fish moved through Queen Charlotte Sound.[407] In fact, the poor conditions extended into that winter.[408] He agreed that conditions in Queen Charlotte Sound or in the Gulf of Alaska contributed to the extremely poor returns in 2009, and added that the critical size / critical period hypothesis acknowledges that mortality does not have to actually occur in the area where those conditions initially started.[409] Dr. Beamish was referred to the 2010 Pacific Salmon Commission hypothesis that "[o]cean conditions (physical and biological) inside Georgia Strait are important indicators of contributors to the Fraser sockeye situation," and the conclusion that the relative likelihood that this hypothesis caused observed changes in productivity during the long-term decline was "likely" and during 2009 was "very likely."[410] He agreed with this conclusion.[411]

Dr. Jim Irvine, research scientist, Salmon and Freshwater Ecosystems, Pacific Biological Station, Science Branch, testified that low returns for Chilko Lake in 2009 occurred despite huge freshwater survivals two years earlier, and that the low returns were caused by anomalously low ocean survivals – or at least smolt-to-adult survivals.[412] On the other hand, he explained, the good returns in 2010 were the result of high freshwater survivals in 2008; the ocean survivals were only average.[413] The anomalously low survivals for the 2007 ocean-entry-year fish could be due to some sort of major catastrophe occurring in some specific location (for which there is no evidence), or a cumulative effect of subnormal conditions at multiple life history phases – the sort of thing one expects to see occasionally in times of climate change.[414]

Harmful algal blooms

The term "harmful algae" includes any phytoplankton species that is harmful to marine organisms, humans, other animals, or the environment.* Blooms of species of the toxic alga *Heterosigma akashiwo* occur annually in British Columbia waters, particularly within the Strait of Georgia and Barkley Sound, and have been identified as a cause of net-pen salmon losses in British Columbia.[415] However, mortalities of sockeye salmon have not been directly attributed to this alga, so no causal link has been established.[416]

Dr. Jack Rensel provided expert testimony on harmful algal blooms (HABs).† He said there is evidence that HABs in the Strait of Georgia could have contributed to the poor 2009 Fraser River sockeye return and may have contributed to the longer-term decline in Fraser River sockeye productivity.[417] Dr. Rensel also said that there is general agreement in the fields of marine ecology and algal bloom science that a major worldwide increase is occurring in the frequency and intensity of harmful algal blooms.[418]

Dr. Rensel suggested that exposure of juvenile Fraser River sockeye to *Heterosigma* blooms could result in direct, acute effects or in chronic effects such as infections, making the fish more susceptible

* Harmful algae do not necessarily cause harm in low concentrations, and they are sometimes important components of the marine food web. See PPR 19, p. 72.

† Dr. Rensel was qualified as an expert in algal zooplankton and marine and freshwater habitats; harmful algal bloom dynamics; monitoring and mitigation studies; and fish physiology studies, bioassays, and fish kill assessments (Transcript, August 17, 2011, p. 4). His curriculum vitae is Exhibit A to Exhibit 1363.

to poor food supply conditions and predation.[419] Adult Fraser River sockeye, Dr. Rensel suggested, are at risk of acute or chronic effects from *Heterosigma* because they swim at shallower depths on return to the river.[420] Dr. Rensel cautioned that *Heterosigma* blooms could have an impact in combination with diseases, low food availability, and other stressors.[421] There are a number of ecotypes of *Heterosigma*, as well as other algal species that may be harmful to Fraser River sockeye.[422]

In the June 2010 PSC workshop proceedings, harmful algal blooms in the Strait of Georgia were rated as a "possible" contributor to the poor 2009 return and as an "unlikely to possible" contributor to the longer-term decline.[423] Dr. Rensel did not agree entirely with the conclusions reached by the workshop because he had already left it when the ratings were applied and there was no expert present to argue for the HABs theory.[424] I note, however, that David Marmorek, who worked on algal blooms and contaminants with Dr. Rensel at the PSC workshop, testified that a lot of consideration went into the ratings.[425] According to Dr. Rensel, all the evidence presented for the various hypotheses was correlational, so if voting were based just on correlations, the harmful algal bloom hypothesis should have had a "very likely" rating.[426]

One of Dr. Beamish's expert reports appears to discount Dr. Rensel's *Heterosigma* theory.[427] Dr. Rensel explained that after this report was tendered into evidence, he corresponded with the lead author, Dr. Beamish.[428] According to Dr. Rensel, Dr. Beamish's discounting of the Rensel theory was based on a misunderstanding about where the sampling for *Heterosigma* occurred in 2007, and Dr. Beamish would be revising his paper to account for this misunderstanding.[429]

Although harmful algal blooms were seen in the Strait of Georgia in 2008, the 2010 Fraser River sockeye return was very good. In response, Dr. Rensel said that the timing of the bloom in 2008 was later than in 2007, so most Fraser River sockeye would have already left the strait.[430]

Pulp and paper mills

Pulp mills also operate on the shores of the Strait of Georgia and in other marine areas through which Fraser River sockeye may migrate. Six pulp and paper mills operated in the Strait of Georgia between 1990 and 2010.[431] In 2003, mills were still operational at Port Mellon and Squamish on the mainland as well as at Elk Falls, Gold River, Harmac, and Port Alberni on Vancouver Island.[432] The Squamish and Elk Falls mills closed in 2006 and 2009, respectively.[433] All these mills are subject to the *Pulp and Paper Effluent Regulations*.[434]

Infectious diseases

As discussed earlier for the freshwater life history stages, Dr. Kent, the author of Technical Report 1, Infectious Diseases, documented and evaluated the potential effects of diseases and parasites on Fraser River sockeye salmon during both the freshwater and the marine life stages. He identified the following pathogens as either high or moderate risk to Fraser River sockeye salmon during the marine life stages.

Viruses. The infectious hematopoietic necrosis (IHN) virus causes severe, acute systemic disease in juvenile salmonids. According to studies in 2002 and 2006, it is highly pathogenic to Atlantic salmon in seawater pens, and outbreaks occur occasionally in British Columbia. The virus has been detected in adult sockeye in seawater. Dr. Kent concluded that the risk was high, noting that sockeye in seawater are susceptible, although the virus at this stage is less virulent because older and larger fish show fewer mortalities when they become infected.[435] During the evidentiary hearings, Dr. Kent testified that the infectious salmon anemia virus (ISAv) occurs in other parts of the world and can cause a serious disease in salmonid fish, but at the time of his report it had never occurred in British Columbia.[436] Dr. MacWilliams added that ISAv has been shown to cause natural infections in marine-farmed Atlantic salmon. Under laboratory conditions, it has been possible to experimentally infect other species, such as rainbow trout, but work done on Pacific salmon has shown that they are relatively resistant to the disease.[437] (See also the discussion below on infectious salmon anemia virus.)

Bacteria. Renibacterium salmoninarum causes bacterial kidney disease (BKD) in salmonids. Infections are contracted and spread in marine as well as freshwater, apparently by oral-fecal transmission, and fish die from a few weeks to months following infection. Sockeye are highly susceptible. The researcher rated the risk as high, noting that the infection progresses after infected smolts migrate to seawater.[438] During the evidentiary hearings, Dr. MacWilliams testified that this bacteria infects the host's immune cells, which can make the host susceptible to other diseases.[439] With *Aeromonas salmonicida*, the infection occurs in both wild and cultured fish in British Columbia, and can result in an acute, severe disease with high mortality. The bacterium is transmissible in seawater from fish to fish, and is recognized as a potentially serious disease in net pen–reared Atlantic salmon. Dr. Kent rated the risk as high. The *Vibrio anguillarum* marine bacterium causes vibriosis in unvaccinated smolts shortly after entry into seawater. It can cause severe disease in seawater pen–reared fish, whereas documentation of mortality in wild salmonids in seawater is less definitive. Infections are exacerbated by chemical pollutants or co-infections by parasites. The researcher rated the risk as high.[440]

Myxozoa. There have been numerous reports of a high prevalence of the infection of the *Parvicapsula minibicornis* parasite in adult sockeye in the Fraser River, as well as in outmigrating smolts. The infection is chronic, and it targets the kidneys. The researcher rated the risk as high, stating that it occurs in smolts shortly after seawater entry but is not detected in older fish in seawater. Thus, assuming that fish do not spontaneously recover, this myxozoan is linked to parasite-associated mortality in seawater.[441]

Helminths (worms). The adult stages of tapeworms of the *Eubothrium* genus are found in the intestine and stomach of juvenile sockeye salmon. Heavy infections may reduce swimming, stamina, growth, survival, and saltwater adaptation, and may alter migration orientation. The researcher rated the risk as moderate.[442]

Parasitic crustaceans (sea lice). Marine parasitic copepod *Lepeophtheirus salmonis* has for many years been reported on all salmon species from the oceans. Articles claim that it causes significant mortality in pink and chum salmon in British Columbia, particularly associated with fish farms, although other research has failed to support the claims of fish farm–caused mortality. A 2010 paper found an association between sea lice on farms and on wild juvenile salmon, but not a negative association with overall survival of the latter.[443] A 2008 study concluded that, based on experimental studies with pink salmon, elevated risk associated with *L. salmonis* occurs only in fish weighing less than 0.7 grams, while sockeye smolts are much larger when they enter seawater.[444] Hence, reports of infections on sockeye are not a direct indication that the parasite causes significant mortality in this species. *Caligus clemensi* is another caligid copepod that infects both farmed and wild salmon in British Columbia. Being smaller, on a per parasite basis it is considered less pathogenic. Another concern with parasitic copepods is that they are potentially vectors for other pathogens. *Caligus* spp. are capable of moving from host to host, and a 2008 study showed that *L. salmonis* may move to predator salmon when infected prey are eaten. The researcher rated the risk as moderate, noting that significant mortality has not been documented in sockeye salmon.[445] (See also the discussion below on sea lice and Fraser River sockeye.)

The researcher said that the state of the science for understanding the impacts of pathogens on wild salmon in British Columbia is minimal. It is also difficult to study the impacts of diseases on wild fish, particularly in the marine environment.[446] He added, "[W]e cannot conclude that a specific pathogen is the major cause of demise to the Fraser River sockeye salmon. However, pathogens cannot be excluded at this time as adequate research on the impacts of disease on this population has not been conducted."[447]

Dr. Kent did not consider the question of whether diseases found in fish farms are transmitted to wild fish because he was instructed that those issues would be explored by the technical reports on aquaculture.[448]

Infectious salmon anemia virus

As discussed in Volume 1, Chapter 9, Fish health management, infectious salmon anemia virus (ISAv) is an orthomyxovirus that infects fish and can cause a systemic and lethal disease known as infectious salmon anemia (ISA) in Atlantic salmon.[449] ISAv is most commonly found in farmed Atlantic salmon, though it has also been found in other species of wild fish and has caused infection in experiments with steelhead trout, chum, and coho.[450] Outbreaks of ISA have occurred on Atlantic salmon farms around the world, including in eastern Canada, the eastern United States, Norway, Chile, the United Kingdom, and the Faroe Islands.[451] The virus may transmit from one fish to another through exposure to organic material (such as blood) containing ISAv, exposure to sea lice from ISAv-infected fish, and exposure to ISAv particles shed into seawater.[452]

To assess what role, if any, ISAv may have had in relation to the decline of Fraser River sockeye salmon, two issues must be considered: (1) whether ISAv is present in BC waters, and (2) whether ISAv is capable of causing disease and death in Fraser River sockeye.

Whether ISAv is present in BC waters

During the hearings on disease in August 2011, I heard testimony from Dr. MacWilliams, Dr. Kent, and Dr. Gary Marty, fish pathologist, Animal Health Centre, BC Ministry of Agriculture, that there had been no confirmed cases of ISA or ISAv in British Columbia.[453] Scientific technical reports prepared for the Commission by Dr. Kent, Dr. Lawrence Dill, professor of biological sciences at Simon Fraser University, and Dr. Donald Noakes, professor of mathematics and statistics and the associate vice-president of research and graduate studies at Thompson Rivers University, reflect a similar understanding.[454] Indeed, in Technical Report 1, Infectious Diseases, Dr. Kent does not list ISAv in his review of pathogens of concern to Fraser River sockeye at all.[455] Its absence reflected the understanding that this pathogen had not been identified as being present in BC waters.

I reopened the hearings in December 2011 to hear additional evidence related to reports of ISAv in British Columbia salmonids, including Fraser River sockeye. A panel of experts on molecular genetics and salmon diseases (including ISAv) appeared before me and could not come to agreement on whether or not ISAv or an ISAv-like virus is present in BC salmon:

- Dr. Frederick Kibenge, chair, Department of Pathology and Microbiology, Atlantic Veterinary College, University of Prince Edward Island, told me that there was "overwhelming" evidence that there is an orthomyxovirus present, and that the reports of ISAv may be "ISA virus sequences or it may be ISA virus-like."[456]
- Dr. Miller expressed her "clear belief" that there is a virus present, which is "very similar to ISA virus in Europe" although she acknowledged that further work would be required to understand just how similar.[457] She also told me that the ISAv or ISAv-like sequences are present in fish archives dating back to 1986 and hypothesized that they have been in Pacific waters longer than that.[458]
- Dr. Are Nylund, professor, University of Bergen, told me that although there had been "a lot of indications" that ISAv could be present in Pacific salmon, he had not yet seen any "hard evidence" of its presence.[459]
- Nellie Gagné, molecular biology scientist and laboratory supervisor, Gulf Fisheries Centre, DFO, expressed her view that there was not enough information available to conclude that ISAv or another orthomyxovirus was present. More work would be necessary to make such a determination.[460]

Although they did not agree on whether ISAv or an ISAv-like virus was present, all agreed that more research was necessary and that, whether ISAv is present or not, there had been no confirmation of ISA in any of the Pacific salmon tested by the time of the December hearings.[461] As stated in Volume 1, Chapter 9, Fish health management, I find that the evidence does not allow me to conclude whether ISAv or an ISAv-like virus currently exists in Fraser River sockeye. However, I accept the opinion of the expert panel (Dr. Kibenge, Dr. Nylund, Ms. Gagné, and Dr. Miller) that, as of December 2011, there was no evidence that fish tested for ISAv (the virus) suffered from ISA (the disease) as that disease was then understood.

Whether ISAv is capable of causing disease in Fraser River sockeye

Evidence of whether ISAv, if present, is capable of causing disease in Fraser River sockeye is mixed. Dr. Dill wrote in Technical Report 5D, Dill Salmon Farms Investigation, that "a close watch should be kept for indications of this disease [ISA], and biosecurity [on salmon farms] rigidly enforced, since ISA could be devastating to BC wild salmon populations."[462] In contrast, Dr. Kibenge, whom I qualified as an expert on ISAv, testified that the disease ISA can be found only in farmed Atlantic salmon and that, as far as he knew, Pacific salmon are not known to develop ISA.[463]

Published scientific literature in evidence before me appears to support the contention that existing, known strains of ISAv do not pose a significant risk to Pacific salmon. In a 2003 report by Rolland and Winton published in the *Journal of Fish Diseases*, the authors injected steelhead trout, chum, chinook, coho, and Atlantic salmon with a known dosage of Norwegian-strain ISAv.[464] The authors found that Pacific salmon are "considerably more resistant to ISAv compared with their Atlantic counterparts" and suggested that "Pacific salmon species are at a relatively low risk should ISA spread to the west coast of North America where these species are endemic."[465] However, they also cautioned that "the potential for ISAv to adapt to *Oncorhynchus* spp. should not be ignored."[466]

A more recent (2007) article by MacWilliams and others, published in the journal *Diseases of Aquatic Organisms*, similarly reported that another member of the *Oncorhynchus* species, rainbow trout, was "highly resistant to developing ISA" following injection with a known ISAv strain.[467] However, this report also documented a unique histopathic lesion occurring in some of the rainbow trout infected with ISAv, which was not previously associated with ISA in Atlantic salmon.[468] The authors report their "considered opinion that this unique lesion is characteristic of fatal ISAv-infection of rainbow trout."[469] The lesions found in rainbow trout in response to ISAv infection were so unique that "if these lesions were viewed in rainbow trout under field conditions, it is unlikely that ISA would have been considered as a differential diagnosis."[470] I take this report as another example of the relative resistance of Pacific salmon to known strains of ISAv, and that ISAv may produce different symptoms among the various species of salmon.

Because the experiments by Rolland and Winton and the article by Dr. MacWilliams involved known strains of ISAv, they provide limited insight into how an endemic or "Pacific-region" strain of ISAv, if it exists, may affect Pacific salmon. Further, neither of these studies involved sockeye.

Unpublished genomic expression research by Dr. Brad Davis, a post-doctoral fellow in Dr. Miller's molecular genetics laboratory, suggests that the Pacific salmon for which Dr. Miller obtained presumptive positive ISAv tests during the fall of 2011 may be exhibiting an influenza-like host response.[471] Dr. Davis's report suggests that "we cannot at this point assume that this virus does not cause disease to these fish" and recommends follow-up laboratory experimentation.[472] According to Dr. Miller, Dr. Davis's preliminary results indicate that fish testing presumptively positive for ISAv sequences in her lab were exhibiting "some level of damage" even though disease and mortality had not been demonstrated.[473] I note that by focusing on the host response, Dr. Davis's results and Dr. Miller's interpretation do not appear to hinge on whether the ISAv sequences detected are associated with a known strain, or newly discovered strain, of ISAv.

Finally, I also heard of the potential for ISAv, if present, to mutate into a form that may cause Pacific salmon mortality. Dr. Nylund told me that, although there was insufficient information to know if a Pacific ISAv or North Atlantic ISAv strain was present in British Columbia waters, "if it is a North Atlantic ISA virus, of course it can mutate into a pathogenic strain."[474] However, both Dr. Kibenge and Dr. Miller stated that, with the information currently available, it was not possible to say what degree of damage such a mutation could do.[475] The 2003 Rolland and Winton article, described above, suggests that the ability of Pacific salmon to carry ISAv in those trials "indicates that it would be unwise to overlook the possibility of ISAv replicating in, or establishing a carrier status among these species should they be exposed to the virus" and that genetic mutations "may result in the evolution of strains with differences in host ranges, virulence or immune response to vaccines."[476]

Sea lice

Fraser River sockeye smolts enter seawater free of sea lice. In the marine environment, they are exposed to sea lice from infected fish, either wild or farmed.

Sea lice are small marine parasitic copepods, visible to the naked eye. As noted above, there are two species that infect Fraser sockeye: *Lepeophtheirus salmonis* (the "salmon louse," or "*Leps*"), and *Caligus clemensi* (the "herring louse," or "*Caligus*"), shown in Figure 2.4.1. The sea lice life cycle includes non-parasitic stages in which the sea lice disperse in the water; several infective stages during which the louse is tethered to its host by a frontal filament; and two pre-adult stages and one adult stage, which are motile (i.e., the louse can move on the surface of the fish and even move from fish to fish).[477] Sea lice feed on the fish's superficial tissues (mucus and skin) and blood.[478] A document in evidence written by Dr. Simon Jones, research scientist, Aquatic Animal Health Section, Science Branch, described their impact: "The impact of sea lice on individual fish is highly variable and ranges from mild stress, osmotic imbalance due to skin damage, increased susceptibility to other infections, impaired swim performance and in severe cases, death."[479]

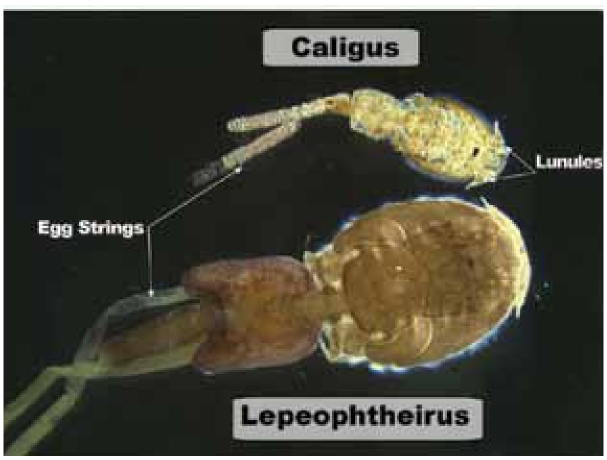

Figure 2.4.1 Pacific sea lice species (enlarged; scale unknown)

Source: Exhibit 1780, p. 3.

Dr. Kent, author of Technical Report 1, Infectious Diseases, rated sea lice as a "moderate" risk to Fraser River sockeye.[480] He cited work by DFO researchers showing that, in a sockeye survey conducted in May and June 2010, the sockeye had a 4 percent prevalence of *Leps* infection (with an abundance of less than one louse per fish) and 70 percent prevalence (number of fish infected) of *Caligus* infection (with an abundance or intensity of between one and 16 lice per fish).[481] Dr. Kent also noted that sea lice are possibly vectors for other pathogens, and are possibly responsible for significant mortalities in pink salmon.[482]

The authors of technical reports 5C, Noakes Salmon Farm Investigation (Dr. Noakes) and 5D, Dill Salmon Farm Investigation (Dr. Dill), both of which are described below (Salmon farms), discussed sea lice in relation to salmon farms. Additionally, during the hearings on aquaculture, I heard from a panel of expert witnesses on sea lice: Dr. Jones; Dr. Orr; Michael Price, biologist with Raincoast Conservation Foundation; and Dr. Sonja Saksida, a fish veterinarian with a private practice and the executive director of the Centre for Aquatic Heath Sciences.* These experts told me about genetic differences between Pacific and Atlantic sea lice; the sources of sea lice that infect Fraser River sockeye; the effect of sea lice infection on Fraser sockeye (at individual and population levels); the potential for sea lice to act as vectors to transfer other pathogens among fish; and the overall risks posed to Fraser River sockeye from sea lice.

Genetic differences in sea lice

The species of *Caligus* that infects salmon and other fish species in British Columbia occurs only in the northeastern Pacific Ocean.[483] In contrast, the species of *Leps* is present in both the Pacific and Atlantic oceans. Dr. Jones told me that there are genetic differences between *Leps* from the Pacific and Atlantic oceans.[484] Farmed Atlantic salmon raised in net pens in the Pacific Ocean have a lower instance of pathology and disease when infected with *Leps* when compared with farmed salmon in the Atlantic Ocean.[485] Dr. Saksida also testified that, based on her observations as a veterinarian working at aquaculture facilities, sea lice in the Atlantic Ocean cause more damage to farmed Atlantic salmon than lice in the Pacific Ocean.[486] Dr. Jones also testified that the Pacific salmon louse behaves differently on different

* I qualified all four witnesses as experts in their field. Specifically, Dr. Jones was qualified as an expert in parasitology and immunology with a specialty in sea lice and diseases of salmon, including as this relates to farmed and wild salmon (Transcript, September 6, 2011, p. 2); Dr. Orr was qualified as an expert in ecological sciences with a research focus on sea lice affecting farmed and wild salmon; Mr. Price was qualified as an expert in juvenile salmon ecology in relation to sea lice infestation; and Dr. Saksida was qualified as an expert in veterinary medicine and veterinary epidemiology with a specialty in fish health.

species of Pacific salmon and on Atlantic salmon.[487] All these differences require "research in British Columbia that is distinct and separate from research that's undertaken in Europe."[488] Dr. Orr said differences in pathogenicity between Atlantic and Pacific *Leps* is based on speculation and that experimentation would be useful to clarify this hypothesis.[489]

Sources of sea lice on Fraser River sockeye

Salmon are the primary hosts for *Leps,* though some life stages of *Leps* have also been found on three-spine stickleback.[490] Dr. Dill, the author of Technical Report 5D, Dill Salmon Farms Investigation, said that, in the Broughton Archipelago region of the British Columbia coast, it is uncontroversial to say that salmon lice on wild fish are coming from the salmon farms.[491] Dr. Noakes, author of Technical Report 5C, Noakes Salmon Farms Investigation, agreed, saying, "I don't think there's any question that some of those lice are coming from the farms and onto pink salmon, but there are other hosts there, as well."[492] Dr. Noakes said that, while no adult lice have been found on sticklebacks, "that doesn't mean that they aren't competent for infecting other fish, in terms of having motile lice."[493] Dr. Orr commented that there is no evidence that alternative sources of lice, such as sticklebacks, are "anywhere near the magnitude of the source of lice from the farms."[494] In relation to the Fraser sockeye migration route, Atlantic farmed salmon are a source of *Leps* infecting Fraser River sockeye in the Discovery Islands.[495]

Although salmon farms may be a source of *Leps* infecting Fraser River sockeye, both Dr. Jones and Mr. Price testified that *Caligus* is the dominant louse species infecting juvenile sockeye migrating through the Strait of Georgia and the Discovery Islands.[496] *Caligus,* while found on salmon farms, is also found on other hosts besides salmon – herring, in particular.[497]

Mr. Price described a peer-reviewed study he conducted to look at whether salmon farms caused increased sea lice infection on migrating Fraser River sockeye in the Discovery Islands.[498] He testified that, in 2007, lice levels (for both species of lice) on Fraser River sockeye found downstream of salmon farms were an order of magnitude higher than on sockeye in a comparison area on the North Coast (an area with no salmon farms).[499] Further, within the Discovery Islands, lice levels on juvenile sockeye were significantly higher *after* they passed fish farms.[500] In 2008, he noticed a similar pattern, though "the differences between upstream and downstream [of salmon farms] were not as clear."[501] Mr. Price said the "lice levels on farmed fish at the time within the Discovery islands, inter-annual variation between the lice levels of *Caligus clemensi* … and *Lepeophtheirus salmonis* … matched the inter-annual variation we saw on juvenile sockeye."[502] He testified that weight or size of the fish did not seem to be a factor relating to lice level, and that salinity and temperature were accounted for in his modelling.[503] He concluded that "position relative to farms was the best predictor of lice levels on juvenile sockeye."[504]

Dr. Jones and Dr. Saksida were both critical of Mr. Price's paper, as were Dr. Noakes in Technical Report 5C, Noakes Salmon Farm Investigation, and Dr. Stewart Johnson, who testified during the hearings on disease.[505] Dr. Jones said he "felt that the conclusions that farms were the only source of the infections … were not always supported by the observations that I saw presented in the paper."[506] More specifically, while there were similar levels of *Caligus* and *Leps* on the farms, after the sockeye passed the farms, their *Caligus* levels appeared to be 4.8 times higher but their *Leps* levels only 1.14 times higher.[507] Also, there were very few *Caligus* on the farms in 2008. Dr. Jones proposed an alternative hypothesis: that the sockeye were infected with *Caligus* from another fish source, such as herring, possibly in the Strait of Georgia before reaching the fish farms.[508] In response, Mr. Price said that if herring or other fish were a source of the lice on the fish farms, then they would "need to assume a similar spatial distribution as the salmon farms in this region. We see no evidence of that."[509] Mr. Price also noted the possibility that sockeye are more resistant to *Leps* and more susceptible to *Caligus,* explaining the differences in lice species abundance on sockeye downstream of farms.[510]

Although Dr. Saksida agreed with Mr. Price's suggestion that sockeye salmon may be more resistant to the salmon louse (*Leps*) than to *Caligus,* she criticized Mr. Price's paper for excluding data from an "outlier" sample site upstream of the fish farms.[511] In 2008, the outlier had some of the highest sea lice prevalence (number of fish infected) and intensity (number of lice per infected fish).[512]

In response, Mr. Price said he ran the analyses with and without the outlier site, and the results remained the same.[513]

Dr. Jones testified that DFO began a "field surveillance effort" on Fraser River sockeye in 2010 (see Volume 1, Chapter 9, Fish health management) as well as laboratory studies. He said that in 2010, as noted by Dr. Kent (above), DFO looked at 300 sockeye and found that 70 percent of them were infected with *Caligus*, and 3 to 4 percent of them were infected with *Leps*.[514] He said that early analysis of the data suggests that, for *Caligus*, "there is a strong relationship between the level of lice on the sockeye and the distance that they've migrated from the Fraser River. In other words, the time spent in the ocean seems to be a strong determinant of the level of infection."[515]

Effects of sea lice on Fraser River sockeye

As noted above, the effect of sea lice on individual fish is variable; fish can exhibit mild stress to mortality. *Leps* infections of unusually high intensity (e.g., an average of 300 lice per fish) can result in significant pre-spawn mortality for adult returning sockeye.[516] (See the discussion in Life stage 5: return migration, below.) The stages of salmon lice that have the most pathogenic effect on individual fish are the sub-adult and adult lice – the motiles.[517] No studies have been done to show the effects of *Caligus* on sockeye, though researchers hypothesize they have a lesser impact on sockeye than do *Leps*.[518]

Dr. Jones emphasized that sea lice infections on sockeye in the Strait of Georgia are very different from those on juvenile pink and chum in the Broughton Archipelago.[519] More research has been conducted in the Broughton Archipelago, and several scientific papers were presented to me in evidence.[520] *Caligus* as opposed to *Leps* is the dominant species on Fraser River sockeye.[521] Dr. Jones also said that sockeye salmon are in most cases a year older than pinks when they enter the marine environment: "They're a larger fish with a more mature scaled skin, and I would expect that that would confer to the sockeye salmon some level of resistance. I would be hesitant to extrapolate further."[522] Laboratory studies on such subjects as critical thresholds of infection and resilience related to size of the fish are not available for sockeye.[523] However, scientists have done some work on other species of salmon.[524] Dr. Jones emphasized that "you can't treat all salmon equally," and that that to determine whether a particular species of salmon is resistant or susceptible to infection by sea lice requires doing the work in relation to that species.[525] Still, Dr. Jones testified, "Certainly the fact that 70 percent of juvenile sockeye salmon that we've seen in our surveys have *Caligus* infestations to me tells me that there will be a cost associated with those infestations."[526]

A presentation by Dr. Jones suggests the following specific research needed to test the hypothesis that sea lice contributed to the decline of Fraser River sockeye:

- Establish inter-annual variations in sea lice levels for juvenile sockeye in the Strait of Georgia.
- Establish inter-annual variations of infections with bacteria, virus, or other parasites.
- Determine lethal and other impacts of sea lice on individual sockeye salmon in controlled laboratory experiments.
- Integrate and analyze health data from farmed and wild salmon in the Strait of Georgia and elsewhere to obtain a global assessment of pathogen dynamics.[527]

Dr. Orr said he would be more concerned about the effects of sea lice on sockeye "if we saw higher numbers of *Leps*," but that we cannot "discount the issue of *Caligus*."[528] He noted that sea lice can have behavioural influences on fish and referred to work on pink salmon which shows lice can cause infected fish to be more vulnerable to predators.[529] He also noted the need for more research into the effects of *Caligus* on sockeye.[530]

Sea lice as a disease vector

Dr. Saksida said that sea lice "are potentially a mechanical vector" for bacteria or viruses, but that these micro-organisms do not likely replicate on the sea lice – just sit on the animal or pass through their digestive tracts.[531] She also testified that the fish diseases of main concern are transmitted through water: "So if the fish are close enough to have a sea louse jump between one fish and another fish, if they're motile sea lice, then there would be water-borne exposure. So I would say that the water-borne exposure is far more significant than any effect that a sea louse would have."[532] Similarly, both Dr. Noakes and Dr. Dill agreed that there is potential for sea lice to serve as vectors for other pathogens, but this is more of an "accidental" vectoring because pathogens do not need the lice as a means of transmission.[533] Dr. Jones said most of the research for lice as vectors has been done on *Leps*.[534]

Level of risk and contribution to the decline

Most of the researchers whom I heard from agreed that sea lice are not directly implicated in the decline of sockeye salmon.[537]

Dr. Jones said sea lice pose a "low risk to moderate risk to sockeye salmon associated with all species of sea lice."[536] He said that, while *Caligus* probably does not pose a threat, *Leps* "has a greater potential to cause harm, and that every effort to manage *L. salmonis* on salmon farms would be appropriate in terms of minimizing that risk."[537] Dr. Saksida also said the risk to sockeye from *Caligus* is "low to moderate" and that more research is required on the distribution of *Caligus*.[538] She thought it unlikely that sea lice contributed to the decline in sockeye productivity.[539] Dr. Orr agreed that there is a "low to moderate risk of mechanical damage" from sea lice to sockeye.[540] However, he also said the possibility for sea lice to act as a disease vector means there is "a fairly high risk" if the lice levels on salmon farms are not controlled.[541]

Mr. Price said the risk from sea lice to sockeye salmon is "fairly high" in combination with other factors such as food limitations or increased predation risk."[542] Although Mr. Price said, "I don't believe sea lice acting in isolation are responsible for the decline in sockeye productivity,"[543] he stated that "factors rarely act in isolation on the population dynamics of a species," and *Leps* or *Caligus* acting with other factors to stress sockeye juveniles "may be a contributing factor to not only productivity declines but also during that 2009 return or the low return."[544]

Salmon farms along the migratory route

Outmigrating smolts encounter salmon farms during their migration through the Discovery Islands toward Johnstone Strait. They may also encounter salmon farms if migrating up the west coast of Vancouver Island. The authors of technical reports 5C, Noakes Salmon Farm Investigation, and 5D, Dill Salmon Farm Investigation, Dr. Noakes and Dr. Dill, independently reviewed and evaluated the effects of salmon farms on Fraser River sockeye salmon.* They considered impacts on Fraser River sockeye from sea lice exposure, from farm wastes that affect benthic and pelagic habitat quality, from Atlantic salmon escapees, and from disease.

To facilitate their work, the author of Technical Report 5A, Salmon Farms and Sockeye Information, Dr. Josh Korman, fisheries ecologist with Ecometric Research,† summarized the "spatial and temporal trends for some important elements of the salmon-farming data, such as sea lice abundance and the frequency of bacterial and viral diseases, which could affect wild sockeye salmon."[545] Dr. Korman used data disclosed to the Commission from past BC Ministry of Agriculture (BCMAL) salmon farm audits and the B.C. Salmon Farmers Association (BCSFA) fish health database, and DFO data on Atlantic salmon escapes from salmon farms.[546]

Also to assist in the analyses of Dr. Noakes and Dr. Dill, the author of Technical Report 5B, Salmon Farms and Sockeye Relationships, Dr. Brendan Connors, post-doctoral fellow in the School of Resource and Environmental Management at Simon Fraser University,‡ statistically examined the "relationship between salmon aquaculture in British Columbia and Fraser River sockeye salmon

* Dr. Noakes was qualified as "an expert in salmon population dynamics, including wild salmon / farmed salmon interactions, fisheries climate interactions and in statistical analysis including time series analysis" (Transcript, August 25, 2011, p. 69). Dr. Dill was qualified as "an expert in behavioural ecology, predator / prey relationships and ecological factors affecting wild fishes, including parasites and fish farms" (Transcript, August 25, 2011, p. 71).

† Dr. Korman was qualified as "an expert in salmonid stock assessment and in statistical analysis, in particular of population level fisheries data" (Transcript, August 25, 2011, p. 62).

‡ Dr. Connors was qualified as "an expert in statistical analysis, fish population dynamics with a particular research emphasis on wild salmon / farmed salmon interactions" (Transcript, August 25, 2011, p. 74).

population dynamics."[547] Dr. Connors used sockeye production data compiled by Dr. Randall Peterman and Dr. Brigitte Dorner in Technical Report 10, Production Dynamics, as well as various salmon farm variables obtained through the Commission's disclosure from BCMAL, BCSFA, and the BC Ministry of Environment.[548]

Although Dr. Noakes and Dr. Dill came to similar conclusions on the effect of many of the specific potential stressors related to salmon farms, they disagreed about the risks posed from disease on salmon farms and about the significance of Dr. Connors's conclusions.

Effects of specific stressors

In their reports and during testimony, Dr. Dill and Dr. Noakes discussed a number of specific stressors stemming from salmon farms, summarized below.

Physical infrastructure. In his report, Dr. Dill wrote that "[f]arm structures themselves can create backeddies in fast flowing channels, perhaps encouraging juvenile sockeye to rest there during migration."[549] Lights from farms (used to encourage growth of farmed fish) could attract sockeye as well as other fish that are their predators or competitors.[550] If farmed fish were infected with disease or sea lice, it could increase the risk of infection to wild sockeye by bringing them into closer proximity to farmed salmon.[551] In his report, Dr. Noakes did not comment on physical infrastructure of salmon farms.

Effect of farm waste on benthic and pelagic habitat. Both Dr. Dill and Dr. Noakes agreed that the effects of waste from fish farms on both benthic and pelagic habitat is unlikely to be driving declines of Fraser River sockeye – that effects "do exist locally" but are probably not sufficient in geographic scale or impact to have been drivers of the decline.[552] However, Dr. Dill explained, there have been no studies of cumulative impacts of the large number of farms the sockeye have to pass in the Discovery Islands.[553]

Chemical inputs. Similarly, chemical inputs including therapeutants such as SLICE (used to treat sea lice in farmed salmon) are unlikely to have anything but a local environmental effect.[554] (See Volume 1, Chapter 9, Fish health management, and Chapter 7, Enforcement.) Moreover, such effects are likely limited to invertebrate species.[555] They are unlikely to have any population-level effects on sockeye.[556]

Atlantic escapees. Both Dr. Dill and Dr. Noakes agreed that "it's very unlikely that escapees are implicated in the decline of Fraser River sockeye salmon."[557] Atlantic escapees are not spawning in streams occupied by Fraser River sockeye, and they are not competing with Fraser River sockeye for food.[558] Very few Atlantic salmon have been found in the lower Strait of Georgia and the Fraser River.[559] Dr. Dill acknowledged a "slight potential for disease to transfer to wild sockeye via escaped Atlantics."[560] Dr. Noakes said "it is far more likely that farms would be a more viable source of pathogens than chance encounters between Pacific salmon and escaped Atlantic salmon."[561]

Sea lice – direct effects. Both Dr. Dill and Dr. Noakes agreed that there was insufficient evidence to conclude that sea lice from salmon farms were linked to the overall decline of Fraser River sockeye.[562] Dr. Korman, who synthesized fish farm data related to sea lice, testified there was "nothing unusual about 2007" that would explain the poor run in 2009, and "pretty similar conditions in the fish farms" in 2008 – so nothing to explain the exceptional run in 2010.[563] With respect to *Leps*, Dr. Dill testified that "migratory allopatry" is interrupted by the existence of salmon farms on wild salmon migration routes. He said that migratory allopatry means that wild adult fish make their return migration at a different time from the smolts' outmigration, so the adult and juvenile fish are not passing one another in the water.[564] Fish farms "close the loop" by providing a reservoir of adult salmon hosts for *Leps* that can then infect juvenile salmon during their outmigration, before they would normally encounter adult salmon and their associated parasites.[565] (See the discussion above related to sea lice.)

Sea lice – as vectors for disease. Both Dr. Dill and Dr. Noakes agreed that sea lice could serve as vectors for other diseases and pathogens from fish farms, but that this may be an incidental vectoring; transmission of pathogens through water may be more effective.[566] (See the discussion above related to sea lice.)

Disease from fish farms. Dr. Dill said of all the fish farm stressors, "disease" was the most likely candidate to provide a mechanism for a negative impact of salmon farms on sockeye productivity.[567] (As discussed below, Dr. Dill concluded that salmon farms do have "some sort" of negative impact on Fraser River sockeye.) Dr. Dill testified that having open-net pens in the ocean is a "game changer" in terms of the disease environment.[568] He said that fish farms can result in biomagnifications of pathogens, and that the high densities of hosts on fish farms "are likely to select for fast-growing, early-transmitted and more virulent pathogens."[569] He also set out several possible routes of transmission from farmed to wild fish: direct horizontal transfer through the water, through fish feces in the benthos, transmission from escaped Atlantic salmon, transmission by sea lice, and discharges of bloodwater from processing plants.[570] Despite the potential for diseases to have a negative impact, Dr. Dill noted that incidents of three of the diseases that Dr. Kent rated as "high risk" to Fraser River sockeye – furunculosis, BKD, and IHN – are not associated with sockeye survival in Dr. Connors's analysis (discussed below).[571]

Dr. Noakes reported that "[a]ll of the diseases found on salmon farms are common in BC and there is no evidence that any exotic pathogens or diseases have been introduced by the salmon farming industry."[572] He also noted that, of the roughly 32 million fish on BC salmon farms, about 3 million die each year (less than 10 percent).[573] Only about 2 percent (about 600,000 fish per year) are "fresh silvers," of which some unknown percentage died of disease.[574] (Other causes of death include predators and environmental factors such as algae or low dissolved oxygen.)[575] In Dr. Noakes's view, the mortality rate for fresh silvers has been "pretty low" when compared with a mortality rate of about 3 percent per day for juvenile wild salmon.[576] Dr. Noakes identified a significant problem in trying to assess the impact of disease on fish farms on the survival of sockeye salmon: "[T]here is no ongoing monitoring of the diseases identified [in Technical Report 1, Infectious Diseases] for any species of wild or hatchery Pacific salmon in BC."[577] "[E]ven if a particular disease is an issue on salmon farms," he added, "there is no way of knowing whether the same disease is causing problems for Fraser River sockeye salmon and if so whether the source of the infection is from other wild or hatchery fish or from salmon farms."[578] Dr. Noakes also traced disease outbreaks on salmon farms for four diseases (IHN, vibrio, furunculosis, and BKD, all identified as high risk by Dr. Kent) back to their farm locations. He found that there have been no IHN outbreaks since 2003, and incidents of the other diseases were predominantly on the west coast of Vancouver Island and in Jervis Inlet and Sechelt, not along the Fraser River sockeye outmigration route.[579]* In testimony, he concluded that diseases from salmon farms are not having a major impact, nor are they likely to have a major impact on the survival of Fraser River sockeye.[580]

Both Dr. Dill and Dr. Noakes testified in August 2011, before the testing for ISAv in wild stocks in the fall of 2011.

Relationships between salmon farms and sockeye productivity / decline

Although there is no evidence proving causation between any stressor related to salmon farming and the decline of Fraser River sockeye, Dr. Noakes and Dr. Dill gave me their views on whether any relationship exists between salmon farming and sockeye decline. This evidence arose in the context of Dr. Connors's work in Technical Report 5B, Salmon Farms and Sockeye Relationships, which I discuss here.

In his report, Dr. Connors used modified Ricker and Larkin models to predict sockeye productivity or survival anomalies for a number of different sockeye populations along the coast from Washington to Alaska.[581] (For an explanation of these productivity models, see Pre-season escapement target planning in Volume 1, Chapter 5, Sockeye fishery management.) In the first part of his analysis, Dr. Connors looked for relationships between sockeye survival anomalies and (a) sea lice abundance on farms, (b) disease frequency on farms, (c) mortalities of farmed salmon, and (d) the number of farmed salmon. Then, in the second part of his analysis, he used a "multi-model inference approach" to quantitatively compare the strength of the relationship between sockeye productivity and salmon farm production, sea surface temperature (SST) (as a

* I note that in May and June 2012, the media reported new outbreaks of IHN on BC salmon farms.

proxy for environmental factors), and pink salmon abundance in the North Pacific Ocean (which other researchers had identified as affecting sockeye productivity).[582]

In the first part of his analysis, Dr. Connors found no statistically significant relationships between sockeye survival and any of the fish farm factors tested.[583] However, he noted that the short time series of aquaculture variables meant that "there is low statistical power to detect a relationship between the aquaculture variables and sockeye survival, should such a relationship actually exist."[584] (See the discussion below.) In the second part of his analysis, Dr. Connors found that "increases in aquaculture production, SST, and pink salmon abundance all increase sockeye salmon mortality" and that the effects of aquaculture production on Fraser River sockeye are likely influenced by the abundance of pink salmon in the open ocean and SST in the winter preceding marine entry.[585] However, he said there was "large uncertainty around these estimated effects," making any conclusions "tenuous."[586]

Dr. Dill relied on Dr. Connors's report to conclude that "farms are having some sort of negative impact on wild salmon productivity, most likely in concert with other factors in the marine environment."[587] Dr. Dill pointed out a study by Ford and Myers (2008), which conducted a "meta-analysis to show that wild salmon stocks have declined, often as much as 50%, wherever aquaculture production has increased."[588] He said that looking at aquaculture worldwide, "wherever there is aquaculture practice there is evidence from population records of declines in wild salmon."[589]

In contrast, Dr. Noakes was highly critical of the second part of Dr. Connors's analysis, stating in his report that there were "several significant problems with [Connors's] assumptions, methods, analyses, and conclusions," and then describing them in detail.[590] Dr. Noakes concluded that "[t]here 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."[591]

Dr. Connors responded to Dr. Noakes's specific concerns about his analysis with a written reply, to which Dr. Noakes then wrote a further reply.[592] Some participant counsel spent considerable time in their cross-examinations of these witnesses to explore the differences of opinion between them. I do not think it necessary or helpful to understanding the evidence as a whole to repeat that debate here. I agree with Dr. Korman, another statistics expert testifying alongside Dr. Connors and Dr. Noakes, who gave his view that little turned on the disagreement between Dr. Noakes and Dr. Connors:

> Well, for one thing I think that when you look at the bottom-line conclusions of Dr. Connors's report, he's not making claims of very strong effects. So the argument between Noakes and Connors in the end as far as conclusions is Noakes saying, you know, no effects shown, Connors saying weak effects in the case of the longer-term dataset only. So from a decision point of view, you know, that the justice may have enough information right there without getting into all the minutiae about how they come to that argument.
>
> In terms of what Dr. Connors did, I think a lot of his rationale is well justified in terms of using variables that other researchers have suggested in terms of the modelling framework that he did, and in terms of his interpretation. And while there is some speculation or assumptions made in his modelling, that's a totally normal part of the scientific process to basically begin with a set of assumptions, evaluate the data. There are some limitations to that result, which he I think adequately stated in his report as being limited. But that's – it would be irresponsible of us not to do the analysis that Dr. Connors did, in my opinion. So I don't have a problem with it because he was quite cautious in his interpretation.[593]

Further, I note that Mr. Marmorek, lead author of Technical Report 6, Data Synthesis, who was qualified as an expert in experimental design and decision analysis and modelling (among other areas), said he did not think Dr. Noakes's criticisms of Dr. Connors's work were sustainable:

> So all in all, I didn't think the criticisms from Noakes about Connors' work, rather, were sustainable. I think there are certainly weaknesses in the historical dataset, and it would be much better if there had been per farm production data and actual disease data going all the way

> back to the 1980s, but it didn't exist … I didn't see anything wrong. I thought [Connors] was quite careful in the way he went through his work.[594]

Assessing the risks of salmon farms to Fraser River sockeye

Dr. Noakes and Dr. Dill took different views of the risk posed by salmon farms to Fraser River sockeye based largely on their views of the adequacy of the data available for assessment. Overall, Dr. Noakes concluded that salmon farms "pose no significant threat" to Fraser River sockeye:

> While some improvements are certainly possible and desirable, the industry generally leads the world in with [*sic*] 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.[595]

In testimony he said that, based on the evidence, "there's a fairly low risk" of a negative impact to Fraser River sockeye from salmon farms.[596] Dr. Dill explicitly disagreed with Dr. Noakes's statement that salmon farming poses no significant threat.[597] He was of the view that the state of information did not allow one to say there was no effect of fish farms in the long term, nor to dismiss the risk:

> 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.
>
> …
>
> 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 it is not possible to say they are *not* implicated. [Emphasis in original.][598]

I heard much evidence on the state of knowledge and the adequacy of the information available.

Dr. Korman, the researcher responsible for synthesizing the fish health data for use by the other researchers, testified that the fish health records from fish farms were available only from 2003 or 2004 to 2010.[599] Considering that five years need to elapse from the time sockeye spawn until the oldest fish from that brood year return, this leaves only about four years of data that can be used "to correlate conditions on the farms with survival rates of Fraser River sockeye."[600] According to Dr. Korman, the short data record affects the ability to reach conclusions from that data:

> And in statistics, that's a very, very low sample, which means two things. For one, if there [is] a true relationship, it's going to [be] very difficult to see it with that small sample size because your statistical power will be very low.
>
> Conversely, it's also possible to, not from a statistical sense, but just by random chance, to see a relationship between those variables just because you've got such a very low sample, that random chance can actually make it such that you'll see a positive correlation when, in fact, none exists. So therefore, there's going to be limited ability to learn something from statistics given our current data availability. Ten years from now, very different story when we'll have 13, 14, 15 years of data.[601]

Dr. Dill suggested that "perhaps eight to 10 years [of data] might be sufficient" to show no correlation between fish farms and sockeye returns, certainly not four or five.[602] However, Dr. Noakes said that, while one of the problems with short-term data is that you often have values around the mean, in this situation we have "a bit more power in terms of an ability to look at the relationship" because we have extreme data in 2009 and 2010.[603] Both Dr. Noakes and Dr. Dill agreed that more research on wild sockeye would be needed to prove any sort of cause-and-effect relationships of fish farms on Fraser River sockeye.[604]

Mr. Marmorek similarly testified that there is a lack of empirical evidence about wild salmon catching disease and that this is a gap that needs to be filled. In the absence of research, scientists are left with plausible hypotheses and mechanisms whereby salmon farms might cause disease in wild fish.[605] He said it would be possible to design studies that would show these mechanisms if they exist, and that the "simple answer, is go out and get the data."[606] One example may be work proposed in a public submission to this Commission, dated December 15, 2011, by Dr. Welch, who testified before the Inquiry in the fall of 2010 and again in July 2011. In his public submission, Dr. Welch reported that since he last testified, he and colleagues reanalyzed data to directly compare survival rates of acoustically tagged sockeye smolts migrating in the Strait of Georgia and then in Discovery Passage / Queen Charlotte Strait. They found that smolt survival rates per week of migration were substantially lower in the Discovery Passage region than in the Strait of Georgia. They therefore proposed a study designed to test the effect of fish farm exposure in the Discovery Islands on the survival of Fraser River sockeye smolts.[607]

Dr. Dill identified the following knowledge gaps in his report:

- detailed information on sockeye smolt migration behaviour and pathways through the Discovery Islands;
- the attraction of sockeye juveniles to net pens;
- the cumulative impacts of swimming past multiple farms (including repeated exposure to poor water quality and pathogens);
- whether the virus identified by Dr. Miller (described above) is found in farmed Atlantic and chinook salmon;
- the infective state of apparently healthy salmon in net pens;
- the potential for lice to act as vectors of high-risk pathogens;
- the impact of both species of sea lice and of other pathogens on feeding and predator avoidance abilities and survival of sockeye smolts;
- the potential for blood water from processing plants to be a source of infection;
- the evolution of resistance and/or increased virulence in sea lice treated with SLICE;
- interactions of lice and other pathogens with other stressors in the marine environment, such as low food availability and pollutants;
- disease incidence and levels in wild sockeye; and
- the potential for biological control of pathogens on farms (e.g., by using mussels to remove *Renibacterium salmoninarum*, the infective agent for BKD, from seawater).[608]

In his report, Dr. Noakes took the view that there is adequate information about fish farms, recommending that "the scope and level of fish health and sea lice monitoring and reporting currently in place for the salmon aquaculture industry" be maintained.[609] He said the focus of future work should be on wild and hatchery fish, recommending long-term disease-monitoring programs for wild fish, and mandatory fish health–monitoring and reporting programs for all federal, provincial, and Community Economic Development Program hatcheries.[610] Dr. Noakes also recommended regular and routine monitoring and reporting of water quality and oceanographic data, and research into the lethal and sublethal effects of sea lice on juvenile sockeye salmon.[611]

Dr. Connors noted that none of the researchers looked specifically at the nine fish farms in the "Wild Salmon Narrows" (one passage through the Discovery Islands, so named by an environmental group: see Volume 1, Chapter 8, Salmon farm management) to see if any relationships exist with wild sockeye productivity.[612] He agreed with both Dr. Dill and Dr. Noakes that more work into monitoring disease in wild fish was needed.[613] He also recommended, along with Dr. Dill, that his analysis be repeated in the future as more productivity data become available.[614]

I heard testimony from other experts on the risks posed by salmon farms – fish health and disease experts such as the author of Technical Report 1, Infectious Diseases, Dr. Kent (see above), and government and salmon farm veterinarians whose evidence I described in Volume 1 of this Report. I also heard evidence from a variety of witnesses with insights and perspectives on the risks posed by salmon farms.

Dr. Kent said, with the exception of sea lice, he has not seen "dramatic evidence" that pathogens are being transmitted from fish farms to wild fish.[615] He did say that there is a potential for salmon farms to change the environment that wild fish swim through, and that two ways in which fish farms can affect wild fish are by introducing new diseases or by making endemic diseases worse.[616]

He also said it is a "reasonable assumption" to say that the numbers of pathogens in and around net pens would be greater during a disease outbreak on a farm; what scientists do not know for sure is the effect that this has on wild salmon.[617] He said there would be an increased potential for wild fish to catch pathogens when swimming past a net pen than swimming through open water.[618]

Dr. Stewart Johnson, head of Aquatic Animal Health, Salmon and Freshwater Ecosystems, DFO, testified that moving salmon farms off the migratory route would be one thing that people could do to prevent wild stocks from being exposed to disease, noting that "other sources of pathogens are pretty much out of our control."[619]

Dr. Marty; Dr. Mark Sheppard, lead veterinarian, Aquaculture Environmental Operations, DFO; Dr. Peter McKenzie, veterinarian and fish health manager for Mainstream Canada; and Trevor Swerdfager, former national director general, Aquaculture Management Directorate, DFO, all agreed that "the risk of disease in salmon farms is manageable with appropriate care and attention."[620] Dr. Sheppard said that "the risk can never be zero," but that managers minimize as best they can the risks to wild fish.[621] He further said that measures taken within the net cages and through the Fish Health Management Plans (described in Volume 1, Chapter 9, Fish health management) serve to minimize health risks not only to farmed fish, but also to "the ecosystem outside those cages."[622] Mr. Swerdfager said the regulatory framework in place does not reduce the risk to zero, but "it substantially reduces it."[623]

Mia Parker, an industry representative formerly from Grieg Seafood BC, testified that she believed fish farms could coexist with wild stocks because of the precautionary and adaptive management framework in place.[624] Another industry representative, Clare Backman from Marine Harvest Canada, said simply that "aquaculture is coexisting with the wild fish without demonstrated significant risk of disease."[625] In contrast, Catherine Stewart, salmon farming campaign manager for the Living Oceans Society and a representative of the Coastal Alliance for Aquaculture Reform, testified that she believed they cannot coexist unless "a serious limit" is placed on salmon farm production.[626] Alexandra Morton, executive director of Raincoast Research Society, said she believed the salmon farming industry "cannot survive biologically" and "there's no place that open net pens can coexist with wild fish."[627]

Marine anemia / plasmacytoid leukemia on chinook farms

In Technical Report 1, Infectious Diseases, Dr. Kent described plasmacytoid leukemia, which he testified is also called "marine anemia" though scientists try not to use that term to avoid confusion with ISA, which is also sometimes called marine anemia in other parts of the world.[628] (I use both terms below to reflect how the witnesses spoke of this condition.)

> **Salmon Leukemia Virus and Plasmacytoid Leukemia (PL).** The histological presentation of this disease is massive infiltration of visceral organs and retrobulbar tissue of the eye by immature lymphocytes or plasmablasts (white blood cells) (Kent et al. 1990). Fish have an enlarged spleen and kidney. The disease causes severe anemia and is usually lethal. It has been most often seen in pen-reared Chinook salmon in British Columbia (Stephen et al. 1996), but has been detected in wild-caught Chinook salmon in the Province and hatchery-reared Chinook salmon in Washington State (Harshbarger 1984; Morrison et al. 1990). Sockeye salmon can be experimentally infected (Newbound and Kent 1991). The cause of PL has been controversial. In the early [1990s] various lines of evidence pointed to a retrovirus as the cause (Kent and Daw 1993; Eaton et al. 1994a, b), which was named the Salmon Leukemia Virus (SLV). The virus was never isolated in culture. In later years, almost all cases that I reviewed from netpen-reared Chinook salmon were associated with infections of the proliferating cells by *Nucleospora salmonis* [a micro-organism that infects lymphocytes].[629]

Dr. Kent and Dr. Stephen, author of Technical Report 1A, Enhancement Facility Diseases, are two of the world's leading experts on plasmacytoid leukemia / marine anemia.[630] They both described it as a "pathology" or "condition" that may have various potential causal pathways or causal agents.[631] Dr. Kent said there were outbreaks of marine anemia at chinook farms in British Columbia in

1988–91, causing "severe losses" at those farms.[632] He also said that, in a general disease survey of multiple species conducted in 1998 by DFO Science (where he was then working), none of the sockeye surveyed showed signs consistent with plasmacytoid leukemia.[633] Dr. Stephen said that, in the period of 1988–92, marine anemia was detected in chinook farms whenever the industry moved into a new area of the BC coast.[634] Both Dr. Kent and Dr. Stephen stopped working on plasmacytoid leukemia in the 1990s, when they moved on to other research.[635]

Dr. Sheppard – formerly the provincial, now the federal, veterinarian responsible for making farm-level diagnoses, and qualified at the hearings as an expert in veterinary medicine, with experience in fish health – explicitly disagreed with Dr. Kent's work from the early 1990s that showed severe losses of farmed chinook salmon due to marine anemia, and he disagreed with the statement that there was a major epidemic of plasmacytoid leukemia in the early 1990s. In his view, marine anemia was "a finding of a clinical syndrome" that "became a point of interest for some researchers."[636] He said those "very same animals" diagnosed with marine anemia were often also infected with BKD, so marine anemia was not the sole cause of mortality.[637] Further, he said that since the early 1990s "we see next to no signs of plasmacytoid leukemia in chinook or coho salmon."[638]

One theory related to the impact of salmon farms on Fraser River sockeye put into evidence by Ms. Morton concerned marine anemia. Her theory was that, in 2007, Fraser River sockeye smolts picked up marine anemia from chinook salmon farms during the smolts' outmigration through the Discovery Islands. This, she hypothesized, contributed to the poor return in 2009. The chinook were harvested from the farms before the 2008 outmigration, so the smolts responsible for the large 2010 run were not affected by the same disease exposure.[639] Ms. Morton based her concern on what she considered to be symptoms of marine anemia appearing in the provincial fish health databases, particularly in relation to chinook salmon farms.[640]

Ms. Morton testified that she looked at the data from the provincial fish health databases showing *symptoms* of different diseases (rather than *diagnoses*) in government audit fish, counted the number of individual fish showing symptoms in different years, and plotted those numbers on a graph.[641] Her counsel showed that graph to Dr. Korman, who agreed that, on the graph, marine anemia symptoms look "a little higher in 2007" than in other years.[642] Ms. Morton said that, despite these symptoms of marine anemia, the disease never gets diagnosed at the farm level because Dr. Sheppard "doesn't believe in marine anaemia."[643] Further, questions to Dr. Korman from Ms. Morton's counsel suggested that, beginning in the fourth quarter of 2006, the Conville Bay fish farm site (a chinook farm owned by Marine Harvest Canada in the Discovery Islands) had elevated symptoms of marine anemia.[644] Dr. Korman agreed that "[i]f there were chinook farms experiencing marine anemia in the Discovery Islands in the Wild Salmon Narrows in 2007 but none at all in 2008," that would be a matter worth investigating.[645] Ms. Morton acknowledged that this was not a matter for her to investigate – just a pattern she saw in documents that she felt should be looked at by someone, presumably with disease expertise.[646]

In a document she wrote and put into evidence during the hearings, Ms. Morton explains that the symptoms of marine anemia that she relied on are those described in the fish health databases disclosed by the province as ISH, or interstitial hyperplasia of the kidney.[647] However, Dr. Kent testified that, while interstitial hyperplasia of the kidney is not inconsistent with marine anemia (and is associated with marine anemia), it is not pathognomonic for (or specific only to) marine anemia – ISH may be caused by a number of pathogens.[648] Indeed, Dr. Marty,* who prepared the fish health databases used by Ms. Morton, said that marine anemia is a clinical syndrome, so it is not something that he would diagnose in the lab.[649] He testified further, in reference to part of the database used by Ms. Morton to extract ISH symptoms, that each of the fish showing symptoms of ISH also has a cause of death associated with it – either BKD or *Piscirickettsia salmonis*.[650] He said it would be inappropriate to diagnose these fish as having marine anemia because "we have another cause of death instead of marine anaemia."[651] However, Ms. Morton pointed out in her testimony that Dr. Marty showed me the diagnoses of BKD associated with ISH symptoms for *Atlantic* salmon farms, not *chinook* farms.[652] She said that when you

* Dr. Marty was qualified as an expert in fish toxicology and fish pathology, with a specialty in veterinary pathology (Transcript, August 31, 2011, p. 13).

look at the Pacific chinook salmon with ISH symptoms, the symptoms are more severe (in terms of a rating scale assigned by Dr. Marty), and many of the diagnoses are listed as "open" diagnoses, not BKD.[653] Therefore, in her interpretation, marine anemia was not ruled out by another cause of death.

In response to Ms. Morton's theory, Dr. McKenzie testified that he spoke to the veterinarian for the Conville Bay fish farm, who told him that marine anemia had never been diagnosed for that site.[654] Also, Dr. McKenzie said he reviewed documents for that site, which showed the harvest began in December 2006, was 75 percent complete by March 2007, and was completed in early May 2007 – before most of the 2007 smolts would have passed by the farm.[655] Mr. Backman testified that marine anemia has never been diagnosed on-site at Conville Bay.[656] However, he also said that the fish health vets working at that site may not have been aware of the information that was recorded in the fish health audit database:

> [H]istopathological reporting is only one element of discovering whether or not there is an issue on a farm site, and so that it's very common and, actually, in most cases, the veterinarian is not made aware of records made through the provincial audit, and the reason for that is that within the provincial team, and that consists of the provincial veterinarians, fish health experts, the decision is made that they're not seeing something of a reportable nature. Should they see something where there's a histopathological result that's confirmed with farm-based evidence, then they will quickly advise the farm site.[657]

Further, Mr. Backman said the pattern of mortality for Conville Bay in 2006 and 2007 was "not inconsistent with what we normally see year over year. There was nothing particularly unusual."[658] He said that, although chinook salmon have not been placed back into the Conville Bay site, two other chinook farms continue to operate in the Discovery Islands area.[659]

Migration to rearing area along the coast

On leaving the Strait of Georgia, juvenile sockeye (also called "postsmolts") continue their migration through Johnstone and Queen Charlotte straits (or Juan de Fuca Strait and the west coast of Vancouver Island) toward the North Pacific Ocean, where they enter south of Haida Gwaii (Queen Charlotte Islands). There is some evidence that the postsmolts, on entering the North Pacific Ocean, migrate north and westward in a band within 35 km off the coasts of British Columbia and Central Alaska until they reach the overwintering grounds south of Alaska during late autumn. Figure 2.4.2 depicts the postsmolt migration along the continental shelf.

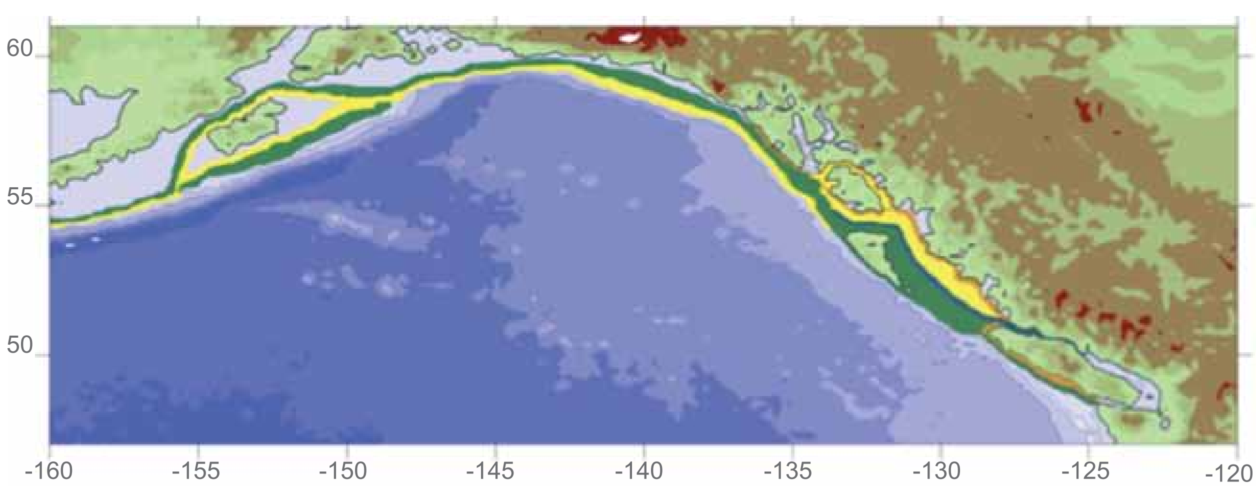

Figure 2.4.2 Seasonal migration of Fraser River sockeye salmon postsmolts after leaving the Strait of Georgia

Blue, May–June; green, July–August; yellow, October–November; orange, February–March.
Source: Technical Report 4, Marine Ecology, p. 17 (Exhibit 1291).

Several of the Commission's technical reports examined, and witnesses testified about, the stressors sockeye salmon encounter on the migration to the North Pacific Ocean, which may have caused or contributed to the recent decline. I summarize these discussions below.

Predation

The Humboldt squid lives in the eastern Pacific and, in recent years, has had a biomass of approximately 9 million tonnes. They were first observed in the waters of British Columbia in 2004, when the surface temperatures of the North Pacific were the highest on record. They move north from California in early summer and appear in British Columbia in late summer and early fall, before they return south. Dr. Christensen and Dr. Trites concluded that Humboldt squid eat prey the size of sockeye smolts, although there is no direct evidence that they prey on sockeye. It is not clear to what degree there was spatial and temporal overlap of Humboldt squid and Fraser River sockeye smolts leaving the Strait of Georgia in 2007. However, the researchers concluded that, if smolts had to pass through an accumulation of Humboldt squid, it is entirely possible they could have a strong predation impact on the sockeye.[660]

During the evidentiary hearings, Graham Gillespie, head of the Shellfish Section, Pacific Biological Station, Science Branch, testified that abundance of Humboldt squid increased between 2004 and 2009, although there are no quantitative estimates of abundance.[661] The squid feed mainly on small pelagic species, myctophids, small schooling rockfish, hake, and pelagic invertebrates, including other species of squid.[662] Mr. Gillespie testified that he did not think that Humboldt squid were responsible for eating a large number of Fraser River sockeye smolts in 2007, although he could not say definitively that they were not implicated.[663] In 2007, Humboldt squid were found off the west coast of Vancouver Island but not farther north, and there is no evidence that they were in the migratory pathways of outbound sockeye smolts.[664]

Climate change

The authors of Technical Report 9, Climate Change, Dr. Hinch and Dr. Martins, concluded that the recent warming of the waters along the British Columbia coast, as well as the negative relationship between early marine survival and coastal sea surface temperature, suggests that survival of juvenile Fraser River sockeye during their coastal migration has likely decreased in the past two decades.[665]

Marine ecology

In Technical Report 4, Marine Ecology, McKinnell and others considered whether marine conditions during the coastal migration facing postmolts in 2007 and 2008 could explain both the poor Fraser River sockeye returns in 2009 (owing to poor food availability) and the historically strong returns in 2010.

The researchers reported that, during the summer of 2007, the surface layer of eastern Queen Charlotte Sound had the lowest average salinity on record since 1970. It was caused by extremely high river discharge volumes from snowmelt combined with high precipitation in early June. Extreme wind anomalies can be added to the list of oceanic extremes that occurred in Queen Charlotte Sound that summer – the highest average southeasterly flow in the 63-year time series. These winds caused ocean surface waters to be pushed into Queen Charlotte Sound, raising coastal sea levels and generally enhancing the poleward flow of surface water along the BC coast. This wind regime caused the warm, less salty surface layer to be retained in the sound. It may also explain why the coast of southeastern Alaska was warmer than average during the summer of 2007.[666]

July 2007 began with neutral to positive sea surface temperature anomalies along the entire coast, strengthening in August and persisting at slightly lower levels through September. The summer temperatures in 2007 were the largest outlier from what May sea surface temperatures might have predicted. Queen Charlotte Sound was the only area along the coast that had extreme absolute sea surface temperature. Warmer-than-average coastal temperatures are normally a sign of lower-than-average survival of Fraser River sockeye.[667]

In years when the spring chlorophyll bloom, which is used as a proxy for phytoplankton presence, is delayed, marine survival of some sockeye populations (e.g., Chilko Lake) is low. The bloom in 2007 was the latest on record since 1998.[668] Although there are likely no Fraser River sockeye postsmolts in Queen Charlotte Sound during April, the lag until their arrival in June and July can allow time for their prey base, which depends on phytoplankton, to develop.[669]

The summer of 2008 was the opposite. Sea surface temperatures along the North American coast were cool following what was the coldest year in the Gulf of Alaska since 1972, and these cool anomalies persisted along the coast through September. Migrating sockeye in 2008, once leaving the coastal straits, would have had a very different thermal experience during their outmigration compared with 2007. This evidence is consistent with the expert report by Thomson and others.[670]

During the evidentiary hearings, Dr. McKinnell testified that there is a correlation between these unusual sea surface temperatures and wind patterns on the one hand, and Fraser River sockeye survival on the other, though that does not establish causation.[671] Further work would be required to understand causation.[672] He said that, in attempting to explain the poor 2009 return, it is also necessary to explain other observations from that time period, including double-the-average returns of sockeye to the Columbia River, better-than-expected returns of sockeye to Barclay Sound, and record high returns to the Harrison River.[673] One needs to develop a model that somehow satisfies all these concurrent observations – and placing the mortality of the 2007 age-one smolts in Queen Charlotte Strait / Sound has the possibility of doing so.[674]

Dr. McKinnell also testified that there is doubt whether a 2009–10 El Niño / La Niña event influenced the 2010 return, as postulated by Exhibit 1303 (Thomson and others, 2011) and testimony of Dr. Beamish.[675] This is because the high return for 2010 was evident in the 2009 test fisheries where the jacks (three-year-olds) were seen in unusually high abundance.[676] He explained that "[w]e interpret this to be an indication that the high abundance of the return in 2010 was established at least a year earlier than the time when the 2010 return occurred."[677]

Life stage 4: growth to adulthood

Growth in the North Pacific

The distribution and movement of immature Fraser River sockeye salmon at sea is the least understood of all life history phases. Stock-specific movements of Fraser River sockeye in the open ocean are unclear, but there is some evidence that different sockeye stocks are in different places in the offshore. Dr. Welch testified that sockeye from the Nass, Skeena, Fraser, and Columbia rivers and Rivers Inlet are spatially separated during the month of June.[678] Dr. Timothy Parsons, professor emeritus at the University of British Columbia and honorary research scientist with DFO, testified that radio isotope testing has shown that different stocks of salmon go to very specific locations in the Gulf of Alaska, and that populations of Atlantic salmon are distributed in different geographic locations in the North Atlantic.[679]

Dr. McKinnell testified that the period between when Fraser River sockeye are migrating northward along the continental shelf and when they appear in deep water is one of the least-understood periods for these animals, in part because logistically difficult winter sampling is involved.[680]

Several of the Commission's technical reports examined, and witnesses testified about, the stressors during the sockeye's residence in the North Pacific Ocean that may have caused or contributed to the recent decline. I summarize these discussions below.

Predation

In Technical Report 8, Predation, authors Dr. Christensen and Dr. Trites stated that salmon sharks migrate between Hawaii and Alaska. They are reported to feed primarily on Pacific salmon in spring and summer. However, Mr. McFarlane testified that salmon sharks are opportunistic and episodic feeders, and a lack of diet information makes it difficult to link salmon shark predation and changes in sockeye population.[681] Although abundance trends are very limited, there is an indication that abundance has increased in recent decades, an occurrence that means the predation impact on Fraser River sockeye salmon may have increased as well. The researchers concluded that the only way to reliably evaluate if salmon sharks have had an increasing impact would be to gather more information about their open-ocean abundance and abundance trends.[682] During the evidentiary hearings, Dr. Christensen testified that the salmon shark was at the top of their list of Fraser River sockeye predators.[683]

Blue sharks are much more abundant than salmon sharks, but since their population has not increased in recent decades, it is unlikely that abundance trends can explain the Fraser River sockeye decline, even if it may have contributed to it. Dr. Christensen and Dr. Trites also discounted the role of the Pacific sleeper shark in the decline.[684]

Sablefish are opportunistic feeders known to consume sockeye salmon, but sablefish in British Columbia and in the Gulf of Alaska have been in decline since the late 1980s. For that reason, the researchers concluded that it is not likely that sablefish would be a major factor in the decline of Fraser River sockeye salmon.[685]

The researchers also considered daggertooth, walleye pollock, and arrowtooth flounder, all of which could exert predation pressure on sockeye salmon. However, owing to inadequate information about abundance and abundance trends, they could not conclude that any of them has been a factor in the decline of Fraser River sockeye salmon.[686]

Climate change

In Technical Report 9, Climate Change, authors Dr. Hinch and Dr. Martins stated that the abundance of sockeye salmon has closely tracked decadal-scale fluctuations in sea surface temperature over most of the past 300 years. These fluctuations have been well documented during the past century and linked to major climate-driven changes in the marine environment occurring every 20–30 years. The abundance of Fraser River sockeye began to increase dramatically at the end of the 1970s, reaching historic high abundance in the early 1990s. Subsequently, abundance and productivity began to decline to recent low levels, in coincidence with the exacerbation of the long-term warming trend of the global climate.[687]

In the North Pacific marine environment, long-term climate change trends are difficult to detect because conditions are strongly related to both inter-annual and inter-decadal modes of climate variability:

- Inter-annual variability is related to El Niño Southern Oscillation events, which occur every two to seven years and persist for up to 1.5 years. Typically, El Niño events lead to warm sea surface temperature in the waters of the west coast of North America, and since the 1970s, El Niño events have become more frequent. By contrast, La Niña events result in cooler waters, and such events have become less frequent.[688]
- Inter-decadal variability in the climate of the North Pacific Ocean has been described by indices such as the Pacific Decadal Oscillation (PDO), which typically persists for 20 to 30 years. Warm sea surface temperatures over the eastern North Pacific Ocean characterize the warm or positive phase of the PDO, whereas opposite sea surface temperature patterns characterize the cool or negative phase. The PDO was predominantly in the positive phase between 1977 and 1997 and, since 1998, has exhibited more frequent alternations, lasting three to four years. Sea surface temperature in the Gulf of Alaska has increased by about 0.25°C per decade since the 1950s. It is now 1.5°C warmer than 60 years ago and 0.5°C warmer than 20 years ago. However, such observed warming has been attributed mostly to the positive phase of the PDO. In contrast to warming trends, both salinity and pH of the North Pacific Ocean has been decreasing in recent decades.[689]

Only a few studies have explored the relationship between temperature and survival of immature sockeye salmon in the open ocean. A 2009 study found that survival of Alaskan sockeye was positively correlated to sea surface temperature during all the years of ocean residence, while a 1991 study found that the survival of Fraser River sockeye was negatively correlated to sea surface temperature in their last few months in the open ocean.[690] The authors of Technical

Report 10, Production Dynamics, reported that increased sea surface temperature in the location of early ocean residence for smolts of a given stock is associated with increased productivity in Alaska.[691] The researchers concluded that increased temperatures in the Gulf of Alaska over the past two decades have possibly resulted in lower survival of Fraser River sockeye during open-ocean residence.[692]

During the evidentiary hearings, Dr. McKinnell testified that Intergovernmental Panel on Climate Change projections for future climate are difficult to represent in terms of the finer-scale climate, such as climate changes that will occur in British Columbia and what the response of the marine ecosystem will be in the northeastern Pacific Ocean.[693]

Marine ecology

Technical Report 4: Marine Ecology

The authors of Technical Report 4, Marine Ecology, considered the hypothesis that a volcanic eruption in the Aleutian Islands in August 2008 led to the widespread deposit of volcanic ash (including iron) in the northwestern Pacific. The theory is that this deposit enhanced productivity of chlorophyll in mid- to late August, benefiting the 2008 smolt year and explaining the strong 2010 Fraser River sockeye return. The authors doubted that this enhanced productivity of chlorophyll benefited the 2008 smolts because the fish would have been migrating along the continental shelf, where iron is not normally the limiting nutrient – so its addition would not have produced much benefit to this cohort. To have directly benefited this cohort, the enhanced biological production would need to be entrained in the pelagic food web and stored through, or made available to it over, the winter. However, zooplankton biomass in 2009 was near the average.[694]

Dr. Parsons testified about the possible impact of the 2008 volcanic eruption on Kasatochi Island, Alaska, on Fraser River sockeye.[695] There is no doubt that an enormous diatom bloom was generated in the Gulf of Alaska and that zooplankton increased by a factor of three, which he said benefited sockeye in the Gulf of Alaska.[696] A similar event occurred in 1956, when a volcano erupted in Kamchatka in eastern Russia, resulting in a return of 20 million fish in 1958. He explained why this affected only the younger 2008 fish, not the 2009 fish:

> Our take on that is that what you have taking place is a massive bloom of diatoms which are absorbed very quickly by the zooplankton. The zooplankton will be rather small zooplankton and they will be consumed much more easily by the young adolescent salmon than the larger 2009 salmon which are still waiting for something big to come along. They've already gone through the stage where they were eating small prey. They're a year older.[697]

Dr. Parsons acknowledged that these are really quite hypothetical answers to a question which is somewhat speculative, but worth recording as a possible mechanism for the 29 million Fraser River sockeye that returned in 2010.[698] Dr. Irvine raised several questions about Dr. Parsons's hypothesis. It was not clear to him why the older salmon (2009 return year) would not have consumed this additional prey, as nutrient sources were extremely important to them because they would be accumulating a lot of mass before beginning their return migration.[699] Also, it was to be expected that the 2010 return would be strong, since the 2008 smolts were migrating northward during a very strong La Niña, with cold waters.[700] Dr. Parsons responded that the impact of the volcanic ash may have been different for different sockeye stocks, since radio isotope testing has shown that different stocks of salmon go to very specific locations in the Gulf of Alaska.[701] Although satellite imagery seems to indicate that the chlorophyll (representing presence of phytoplankton) was distributed throughout the Gulf of Alaska, that does not mean that it was necessarily evenly distributed.[702]

McKinnell and others concluded that there was a strong, abrupt, and generally persistent shift to warm sea surface temperature anomalies along the continental shelf in late June of 2007. However, since most southern stocks were likely using this migratory route during 2007, and non-Fraser stocks did not suffer incremental mortality, it seems unlikely that this coast-wide phenomenon was the cause of incremental mortality of the Fraser River stocks.[703]

The report noted that lack of observations of salmon at sea, at relevant time and space scales, severely limits the ability to draw firm conclusions about their fate.[704] It concluded that, for most Fraser River sockeye populations (where smolt abundance is not observed), the relative contributions of freshwater and marine effects on survival can only be assumed. Fry-to-adult survival trends tend to favour a marine origin for the decline, because they share a common ocean but not a common lake. These populations also share a common means of egress to the sea, although this life history stage is rarely examined in detail.[705]

According to the researchers, the sea provides only limited amounts of food for growing sockeye salmon. Fraser River sockeye were smaller when the total abundance of sockeye in the Gulf of Alaska was greater, but this is not a universal truth.[706] During the habitat enhancement and restoration hearings, Dr. Peterman testified that the body size of a given age of adult sockeye salmon decreases as abundance of competitors increases.[707]

McKinnell and others said that there is some evidence that the mean fork length* of Fraser River sockeye was significantly smaller in brood years that matured in odd years. Because the odd / even cycle of abundance of pink salmon in the Fraser is potentially a source of competition for Fraser River sockeye returning the same year, it is reasonable to postulate that a reduction in mean size in odd years is a consequence of competition for food with pink salmon during the period of overlap in the Gulf of Alaska.[708]

Interaction between wild and enhanced salmon

Dr. Randall Peterman, professor at the School of Resource and Environmental Management, Simon Fraser University, and Canada Research Chair in Fisheries Risk Assessment and Management, testified about potential interactions between wild and enhanced fish.† In his view, increasing fish densities in the North Pacific may have negative impacts on wild stocks, including Fraser River sockeye.[709] None of Dr. Peterman's evidence was contested by DFO.

I also heard in hearings on the marine environment that the interactions between hatchery and wild salmon is a substantial issue in fishery science, and that there is extensive literature on the potential interactions for pink, chum, chinook, and coho.[710] Dr. Beamish stated that there is evidence of hatchery–wild interactions among various salmon species, although whether there could be a long-term substantial reduction in production is less clear among the scientific community.[711]

Dr. Peterman explained that in the North Pacific Ocean there is considerable potential for indirect interactions between wild and enhanced salmon.[712] Across pink, chum, and sockeye salmon, 22 percent of adults in the North Pacific Ocean are of hatchery origin, and plans exist to further increase annual hatchery releases, particularly in Russia and Alaska.[713] Although relatively few sockeye are produced by hatcheries, wild sockeye appear to interact with pink salmon.[714] Dr. Beamish testified that there is the potential, particularly for chum salmon that are enhanced in Asia and pink salmon enhanced in Alaska, to have a density-dependent effect on Fraser River sockeye in the Gulf of Alaska as a result of the large numbers of enhanced fish released into the same area.[715]

Dr. Peterman described several mechanisms for interactions between wild and enhanced salmon. Competition for food can occur between wild and enhanced salmon because their diets overlap and they are thought to generally pass through feeding areas at similar times and places.[716] Food supply in the open North Pacific Ocean has diminished as a result of feeding largely by pink salmon.[717] Also, predation-induced mortality on wild juvenile salmon can be increased because of the attraction of predators to high abundances of juvenile salmon driven by large hatchery releases.[718] Dr. Peterman noted, however, that high total abundance of hatchery plus wild juveniles could also increase the survival rate of wild juvenile salmon co-migrating

* Fork length is measured from the tip of the snout to the end of the middle caudal fin rays.

† Dr. Peterman was qualified as an expert in density-dependent effects on wild and enhanced fish populations for the purpose of this hearing topic (May 2, 2011, pp. 10–11). He was also previously qualified as an expert in fisheries biology with expertise in fish population dynamics and ecology and risk assessment during hearings on Exhibit 748 (Technical Report 10), which he co-authored for the Commission (May 2, 2011, pp. 4–5). His curriculum vitae is Exhibit 749.

with hatchery fish because the abundance of prey may satiate predators.[719]

Where adults of wild and enhanced salmon co-migrate through fishing areas, pressure is intense on managers to allow high harvest rates.[720] However, wild stocks generally have lower productivity (adults per spawner) than enhanced fish, so high percentage harvest rates targeted on enhanced fish are known to eventually lead to overharvesting and depletion of abundance of wild co-migrating stocks that are subject to those same harvest rates.[721] Finally, after adults leave the ocean, large numbers of hatchery fish straying into spawning areas for wild fish can decrease biological diversity and fitness of the wild stocks.[722]

Dr. Peterman provided evidence that the body size at a given age of adult sockeye salmon decreases as abundance of competitors increases.[723] He also explained how the survival rate of sockeye salmon can decrease as the abundance of pink salmon competitors increases, although he said that there are only a few documented examples of this reduction in survival rate compared with examples of reduced growth rate (reflected by adult body size).[724] Dr. Peterman noted that the concern about competition among wild and enhanced salmon for limited resources may become considerably more acute if the North Pacific Ocean becomes less productive again (as it was before the mid-1970s).[725] (For a discussion on DFO's management response to interaction between wild and enhanced salmon, see Volume 1, Chapter 6, Habitat management.)[726]

Return to the Fraser River

In their fourth (or in some cases, fifth) year of life, and after spending one-and-a-half years (or in some cases, two-and-a-half years) in the Gulf of Alaska, Fraser River sockeye leave the Gulf of Alaska and return to the Fraser River to spawn. During the evidentiary hearings, Dr. McKinnell testified that the decision when to return appears to be made in the winter preceding the year that the fish will mature; the decision has genetic and growth components.[727] From that time on, the maturing sockeye needs to find enough food to double its body weight in that last spring at sea. He stated:

> So there's a huge energetic demand on the maturing fish that does not exist for the immature fish, because they have to be able to have enough resources to get from the Gulf of Alaska to fresh water, to swim up the river, to mate and produce gametes and everything that goes along with maturation. That's an energy intensive process.[728]

Fraser River sockeye are captured in fisheries between Alaska and Washington State; their availability depends on their migration route. There are two migratory return routes – down the west coast of Vancouver Island and through Juan de Fuca Strait, or through Johnstone Strait and the Strait of Georgia (the northern diversion route).[729] (See also the discussion of pre-season forecasting in Volume 1, Chapter 5, Sockeye fishery management.)

The percentage that follows the northern diversion route varies from year to year. Dr. Welch testified that, when the ocean temperature is at 10°C, the migration is almost entirely through Juan de Fuca Strait, but when the temperature increases to 12–13°C, 80 to 90 percent of returning sockeye come through the northern diversion route.[730]

Several of the Commission's technical reports examined, and witnesses testified on, the stressors that may have caused or contributed to the recent decline during the return of adult sockeye to the Fraser River. I summarize these discussions below.

Predation

In Technical Report 8, Predation, authors Dr. Christensen and Dr. Trites reported that, after harbour seals received protection under the*Fisheries Act* in 1970, their numbers increased from approximately 9,000 to 108,000, with about 40,000 of these in the Strait of Georgia. An analysis of 3,000 fecal samples collected from 58 Strait of Georgia sites during the 1980s indicated that harbour seals primarily ate Pacific hake (42 percent) and herring (32 percent), while salmonids comprised only 4 percent of the overall diet. Harbour seals appear to prefer chum and coho salmon over sockeye or pink salmon.[731] The researchers concluded that the numbers of seals have been relatively stable in British Columbia for the past decade and showed no changes that might indicate a disproportionate level of predation on the Fraser River sockeye salmon run.[732]

Steller sea lions have also increased in abundance since being protected under the *Fisheries Act* in 1970. They stabilized at about 10,000 until the mid-1980s, then grew at about 4 percent per year, now totalling approximately 30,000.[733] Daily consumption ranges from 15–20 kg (females) to 30–35 kg (males). Salmon accounts for about 17 percent of their diet in British Columbia, although sockeye salmon appears to be the least favourite salmonid prey. The researchers concluded that Steller sea lions could exert some impact on returning numbers given their large body sizes and relatively high food requirements.[734]

During the evidentiary hearings, Peter Olesiuk, head of the Pinniped Research Program, Pacific Biological Station, Science Branch, testified that the total Steller sea lion population for British Columbia and southeastern Alaska is estimated to be 60,000.[735] Mr. Olesiuk and Dr. John Ford, program head of the Cetacean Research Program, also at DFO's Pacific Biological Station, did not stray from the opinion they had expressed at the 2010 Pacific Salmon Commission conference that Steller sea lions (and Pacific white-sided dolphins) appear to be the only potentially significant marine mammal predators of sockeye salmon.[736] For other species of marine mammals, sockeye seems to be the least preferred of salmon species.[737] Mr. Olesiuk testified that he would add the Steller sea lion to the list of species that warrant more attention in relation to the decline of Fraser River sockeye.[738]

California sea lion males migrate from Mexico to British Columbia during the non-breeding season and are most prevalent in the Strait of Georgia between January and May. Since 1984, the population has stabilized at about 3,000, and there is no diet information available. Because their residency in the Strait of Georgia does not overlap with returning Fraser River sockeye adults, they are unlikely to have contributed to the decline.[739]

Of the three forms of killer whales in British Columbia (resident, offshore, and transient), only the resident ecotype are known to feed on salmon. Northern resident killer whales (244 individuals) forage selectively on chinook and chum. For southern resident killer whales (85 individuals), a 2010 study of partial remains from kills in Juan de Fuca Strait and the San Juan Islands indicates that 82 percent of the diet was chinook. Smaller-bodied sockeye and pink were not significant prey despite their far greater seasonal abundance.[740]

During the evidentiary hearings, Dr. Ford testified that, in the analysis of 800 samples of salmonid kills conducted over 20 years, only four were sockeye salmon.[741] Three-quarters were chinook, because they are resident in the killer whale range throughout the year, they are much larger than sockeye, and they have the highest fat content of all salmonids.[742] Sockeye appears to be insignificant in killer whale diets.[743]

Approximately 100 Pacific white-sided dolphins took up year-round residency in the Strait of Georgia during the past decade, but little is known about their movement or diets.*

Climate change

The authors of Technical Report 9, Climate Change, Dr. Hinch and Dr. Martins, did not specifically discuss this phase of the Fraser River sockeye salmon life cycle. However, their discussion of changing climatic conditions, especially the trend toward warmer sea surface temperature, summarized earlier, could apply to this life stage as well.

Marine ecology

In Technical Report 4, Marine Ecology, authors McKinnell and others reported that, between 1952 and 1993, there was a significant linear decrease in mean size at maturity of 10 Fraser River stocks. The researchers felt the trend was due to increasing surface temperatures affecting sockeye metabolism on the return migration. However, when a more comprehensive view of the time series is considered (1952–2009), there is significant low-frequency variability in mean size. This variability is not a simple linear trend and, in fact, indicates in recent years that the mean size is increasing.[744]

During the evidentiary hearings Dr. McKinnell testified that, when the sea surface temperatures

* See also Exhibit 788 and Transcript, May 4, 2011, pp. 50–53, to the effect that they could have played some role in the overall cumulative predation impacts on Fraser River sockeye.

in the Gulf of Alaska get warmer, the sockeye get smaller.[745] There is also another effect – when the abundance of fish is high, their mean size tends to be low.[746]

Mortality-related genomic signature

Earlier in this chapter (see Life stage 1), I summarized the research under way within DFO on a mortality-related genomic signature, led by Dr. Miller. Her research is relevant to this life history stage as well. In brief, in 2008, 60 percent of smolts left the river with the mortality-related signature in the brain, and 40 percent with the signature in the liver. Overall, 82 percent of fish were affected in at least one tissue. However, there were 2.4 times as many fish without the signature in the fall as in the summer.[747]

In the case of adults returning to spawn, 50 percent carried the mortality-related signature. In the marine environment, when fish carry this signature, they had a 13.5 times lower probability of making it to the spawning grounds and spawning.[748] Dr. Miller testified that this study showed unequivocally that Fraser River sockeye are entering the river in a compromised state, and the freshwater environment alone may not be the sole source of the highly fluctuating mortalities of salmon in the river.[749]

Dr. Miller told me that she and Dr. Garver are trying to establish whether this signature is a virus, and possibly a novel parvovirus.[750] It had not been determined, when these witnesses testified in August 2011, whether it is infectious or whether it causes disease.[751]

Sea lice

A study published by DFO scientists on Alberni River sockeye in the 1990s showed a high prevalence (100 percent) and intensity (49 to 1,372 lice per fish, with an average of 300 lice per fish) of *Leps* infection on Alberni sockeye in coastal waters before river entry on the return migration.[752] The sockeye suffered anything from minor skin discolorations to large open lesions that exposed the musculature (87 percent of the fish).[753] In 1990, when these fish were delayed in their escapement into the river system, they suffered high mortality thought to be associated with the large lesions caused by the salmon lice, though death might actually be caused by secondary bacterial or fungal infections, or, in severe cases, osmotic stress.[754] The prevalence and severity of the lice infections in this study were "greater than previously reported for sockeye."[755] Dr. Dill described the circumstances as "a very unusual event."[756] The authors of the study described how high river temperatures forced 60 percent of the sockeye to remain in the inlet much longer than normal, exposing them to "an extended period of crowding, high water temperatures and low dissolved oxygen levels."[757] They concluded it was "highly probable" that, as sockeye mature sexually or are exposed to stresses such as adverse environmental conditions, they may become more susceptible to *Leps* infection.[758] The researchers summarized their results as follows:

> In summary, we saw higher prevalence and intensities of *L. Salmonis* on mature sockeye in Alberni Inlet than reported for immature and maturing sockeye collected on the high seas. Sockeye may become infected with *L. salmonis* as they pass through coastal waters or hold in inlets prior to entering fresh water. It is also possible that immunosuppression concomitant with maturation makes sockeye more susceptible to infection with sea lice as they come ashore. Stocks of Alberni sockeye were shown to differ in the severity of lesions caused by sea lice. The reasons for this difference are unknown. In years such as 1990, when unfavourable river conditions force the fish to remain in the inlet longer than normal, serious disease and mortality induced by sea lice can occur. In extreme cases, disease induced by sea lice appears to cause pre-spawning mortality in freshwater environments, thereby further affecting the reproductive success of these stocks. This observation highlights the important role that diseases may play in the population dynamics of fish stocks.[759]

Although the study was not about Fraser River sockeye, I understand this to be one of the few published field studies looking at the effects of sea lice, particularly *Leps*, on sockeye in the wild. It indicates that *Leps* is capable of causing mortality in sockeye if present in large numbers and/or in combination with adverse environmental factors.[760]

Life stage 5: return migration

Entry into the Fraser River and upriver migration

As returning Fraser River sockeye approach the mouth of the Fraser River, either through Juan de Fuca Strait or through Johnstone Strait, there is some variation in how promptly they move into the river and begin their upstream migration.

This variation is based on the four timing groups – Early Stuart, Early Summer, Summer, and Late-run. The Early Stuarts (which return in June and July) and the Early Summers and Summers (which return in July and August) enter the Fraser River with little or no delay – perhaps one day. Thus, sockeye passing through Johnstone Strait will need six or seven days to move through the Strait of Georgia, enter the river, and reach Mission. Fish returning through Juan de Fuca Strait will need five or six days to reach Mission.

However, the Late-run timing group, which has historically returned in August–September, exhibits two distinctive types of behaviour. Since the 1990s, some parts of the run will enter the river with little or no delay, at the same time as the Summer timing group. The others will, as Late-runs have done historically, delay at the mouth of the Fraser for 20 to 30 days, or longer in some years.[761]

Factors that influence river-entry timing for all Fraser River sockeye stocks include fish maturity, tides, river flow, and water temperature.[762] Over time, it has been observed that there has been increasing overlap of the different run-timing groups.[763] Karl English, the author of Technical Report 7, Fisheries Management, described the earlier appearance of the Late-run timing group at Mission from late August during the 1990s to late July in the 2000s.[764] Research undertaken between 2002 and 2006 showed that Late-run sockeye entering the river before the middle of August experienced a very low probability of survival, whereas those beginning their upstream migration in mid- to late September had a much better likelihood of reaching the spawning ground and actually spawning.[765]

During the evidentiary hearings, Dr. Hinch testified that several explanations have been proposed for why some Late-run stocks begin their upriver migration without holding at the mouth of the Fraser River for several weeks:

- The fish are physiologically compromised in some fashion (e.g., accelerated maturation), so the system which regulates their capacity to live in the marine environment is altered, or some form of disease may be pushing them into freshwater.[766]
- The changing salinity concentrations in coastal areas make the fish perceive they are entering freshwater.[767]
- The "stay in the school" hypothesis – the high abundance of Summer-run stocks reaches the mouth of the Fraser River at the same time as the Late-runs, which may entice the Late-runs to migrate with the Summer-run stocks.[768]

Once Fraser River sockeye begin their upstream migration, their digestive tract shuts down. Dr. Welch described the transformation that occurs:

> Sockeye store fat as oil in the muscles and as they migrate up the river, for example, they burn that oil or fat to fuel the migration and they replace it with water. So as they progress up the river, their shape doesn't change, but they replace fat, which is energy-rich, with water and they become softer.[769]

According to Dr. Hinch, warmer river temperature can affect fish entering the river for these reasons:

- The metabolic and cardiac systems can cease operation at certain critical temperatures, resulting in acute mortality.
- High flows or high temperatures can lead to more rapid metabolism of energy, using up energy resources.
- Diseases, many of which are temperature-dependent, can proliferate.
- The buildup of stress metabolites can create conditions for mortality.[770]

Mr. English testified that, through the use of radio transmitters in fish and monitoring locations along the Fraser River, it is possible to measure how quickly the returning salmon move upriver, and to assess their passage through challenging areas such as Hell's Gate and the Bridge River rapids. Early Stuarts move the fastest – one fish, tagged at Mission, swam 800 km to the Stuart system in 16 days, averaging 45–50 km per day. A Summer-run sockeye, moving more slowly, took 24 days of freshwater migration to reach the Chilko system. During 2009, migration speeds of Summer-run sockeye ranged between 32 and 40 km per day.[771]

Water temperature plays an important role in survival. In the ocean, sockeye prefer temperatures of 12–14°C, or even cooler. However, as the fish migrate upstream, river water temperature is frequently between 18 and 20°C. There is some evidence that sockeye will interrupt their migration by remaining in cooler lakes for a week or more in order to moderate high temperatures, before pressing upstream to their spawning area.[772]

Mr. Lapointe testified that Environment Canada records show that increasing Fraser River water temperature is a significant environmental change – eight of the 10 warmest summer river temperatures on record have occurred in the past 15 years.[773]

Freshwater contaminants

In Technical Report 2, Contaminants, authors MacDonald and others stated that exposure to endocrine-disrupting compounds may be an even greater concern for sockeye returning to the Fraser River than during the outmigration, for these reasons:

- The sockeye are exposed to persistent endocrine-disrupting compounds (e.g., PCBs) during outmigration and during their residence in the marine environment. Then, during upstream migration, they use lipid and protein stores to promote gonadal development and undergo morphological alterations. The rigours of upstream migration can result in a 50–90 percent depletion of somatic energy reserves, with the result that concentrations of those contaminants in somatic or gonadal tissues can increase dramatically between the time they enter the river and the time they arrive at their natal streams. Such contaminant magnification may result in concentrations in eggs that exceeded the toxicity threshold for salmonid fish of 3 ng/g lipid, a level associated with 30 percent mortality of eggs.[774]
- Exposure during upstream migration could also compromise immunocompetence. The result could make sockeye more susceptible to infection by disease agents, particularly during migration periods characterized by elevated water temperatures. This susceptibility could translate into increases in en route mortality and/or pre-spawn mortality.[775]

Infectious diseases

The author of Technical Report 1, Infectious Diseases, Dr. Kent, documented and evaluated the potential effects of diseases and parasites on Fraser River sockeye salmon, during both the freshwater and marine life stages. Dr. Kent identified the following pathogens as either high or moderate risk to Fraser River sockeye salmon during their upriver migration.

Fungi and related organisms. Species of the *Saprolegnia* genus infect the skin and gills, and almost always follow damage that has been caused to these tissues by other factors. With wild salmon, it is one of the most common infections of adult fish once they return to freshwater to spawn, and occurs in warmer waters or those with high organic load. The researcher rated the risk as moderate.[776]

Protozoa. Ichthyophthirius multifiliis parasites cause severe damage to the skin and gills, often killing the fish by asphyxiation due to the tissue reaction to the parasite in the gills. Whereas pre-spawn mortality as high as 70 percent has occurred in the Nadina River, it has not increased in severity since 1990. The researcher rated the risk as high, noting that severity would increase with increased water temperature and reduced water flows. *Cryptobia salmositica* is a blood flagellate common in salmonids from freshwater throughout the Pacific Northwest. In wild fish, the infection is usually seen in sexually mature salmon that have returned to freshwater to spawn. Infections are often lethal. In 2008, it was associated with pre-spawn mortality in sockeye at Weaver Creek. The researcher rated the risk as moderate.[777]

Myxozoa. The *Parvicapsula minibicornis* parasite targets the kidneys. The infection may be severe in sockeye adults suffering pre-spawn mortality compared with successful spawners. The researcher rated the risk as high. *Myxobolus arcticus* has been detected in some pre-spawn mortalities from Weaver Creek, along with a variety of other pathogens. The researcher rated the risk as low to moderate.[778]

Hydroelectric power projects

There are no hydroelectric power projects on the mainstem Fraser River.[779] Section 4 of the *Fish Protection Act* now prohibits bank-to-bank dams on a number of BC rivers, including the Fraser River.[780]

Hydroelectric power projects have the potential to change freshwater environments that support salmon populations. These changes may be grouped into two general categories:

- *barriers*, which are the infrastructure that prevent or affect upstream and downstream movement of fish; and
- *alteration of the flow regime*, which encompasses changes to stream characteristics related to the amount of water present in a stream and its movement.[781]

Three dams now operated by BC Hydro were built on migration routes for Fraser River sockeye: the Alouette, the Coquitlam, and the Seton.[782] There is also the Wilsey Dam at Shuswap Falls, but it is not located on a sockeye migration route, and although it has the potential to affect sockeye habitat below the dam, apparently it does not do so in a significant way.[783] The Alouette and Coquitlam dams, completed in the early 1900s, caused the extirpation of historic sockeye runs.[784] Fish passage structures were not provided at either facility.[785] The Seton Dam (part of the Bridge River-Seton power project near Lillooet), completed in 1956, is located on the migration route of two Fraser River sockeye runs (Gates Creek and Portage Creek); a fish ladder provides access to spawning grounds above the dam.[786]

The two large-scale hydroelectric projects in the Fraser River watershed with the potential to affect Fraser River sockeye during the return migration are BC Hydro's Bridge-Seton Power Project and Rio Tinto Alcan's Kemano Hydroelectric Project (which diverts water from the Nechako River).[787]

There are two issues associated with upstream passage at the Seton Dam that have the potential to affect the Gates Creek and Portage Creek sockeye populations:

- When returning to Seton Lake, sockeye must successfully pass the "tailrace" of the Seton powerhouse and enter the Seton River.* However, due to the strong smell of Seton River water pouring into the Fraser River from the turbine, sockeye tend to school in the tailrace, thus delaying their migration upstream. BC Hydro sought to mitigate this concern by diverting flow from Cayoosh Creek into Seton Lake, which reduced the ratio of Cayoosh Creek water in the Seton River. Studies indicated that sockeye would move past the tailrace if the concentration of Cayoosh Creek water in the Seton River was reduced to 20 percent for Gates Creek sockeye and less than 10 percent for Portage Creek sockeye. BC Hydro has, since 1979, attempted to meet dilution guidelines reflecting these numbers. But a recent study raised concerns that the tailrace may still attract and delay sockeye, even if guideline conditions are met for dilution.[788]
- If returning sockeye successfully pass the tailrace and enter the Seton River, they must then locate the entrance of the fish ladder and ascend it.[789] A recent study suggests that sockeye may have trouble locating the entrance of the fish ladder, possibly owing to high flow discharge from the Seton Dam into the Seton River.[790] When asked about this study, Dr. Bradford, research scientist with DFO and Simon Fraser University, cautioned that the results of the study should be interpreted carefully because some fish may have failed to traverse the dam on account of handling and other cumulative stresses.[791]

Under the St'át'imc (PC) Settlement Agreement, BC Hydro agreed to undertake a collaborative research program with the St'át'imc First Nation

* Water discharged from the powerhouse of a hydroelectric dam enters the river through a channel called the "tailrace." See PPR 21, p. 35.

to study factors that may impede the success of upstream migration of salmon at the Seton Dam, including potential impacts caused by tailrace delay and the fish ladder.[792] This research program has been incorporated as a term of the Bridge River Water Use Plan.[793] (For a discussion of the regulation of hydroelectric power projects of water plans and planning, see Volume 1, Chapter 6, Habitat management.)

Adult mortality during river migration and on spawning grounds

In Technical Report 9, Climate Change, authors Dr. Hinch and Dr. Martins stated that several behaviours and physiological systems which can facilitate energy conservation are critically important for successful migration. For example, sockeye populations with difficult river migrations depart the ocean with high reserve energy and morphologies – such as short and relatively round bodies – that favour energy conservation. Also, when river discharge is unusually high, migration rates of some stocks are slowed, extending migration duration by several weeks. This process can deplete energy reserves to levels below critical thresholds. In years of extremely high discharge, hundreds of thousands of Fraser River sockeye have died during their migration, and energy exhaustion is thought to be partly responsible.[794]

Temperature is the most important environmental factor governing fish during the return migration because of its underlying effect on physiological, ecological, and behavioural aspects of life history. En route mortality could occur in rivers as a result of several high-temperature-mediated factors, such as collapse of aerobic scope, poor recovery from stress and strenuous exercise, and increased susceptibility to disease and parasites. High river temperatures can also deplete energy resources by accelerating routine metabolism. This change is unlikely to cause mortality by itself, although energy depletion in combination with other thermal-mediated processes could play a significant role in en route mortality.[795]

The researchers stated that, because river discharge in most years since the early 1990s has not been exceedingly high, discharge alone is not believed to be the driving factor underlying recent years' trends in en route mortality.[796]

Regarding temperature, Early Stuart-run and Late-run stocks experience the coolest Lower Fraser River temperatures (approximately 12–16°C historical daily average), whereas Early Summer and Summer-run stocks experience the warmest temperatures (approximately 15–17.5°C). Long-distance migrating stocks and early entering Late-runs accumulate relatively high levels of "degree days," whereas stocks that migrate in early August encounter the peak Fraser River temperatures.[797]

Three broad changes to the thermal experience of Fraser River sockeye have occurred over the past several years:

- The Fraser River has experienced approximately 2°C warming in the summer compared with 60 years ago.
- There have been several recent years with record high temperatures during mid-summer.
- As described above, since 1996, segments of Late-run sockeye have been entering the river three to six weeks earlier than normal, and thus may encounter temperatures up to 5°C warmer than they normally would.[798]

Taken together, these facts indicate that thermal conditions have been one of the largest environmental challenges that migrating adult Fraser River sockeye have had to deal with over the past 20 years.[799]

Some Fraser River sockeye stocks (Adams, Stellako, Late Stuart, and Quesnel) are affected by warm river temperatures, while others, such as Chilko, are insensitive, at least up to 20°C. For those migrants that were affected by temperature, one study showed that 17–18°C was the tipping point, and at 19–20°C stocks were exhibiting 20–40 percent mortality. In a 2004 study of Weaver Creek sockeye, 100 percent of fish perished if they encountered river temperatures exceeding 20°C, with 90 percent mortality at 18–19°C, and 20–50 percent mortality at less than 17°C. The researchers concluded that patterns of en route mortality are stock-specific. Stocks appear to be physiologically fine-tuned to function best at the river migration temperatures they historically encountered.[800]

The researchers described how river temperature and disease can cumulatively affect survival. One parasite (*Parvicapsula minibicornis*) infects kidneys and gills of all adult Fraser River sockeye salmon as they migrate through the estuary.[801] In laboratory studies, kidney infection has been shown to start when accumulated degree days exceed 350, and to become full blown at approximately 500 degree days.*

They concluded that en route loss has occurred in all run-timing groups of Fraser River sockeye over the past 17 years, and there is ample evidence that adverse environmental conditions, in particular those related to thermal issues, are largely responsible for the patterns. En route loss has been least severe and least frequent in the Summer-runs and most severe and most frequent in the Early Stuart and Late-runs.[802]

The researchers concluded that recent trends in climate have very likely decreased Fraser River sockeye survival during this life stage over the past 20 years.[803] During the evidentiary hearings, Dr. Hinch addressed the possible explanations for a fish reaching the spawning ground but not depositing its eggs:

> So these fish, you have to remember from the moment they are entering freshwater they are on a trajectory to die. They are all senescing just like we all senesce as we get older, our bodies, our immune systems start to break down. Their immune systems are becoming dysfunctional during the freshwater migration, and when they get to the spawning grounds, their immune function is almost nil. They have no ability to fight off diseases by the time they get to spawning grounds.
>
> They are going through rapid, rapid changes in their physiological systems that are irreversible at that point, with reproductive hormones and stress hormones flying up the charts. So on top of the natural diseases that they may be encountering and incubating within them, they also have these rapid changes in their body physiology that's occurring naturally, and the rate at which that changes on spawning grounds not only is mediated by temperature, but also by the density of fish, as well as the amount of time they spend once they're on the spawning ground looking for a mate.[804]

In Technical Report 9, Climate Change, Dr. Hinch and Dr. Martins stated that levels of pre-spawn mortality (females that do not suffer en route mortality because they arrive at spawning grounds but that die with most of their eggs retained in their bodies) are highly variable among stocks, run-timing groups, and years.[805] The causes are complex and multi-factorial, and include disease, stress, and energy level in adults, and time alive on spawning grounds. Most of these factors are accentuated by increasing temperatures.[806]

Across all run-timing groups over the past 70 years, pre-spawn mortality averages approximately 10 percent. It has exceeded 30 percent in only 12 years, and has exceeded 40 percent in only four years. Unlike en route mortality, there is no clear indication that pre-spawn mortality has been increasing over the recent decades, with the possible exception of the past 25-year trend in Late-run pre-spawn mortality.[807]

The researchers also examined the different freshwater conditions experienced by returning adults in 2009 and 2010. Significant mortality can occur during the upstream migration. The researchers found:

- In 2009, river temperatures were well above the long-term average during much of the migratory period. Temperatures exceeded 18°C from the third week of July to the third week of August, and during that period temperatures rose above 20°C for nine days – levels of thermal stress which would be expected to cause significant levels of en route mortality. Also, at least 50–60 percent of the Late-runs migrated in-river earlier than historically normal, and it would be expected that a large portion of these early migrants would suffer either en route or pre-spawn mortality.[808]

* Accumulated degree days is calculated by multiplying the number of days (e.g., 20) that a fish is exposed to water of a certain temperature (e.g., 18°C), in this example to get 360 degree days.

- In 2010, river temperatures were generally above the long-term average, but not as high as 2009. Temperatures exceeded 18°C from the third week of July to the third week of August, but exceeded 19°C on only six days. Only approximately 40 percent of Late-runs migrated in-river earlier than historically normal.[809]

En route and pre-spawn mortality 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.

The researchers concluded that recent trends in climate have possibly decreased Fraser River sockeye survival during this life stage over the past 20 years.[810]

However, it is important to understand that, while stressors along the upstream migratory route affect harvest and escapement, they do not affect productivity measured as recruits per spawner, because salmon biologists estimate recruits by adding the adults that reach the spawning grounds to harvest and en route mortality. Thus, adult mortality during river migration does not explain the long-term decline in productivity discussed throughout this Report.[811]

High spawner abundance

There are several ways to illustrate the decline in Fraser River sockeye salmon. One way is through data relating to abundances or annual sockeye returns. The other is in reference to productivity – comparing the number of adults returning to spawn (recruits) with the number of spawning adults four years previously.

In Technical Report 10, Production Dynamics, authors Dr. Peterman and Dr. Dorner examined production dynamics. During the evidentiary hearings, Dr. Peterman said that productivity is simply a measure of how successful parents are at producing offspring that mature to come back to the coast.[812] One of the measures of productivity is "recruits per spawner," which is the number of adults that return to the coast before the onset of fishing, produced per spawner. He testified that, for most Fraser River sockeye stocks, there has been a declining number of recruits per spawner since the early 1980s.[813] This decline is shown graphically in Figure 2.4.3. As noted in my Interim Report, if the number of progeny is less than the parental numbers, the stock would appear to be in decline. Since the early 1990s, there was a steady decline until 2009, to the point where the ratio of returning progeny per spawner was well below the 1:1 replacement level.[814]

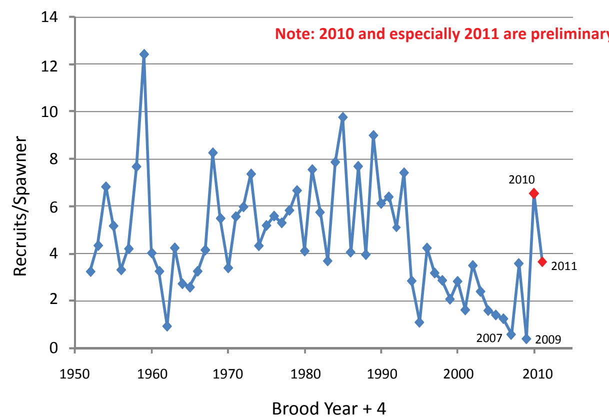

Figure 2.4.3 Annual variation in total Fraser River sockeye productivity, 1952–2011

Source: Exhibit 1851.

Dr. Peterman and Dr. Dorner examined the high spawner abundance, or "over-escapement," hypothesis. This hypothesis holds that a large number of spawners could be detrimental to productivity.[815] (For a discussion of the concept of over-escapement and its management implications, see Volume 1, Chapter 5, Sockeye fishery management.)

The researchers said that there are two ways in which increased escapement may have negative effects on productivity:

- *simple density dependence* – a large escapement (spawning population) in a given brood year (year of spawning) may cause the number of resulting adults to be low (less than the parental spawner abundance) owing to competition for limited resources (such as food for fry or oxygen for eggs in the gravel), and possibly mortality from the frequently observed diseases of sockeye salmon. The key issue in this context is the frequency and magnitude of their effect in years of high spawner abundance.[816]

- *delayed density dependence* – a large abundance of spawners in a given brood year would affect not only that brood year's productivity, but also productivity of the subsequent three brood years. The latter lag effect could occur through increased incidence of diseases on densely crowded spawning grounds, severe depletion of food supply in rearing lakes for juveniles across successive cohorts, increased reproduction and survival of long-lived predators of juvenile sockeye when their prey are plentiful, or any combination of the three. Delayed density dependence has been hypothesized to explain the phenomenon of cyclic dominance, but it appears other factors may be involved.[817]

The researchers stated that the literature offers some support that both simple and delayed density dependence occur for Fraser River stocks, but studies have so far failed to show conclusively that either form of density dependence has had a substantial influence on sockeye population dynamics in the Fraser River.[818] The effects can be examined most simply by plotting spawners and resulting recruits and looking for extremely low recruit numbers associated with extremely large previous spawning escapements.[819] Their analysis confirmed the findings of Dr. Carl Walters and others (2004): that there was no evidence of catastrophic decrease or collapse in recruitment per spawner following runs with very large numbers of spawners.* Witnesses who testified during the harvest management hearings generally agreed that the evidence did not support high spawner abundance leading to stock collapse.[820]

The researchers stated:

> For our 19 Fraser sockeye stocks across a total of 977 stock-years, there were only 70 instances (7.2 percent) in which the abundance of recruits was less than twice the number of effective female spawners (i.e., roughly below replacement). None of those cases followed an extremely large spawner abundance that subsequently led to chronic low abundance or stock collapse. The main reason for this result may be that there is only weak density-dependence in the spawner-to-recruit relationship for most of these Fraser sockeye populations.[821]

Looking for delayed density-dependent effects, which may be more diffuse over longer time periods, the researchers found that, for some Fraser River stocks (Quesnel, Chilko, and Fennell), recent declines in productivity were indeed associated with higher levels of spawner abundance.[822] Similarly, Dr. Walters, fisheries professor, University of British Columbia, and Dr. Brian Riddell, chief executive officer of the Pacific Salmon Foundation, formerly with DFO, cited the Chilko, Quesnel, and Adams as examples of stocks that have experienced a loss of productivity correlated with large escapements in prior years.[823] However, other stocks with declining productivity had normal or below-normal spawner abundances. This finding led Dr. Peterman and Dr. Dorner to conclude that "it appears that although density-dependence may have contributed to declines in productivity for some stocks such as Quesnel, it is *not* a sufficient explanation for the widespread regional pattern of decline in recruits per spawner apparent in the data[.]"[824]

There is some question over how many stocks show statistically significant delayed density-dependent effects. At the June 2010 PSC workshop, there was some support for the idea that delayed density dependence could have played a role in the long-term decline. At our hearings, Dr. Walters testified that, while in the early days none of the stocks showed such effects, new analyses "show it for most stocks."[825]

He expanded:

> It's possible that this is an artefact of confounding between the effects of population density and other things that are causing declining survival, coincident with high spawning stocks. But it's getting harder and harder to explain the patterns away as statistical artefacts of that kind.[826]

* The hypotheses being investigated in the Walters and others (2004) study (Exhibit 417) and in Technical Report 10, Production Dynamics, were somewhat different. Exhibit 417 looked only at whether there was stock collapse associated with higher spawner abundances, whereas Technical Report 10 examined whether high spawner abundances may be responsible for declines in Fraser River sockeye productivity, not necessarily extreme declines or collapse.

In contrast, Ken Wilson, a fisheries biologist, provided his view that over-escapement is a fisheries management construct better understood as "under-fishing," and should not be construed as biologically harmful.[827] He explained his view that historical Fraser River sockeye escapements may have been substantially larger than they are today – perhaps as high as 160 million – and that the ecosystems and the sockeye themselves have adapted to this natural periodic influx of nutrients.[828] Other witnesses also told me there were some ecosystem benefits to high levels of abundance, including more nutrients for other fish, for bears, and for eagles.[829]

Thomas Alexis from the Tl'azt'en Nation provided his perspective that there is no such thing as "over-escapement," nor has there ever been. He explained that fish are smart animals and they know where they are going. There are enough systems to accommodate these fish; if a stream is overfilled or overpopulated, the fish look to an empty or less full stream. For example, in Takla, there are over 100 natal streams that the salmon return to. If there was high abundance, then all these natal streams would be filled up and fully utilized, he testified.[830] Grand Chief Saul Terry of the St'át'imc Nation and a commissioner on the PSC spoke to over-escapement and dismissed this concern, saying that "nature looks after itself quite well," so long as we take care of habitats.[831]

Dr. Walters countered that allowing large escapements can ultimately create a strong cyclic dominant pattern wherein a number of large stocks are synchronized with respect to timing of a large year followed by three very small years.[832] This extreme synchronization, he explained, would not be good for a stable fishery or a stable ecosystem.[833]

Dr. Peterman and Dr. Dorner concluded that, although there is evidence of both simple and delayed density dependence for many Fraser River sockeye stocks, their results did not support the general hypothesis that efforts to rebuild Fraser River sockeye populations in recent years may have resulted in "over-spawning," thereby causing substantial declines in productivity for these stocks. They did, however, identify the Quesnel stock as an exception to this generalization.[834]

When Mr. Marmorek testified about his conclusions in Technical Report 6, Data Synthesis, there was some contradictory evidence on delayed density dependence in the form of an email exchange between Mr. Marmorek and Dr. Walters and a handout from the June 2010 PSC workshop, where Dr. Walters presented his hypothesis that several stocks exhibited delayed density dependence.[835] Mr. Marmorek explained the differences between Dr. Peterman and Dr. Dorner's methods, which were set out in detail in Technical Report 10, Production Dynamics, and Dr. Walters's methods.[836] Mr. Marmorek said that to compare the two, one would need to be able to examine Dr. Walters's methods.[837] He added that in Technical Report 6 he put "a lot more weight on the very thorough analysis by Peterman and Dorner in their Technical Report 10."[838]

Productivity comparisons across stocks

Across Fraser River sockeye populations

In Technical Report 10, Production Dynamics, authors Dr. Peterman and Dr. Dorner found clear shared trends across most Fraser River sockeye stocks, when clustered according to the four run-timing groups.* For the Early Stuart and most Early Summer stocks, productivity started a long downward trend in the 1960s and/or 1970s. Strong and persistent declines for the Summer and Late-run stocks occurred starting in the late 1980s.[839] The researchers concluded that most Fraser River sockeye stocks show declines in adult returns over recent years, and most of these declines have been associated with decreases in productivity (recruits per spawner).[840]

Between Fraser River stocks and non–Fraser River stocks

Dr. Peterman and Dr. Dorner also obtained data on abundance of spawners and their resulting

* Several stocks did not conform to the pattern of recent decline; most notably Harrison, Quesnel, and Pitt.

adult returns of all ages (recruits) for a total of 64 sockeye populations from Washington State, British Columbia, and Alaska.[841] They found that most Fraser River and many non–Fraser River sockeye stocks, both in Canada and the United States, show a decrease in productivity, especially over the past decade and often also over a period of decline starting in the late 1980s or early 1990s. In other words, declines since the late 1980s have occurred over a much larger area than just the Fraser River system and are not unique to it.[842] During the evidentiary hearings, Dr. Peterman noted that several stocks that migrate along the west coast of Vancouver Island, such as Washington State stocks and Great Central and Sproat Lake stocks, showed this decreasing productivity trend, although the Harrison River stock, which may follow a similar migratory route, showed increasing productivity.[843]

The researchers also found that *declines* in productivity of Fraser River and other BC stocks have generally coincided with *increases* in productivity of stocks in western Alaska, most notably Bristol Bay. The converse is also true. They reported that sea surface temperatures may be partially responsible for these patterns.[844] In testimony, Dr. Peterman said that the Bristol Bay anomaly may be explained by the regime shift in the 1970s.[845] Wind circulation patterns changed substantially. Those changes altered ocean currents, which led to an increase in productivity of the food supply – and the number of recruits per spawner increased dramatically.[846]

The researchers emphasized that their data analyses merely describe the extent to which time trends in productivity are similar across sockeye salmon stocks, but said that the causes for that similarity were not investigated in their study, except for delayed density dependence. However, they added that the large spatial extent of similarities in productivity patterns suggests that mechanisms which 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.[847]

Moreover, the causes of declining trends in productivity may or may not have been the same across sockeye stocks from Lake Washington, British Columbia, southeastern Alaska, and the Yakutat region of Alaska. The prevalence of downward trends in productivity among these stocks might be coincidental. It is conceivable that, just by chance alone, processes that have operated independently in each sockeye population outside the Fraser River system (e.g., freshwater habitat degradation, contaminants, pathogens, predators) led to decreasing trends in productivity similar to the trends within the Fraser River.[848] However, in testimony Dr. Peterman gave his view that the coincidence was unlikely:

> To us it seems like there's a much greater chance that there's some shared trend across these populations to varying extents, than that there's some near coincidence of independently operating factor causing a downward trend in productivity of all these stocks simultaneously. It's possible that there's a coincidence. We can't deny that. But it seems unlikely over such a large spatial scale that that would happen. So it seems like there would be processes operating on a larger scale that would be affecting these populations simultaneously. And these could be things such as oceanographic patterns driven by climatic processes.[849]

Dr. Peterman added that it seems unlikely that these decreases in productivity are due to shared variation in freshwater processes, because those freshwater processes would have to occur in all those stocks.[850] He added that delayed density dependence can probably also be ruled out as the shared source of downward trend in productivity, since it appears to have played an important role only in the Quesnel stock.[851] Similarly, en route mortality can be ruled out, because estimates of adult recruits take en route loss into account.[852]

Dr. Peterman emphasized a need to know more about sockeye salmon in this environment:

> So if we really want to understand what is going on in the marine environment with these fish, I think we need to have a lot better coverage of where these fish are at various times, and that may require some tagging of a great extent, much larger than has been done for years, decades in fact, to find out where these fish are and what is happening to them.[853]

Data synthesis

The Inquiry commissioned ESSA Technologies Ltd. to synthesize the results of the Commission's other technical reports into an assessment of various factors potentially affecting the Fraser River sockeye fishery over the recent period of declining productivity.

The authors of Technical Report 6, Data Synthesis, organized their analysis of the other technical reports according to the Fraser River sockeye life stages, adopting a five-life-stages categorization. Their conclusions are summarized below.

Incubation, emergence, and freshwater rearing. The authors concluded that it is possible that climate change contributed to overall declines in productivity in recent decades. It is unlikely that most of the other stressors identified in the other technical reports did so.* No conclusion was possible respecting pathogens and hatchery-origin disease.[854]

Smolt outmigration. The authors' conclusions were the same for this life stage as above.[855]

Coastal migration and migration to rearing areas. The authors concluded that it was likely that climate change, and marine conditions along the nearshore migratory route, contributed to the overall declines in productivity. It was possible that predators contributed to the decline, and possible that disease originating at salmon farms contributed to the decline, if the conclusions of Technical Report 5D, Dill Salmon Farms Investigation, were accepted. The authors rated several other stressors as unlikely, or said that no conclusion was possible.[856]

Growth in the North Pacific and return to the Fraser River. The authors concluded that it was possible that predators, climate change, and marine conditions contributed to the long-term decline in productivity. They rated several other stressors as unlikely, or said that no conclusion was possible.[857]

Migration back to spawn. The authors concluded that climate change definitely affected harvest and escapement, but that en route mortality was unlikely to explain trends in recruits per spawner (productivity). They rated other stressors as unlikely, or said that no conclusion was possible.[858]

In their report, the authors of Technical Report 6, Data Synthesis, explained their usage of the terms "unlikely," "possible," and "likely":

> Even with considerable gaps in data and understanding, and mostly indirect evidence, contrasts over space and time in both salmon stock productivity and the potential stressors allow us to judge certain stressors to be unlikely to have been the *primary* factors causing declines in sockeye productivity or abundance. Other factors may be possible or even likely, provided that they fulfill most or all of various criteria (i.e., have a plausible mechanism by which survival could be affected; have generally exposed Fraser sockeye to increased stress over the period of productivity declines; correlate over space, time and stocks with variations in productivity; and (ideally) have other corroborating evidence from cause-effect studies).[859]

Having presented the conclusions of the authors of the technical reports, and having summarized the synthesis of those reports presented in Technical Report 6, I turn now to my own findings of fact respecting the causes of the decline of Fraser River sockeye salmon.

Notes

1 Exhibit 8, p. 10.
2 Exhibit 1454, pp. 23–24.
3 Mike Lapointe, Transcript, October 25, 2010, p. 24; Jim Irvine, Transcript, July 8, 2011, p. 91; Exhibit 1352.
4 Exhibit 1, p. 23.
5 Transcript, October 25, 2010, pp. 18–19.
6 Exhibit 783, p. 13.
7 Exhibit 783, p. 16.

* The researchers concluded that contaminants were unlikely to have contributed to the long-term decline in productivity. However, in reaching this conclusion, they considered only the impact of contaminants that were *measured* by Technical Report 2, Contaminants, and did not consider the potential impact of the large suite of chemicals (including endocrine-disrupting chemicals) that are not currently measured in the watershed (Transcript, David Marmorek, September 19, 2011, pp. 17, 22–24, 60).

8 Exhibit 783, p. 17.
9 Exhibit 783, pp. 17–18.
10 Exhibit 783, pp. 20–21.
11 Exhibit 783, p. 21.
12 Eduardo Martins, Transcript, May 8, 2011, p. 23.
13 Exhibit 553, pp. 21–22.
14 Exhibit 553, p. 22.
15 Exhibit 553, p. 25.
16 Exhibit 553, p. 26.
17 Exhibit 553, p. 26.
18 Exhibit 553, pp. 28–29.
19 Exhibit 553, p. 29.
20 Jason Hwang, Transcript, April 5, 2011, p. 1; Rebecca Reid, Transcript, April 5, 2011, p. 1; Patrice LeBlanc, Transcript, April 5, 2011, p. 2.
21 Randy Nelson, Transcript, April 8, 2011, p. 75.
22 Exhibit 562, p. 22.
23 Exhibit 562, pp. 25–26.
24 Exhibit 562, p. 30.
25 Exhibit 562, pp. 30–33.
26 Exhibit 562, p. 39.
27 Exhibit 562, p. 41.
28 Exhibit 562, pp. 41–42.
29 Exhibit 562, pp. 44–45.
30 Exhibit 562, p. 46.
31 Exhibit 562, p. 57.
32 Transcript, March 10, 2011, p. 33.
33 Marc Nelitz, Transcript, March 10, 2011, p. 33.
34 Transcript, March 10, 2011, p. 29.
35 Transcript, June 17, 2011, p. 6.
36 Transcript, June 17, 2011, p. 12; see also Exhibit 1107.
37 Peter Tschaplinski, Transcript, June 17, 2011, p. 12; see also Exhibit 1107, p. 27.
38 Transcript, June 17, 2011, pp. 50–51.
39 Transcript, June 17, 2011, pp. 48–49, 57–58, 76.
40 PPR 17, p. 72.
41 PPR 17, p. 72.
42 PPR 17, p. 72.
43 PPR 17, pp. 74.
44 Transcript, June 17, 2011, p. 38.
45 Peter Tschaplinski, Transcript, June 17, 2011, p. 10; Ian Miller, Transcript, June 17, 2011, p. 47.
46 Peter Tschaplinski, Transcript, June 17, 2011, p. 10.
47 Peter Tschaplinski, Transcript, June 17, 2011, pp. 10–11.
48 Exhibit 1124, p. 5.
49 Transcript, June 17, 2011, p. 11.
50 Transcript, June 17, 2011, p. 73.
51 Exhibit 1125.
52 Peter Tschaplinski, Transcript, June 17, 2011, pp. 45–46; see also Exhibit 1125, p. 32.
53 Transcript, June 17, 2011, pp. 75–76.
54 Transcript, September 15, 2011, pp. 1–3; see also Exhibit 912.
55 Transcript, September 15, 2011, p. 5.
56 Michael Bradford, Transcript, September 15, 2011, pp. 4–5.
57 Michael Bradford, Transcript, September 15, 2011, p. 5.
58 Michael Bradford, Transcript, September 15, 2011, p. 5.
59 Michael Bradford, Transcript, September 15, 2011, pp. 5–6.
60 Transcript, September 16, 2011, p. 8.
61 Transcript, September 16, 2011, p. 8.
62 Transcript, September 15, 2011, p. 6.
63 Steve MacDonald, Transcript, September 15, 2011, p. 8.
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65 Transcript, September 15, 2011, pp. 2–3, 9; see also Exhibit 1760.
66 Transcript, September 15, 2011, p. 57.
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69 Jason Hwang, Transcript, September 16, 2011, p. 45.
70 Michael Bradford, Transcript, September 15, 2011, p. 37; Jason Hwang, Transcript, September 16, 2011, p. 36.
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73 Transcript, June 7, 2011, pp. 94–95; see also PPR 14, p. 45.
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152 Transcript, August 24, 2011, pp. 2–3; see also Exhibit 1511.
153 Transcript, August 24, 2011, p. 18.
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177 Mike Lapointe, Transcript, October 25, 2010, pp. 19–20; see also Exhibit 1, pp. 14–15.
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554 Lawrence Dill, Transcript, August 25, 2011, p. 98; Donald Noakes, Transcript, August 25, 2011, p. 99; see also Exhibit 1540, pp. 19–20.
555 Exhibit 1540, pp. 19–20.
556 Donald Noakes, Transcript, August 25, 2011, p. 99; Lawrence Dill, Transcript, August 25, 2011, p. 98.
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571 Exhibit 1540, p. 24.
572 Exhibit 1536, p. 24.
573 Exhibit 1536, p. 25.
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575 Exhibit 1543, p. 18.
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591 Exhibit 1536, p. ii.
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598 Exhibit 1540, pp. 1, 4.
599 Josh Korman, Transcript, August 25, 2011, p. 79.
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601 Transcript, August 25, 2011, pp. 86–87.
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604 Transcript, August 26, 2011, pp. 79–80.
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617 Transcript, August 23, 2011, p. 43.
618 Transcript, August 23, 2011, p. 58.
619 Transcript, August 23, 2011, p. 91.
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621 Transcript, August 31, 2011, p. 89.
622 Transcript, August 31, 2011, p. 94.
623 Transcript, August 31, 2011, p. 114.
624 Transcript, September 7, 2011, pp. 103–4.
625 Transcript, September 7, 2011, p. 105.
626 Transcript, September 7, 2011, p. 105; Transcript, September 8, 2011, p. 39.
627 Transcript, September 7, 2011, p. 105; Transcript, September 8, 2011, p. 39.
628 Transcript, August 22, 2011, pp. 73–74.
629 Exhibit 1449, p. 8.
630 Transcript, August 22, 2011, p. 75.
631 Transcript, August 22, 2011, p. 76.
632 Transcript, August 23, 2011, p. 55; Exhibit 1488, p. 1.
633 Transcript, August 23, 2011, p. 64.
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643 Transcript, September 7, 2011, p. 81.
644 Transcript, August 29, 2011, p. 50.
645 Transcript, August 29, 2011, pp. 51–52.
646 Transcript, September 7, 2011, p. 82.
647 Exhibit 1976, p. 19.
648 Transcript, August 23, 2011, p. 34.
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650 Transcript, August 31, 2011, pp. 63–65.
651 Transcript, August 31, 2011, p. 65.
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654 Transcript, August 31, 2011, p. 80.
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676 Stewart McKinnell, Transcript, July 6, 2011, pp. 45–46.
677 Transcript, July 6, 2011, p. 46.
678 Transcript, October 25, 2010, p. 40.
679 Transcript, July 8, 2011, pp. 101–2; see also Exhibit 1892, p. 11.
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681 Transcript, May 5, 2011, p. 35.
682 Exhibit 783, p. 37.
683 Transcript, May 4, 2011, p. 26.
684 Exhibit 783, p. 37.
685 Exhibit 783, p. 42.
686 Exhibit 783, pp. 45, 52–53.
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688 Exhibit 553, p. 27.
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690 Exhibit 553, p. 23.
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748 Kristina Miller, Transcript, August 24, 2011, p. 5.
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787 Exhibit 562, p. 34.
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Chapter 5 • Findings

The Terms of Reference direct me to investigate and make independent findings of fact regarding the causes of the decline of Fraser River sockeye salmon. I am specifically instructed to consider 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 the ocean or to reach traditional spawning grounds, but I am not precluded from considering other potential causes as well.

As the previous chapters show, I received a great deal of evidence through technical reports and the testimony of witnesses about a wide range of potential stressors that may have caused or contributed to the two-decade decline of Fraser River sockeye salmon. I also received thoughtful and articulate submissions from participants and interested members of the public on these issues. I have given careful consideration to this evidence and these submissions. In this chapter of the Report I analyze this evidence and reach conclusions respecting the causes of the decline. However, before doing so I first discuss two preliminary matters:

- my understanding of "the decline"; and
- the findings of Dr. Randall Peterman and Dr. Brigitte Dorner, authors of Technical Report 10, Production Dynamics, that declines in sockeye productivity since the late 1980s or early 1990s have occurred over a much larger area than just the Fraser River system.

The "decline"

The preamble to the Terms of Reference speaks generally about "the decline in sockeye salmon stocks in the Fraser River" without referencing a specific time period, and states that this 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." It also

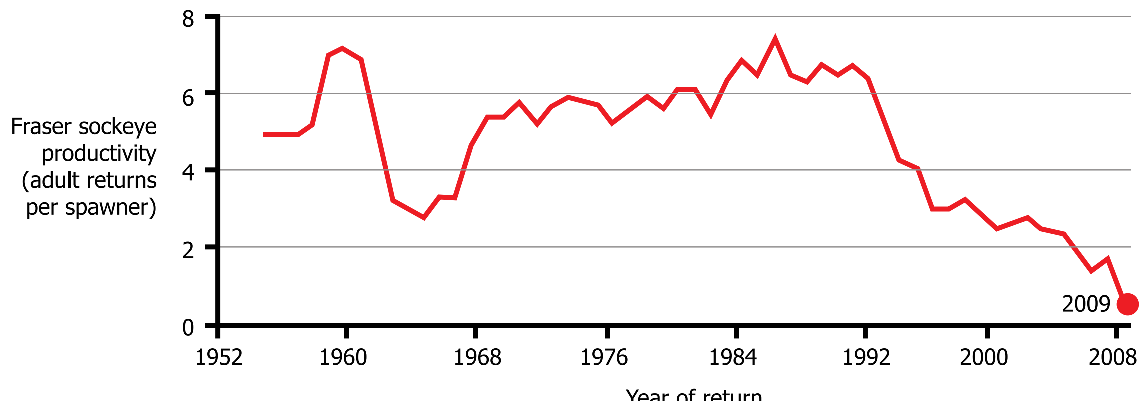

Figure 2.5.1 Fraser River sockeye adult returns per spawner, 1950s–2009

Notes: This productivity chart compares the number of adults returning to spawn (recruits) with the number of spawning adults four years previously. If the number of progeny is less than the parental numbers, the stock would appear to be in decline.
Source: Reproduced from Exhibit 11, p. 2.

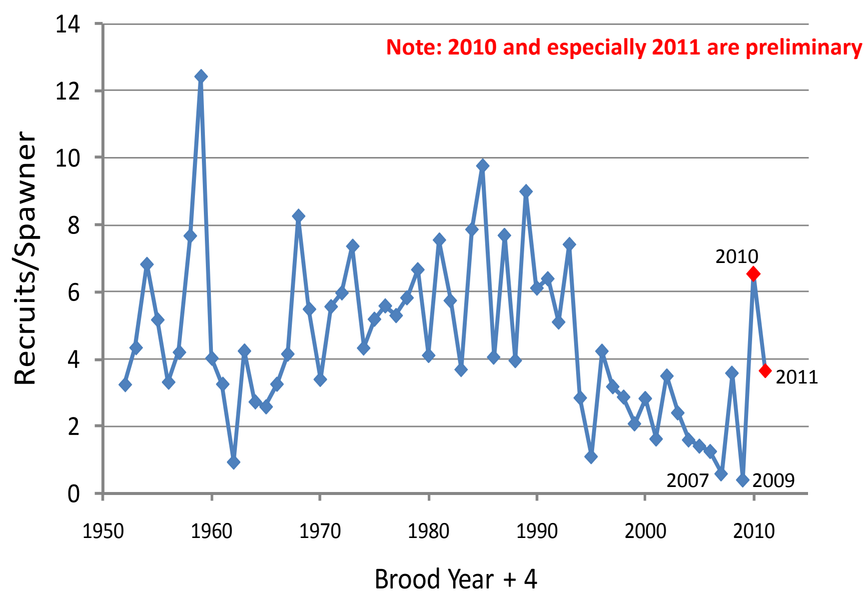

Figure 2.5.2 Annual variation in total Fraser River sockeye productivity, 1952–2011

Note: This figure shows the annual variation in recruits per spawner while Figure 2.5.1 shows the four-year moving average, resulting in a smoother graph.
Source: Exhibit 1851.

refers to fishery closures in three consecutive years (2007, 2008, 2009), the last of which occurred despite favourable pre-season estimates of the number of sockeye salmon expected to return to the Fraser River.

In my Interim Report, I illustrated this decline by means of a productivity chart showing Fraser River sockeye adult returns per spawner indicating a steady and profound decline between about 1990 and 2009 (see Figure 2.5.1).

Now that preliminary results of the 2010 and 2011 returns are available, an updated chart shows a dramatic improvement in productivity (see Figure 2.5.2).

An alternative way to illustrate the decline is through data relating to abundances, or annual Fraser River sockeye salmon returns, as shown in Figure 2.5.3.

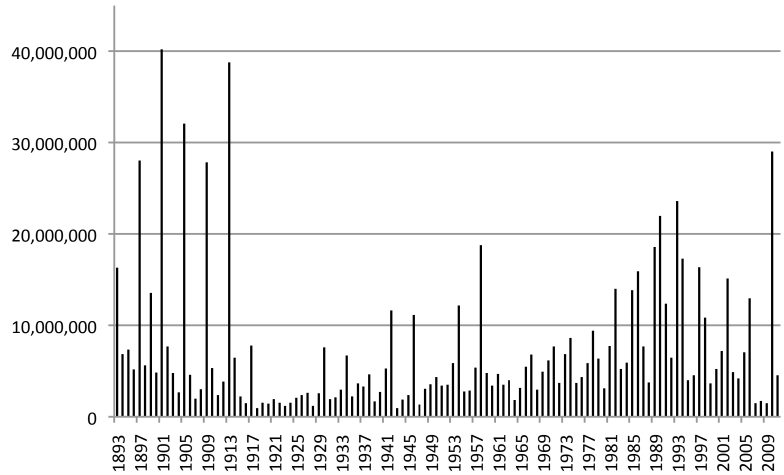

Figure 2.5.3 Total Fraser River sockeye returns, 1893–2011

Note: The 2011 estimate is preliminary.
Source: Exhibit 1967, p. 4.

This chart of abundances shows that between 1893 and 1913 there were extraordinarily good returns every four years, but returns of well under 10 million in most intervening years. Since the Hell's Gate rockslide occurred in 1913, returns have gradually increased from about 2 million to about 8 million, with several dominant-year exceptions. Then, beginning in the late 1970s, there was a significant increase in abundances until about 1992, peaking at about 24 million. Beginning in about 1993 and continuing until 2009, there was a steady and profound decline. However, when viewed in the larger context, the 1993–2009 decline began from the highest level of returns in 80 years.

The abundance chart also shows that the dismal 2009 return of 1.36 million (the worst since the 1940s) was preceded by only marginally better returns in 2007 and 2008, with returns of 1.51 and 1.75 million, respectively. The Terms of Reference and many witnesses singled out 2009 as an exceptionally bad year, not because the return was so poor in absolute numbers, but because it fell so far short of the pre-season forecast of 11.4 million. Although the 2009 return was only 13 percent of the forecast, it is worth noting that the 2007 return was the second-worst in recent decades, at only 24 percent of the forecast. The abundance chart also illustrates how unpredictable returns have been in recent years.

The productivity and abundance charts tell another important story: the 2010 return of 29 million (the largest return since 1912), and the 2011 return of more than 5 million based on preliminary data (approximating the historical average back to 1913). What do we make of these numbers? Has the decline reversed itself? It should be remembered that this recent rebound was not consistent across all stocks – many small stocks from the Upper Fraser River have not fared well. Also, two years' worth of data do not establish a trend, but at the same time the returns of those two years cannot be ignored. Given the importance of cyclic dominance in several Fraser River sockeye stocks, it will require at least two more years' returns before conclusions about trends will be prudent. However, the 2010 and 2011 returns are an important factor to bear in mind when discussing the 1993–2009 decline.

The widespread decline in sockeye salmon productivity

As described in Chapter 4, Dr. Peterman and Dr. Dorner obtained data on abundance of spawners and their resulting adult returns for a total of 64 sockeye populations from Washington State,

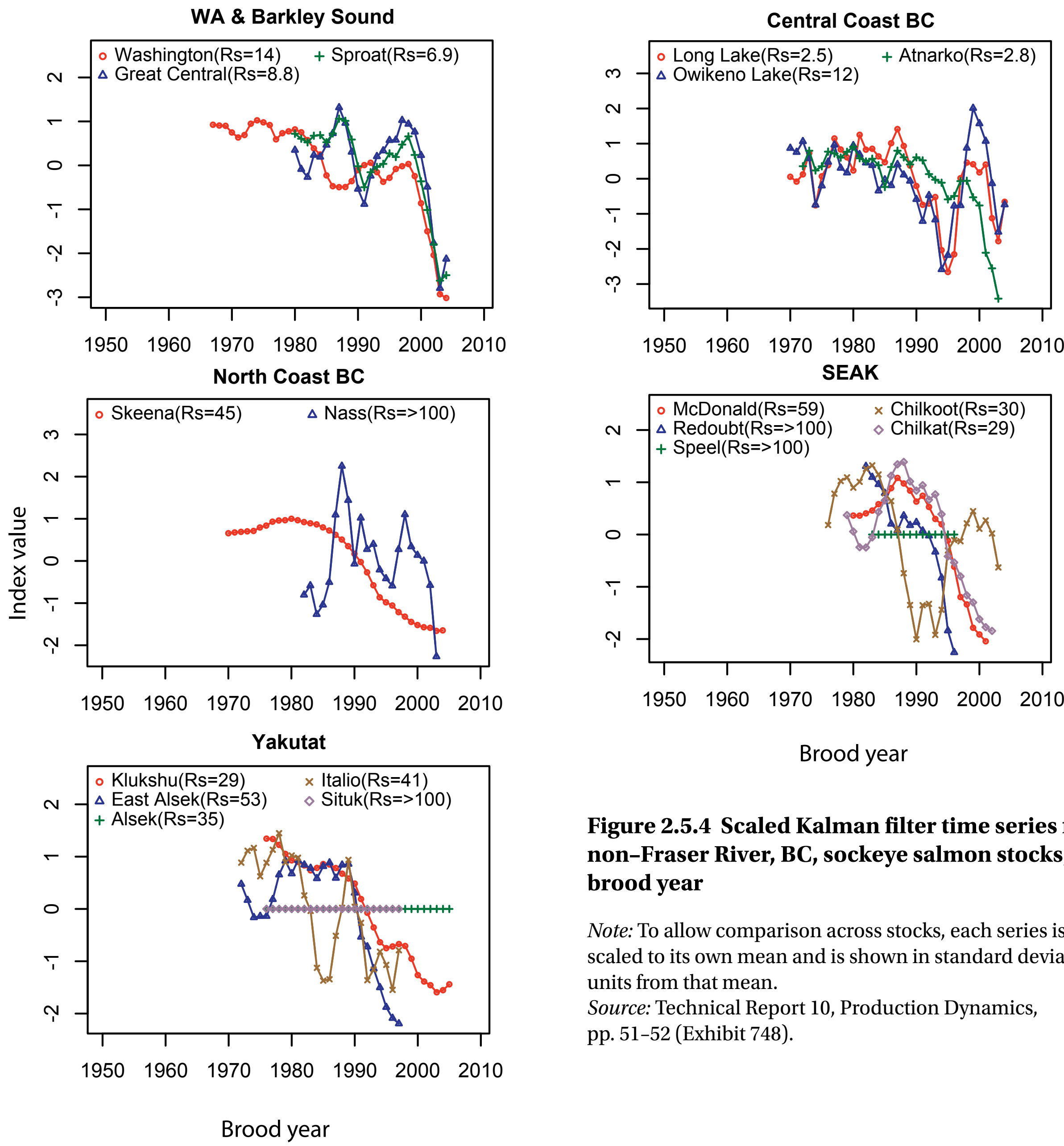

Figure 2.5.4 Scaled Kalman filter time series for non–Fraser River, BC, sockeye salmon stocks, by brood year

Note: To allow comparison across stocks, each series is scaled to its own mean and is shown in standard deviation units from that mean.
Source: Technical Report 10, Production Dynamics, pp. 51–52 (Exhibit 748).

British Columbia, and Alaska. They found that most Fraser River and many non–Fraser River sockeye stocks, both in Canada and the United States, show a decrease in productivity, especially over the past decade and often also over a period of decline starting in the late 1980s or early 1990s. This decrease includes several stocks that migrate along the west coast of Vancouver Island. Their analyses described the extent to which time trends in productivity are similar across sockeye salmon stocks, but the causes for that similarity were not investigated. The researchers' findings are set out in Figure 2.5.4.

In their view, the large spatial extent of similarities in productivity patterns suggests that mechanisms which operate on larger, regional spatial scales, and/or in places where a large number of correlated sockeye stocks overlap, should be seriously examined.

Dr. Peterman and Dr. Dorner raised the possibility that these large regional-scale patterns might be coincidental and that it is conceivable that, just by chance, processes that have operated independently in each sockeye population outside the Fraser River system (such as contaminants, pathogens, and predators) led to decreasing trends in productivity similar to the trends within the Fraser River. However, the researchers thought it much more likely that some shared trend occurs across these populations, causing a downward trend in productivity of all these stocks simultaneously. In testimony, Dr. Peterman suggested that these could be things such as predators, pathogens, or oceanographic patterns driven by climate processes.[1]

Assessment of the evidence

In the field of law, lawyers and judges ask whether the evidence led at a trial "proves" the case. In a civil trial, the plaintiff must prove his or her case on the balance of probabilities – that is, the judge or jury must be satisfied that the plaintiff's version of events is more likely than not true. In a criminal case, the prosecution must prove the accused's guilt to a much higher standard – beyond a reasonable doubt.

In this Inquiry, I have not conducted a trial, and in relation to making findings of fact regarding the causes of the decline, it would not be appropriate in my view to apply either the civil or the criminal standard of proof set out above. Rather, I use terms that express likelihood or degrees of certainty to describe the strength or weakness of the evidence, as did many of the authors of technical reports and other witnesses who testified during our hearings.

Life stage 1: incubation, emergence, and freshwater rearing

This 20-month life stage consists of about five months' incubation as eggs in the gravel, two to three additional months in the gravel as alevins, and about 12 months (or in some cases two years) living in a nursery lake as fry. It is the most precarious stage of the life cycle – in the case of a spawning female who lays 3,000 eggs, it is estimated that only about 420 survive through the fry stage.

Incubation

Eggs and alevins are susceptible to predation by cutthroat trout, rainbow trout, steelhead trout, and sculpins. I accept the evidence of the authors of Technical Report 8, Predation, that several of these species have recently either declined or not increased in abundance (steelhead trout, sculpins), which makes it unlikely that they are responsible for the decline. For the others (cutthroat trout, rainbow trout), there is little available information about abundance and trends in abundance, from which I conclude that it is not possible to evaluate their role in the decline of Fraser River sockeye salmon survival.

In deciding whether climate change may have been a factor in the decline, several known consequences of climate change must be considered. I accept the following evidence from Technical Report 9, Climate Change:

- *Increased water temperature.* The survival of sockeye eggs has been shown to be the highest when the river water temperature is about 8°C, and to decline under cooler and warmer temperatures. At present, the typical temperature during incubation is about 5°C. Although there is evidence that the temperature of the Fraser River is now 2°C warmer than 60 years ago, it does not appear that average stream temperatures through winter and spring have become warmer than 8°C throughout the Fraser River watershed. Consequently, I accept that it is unlikely that recent changes in river water temperature have resulted in increased mortality of eggs and alevins.
- *Increased precipitation.* In British Columbia, precipitation has increased by 22 percent per century, especially in the interior, and more of it now occurs as rainfall. Warm winters and springs since the 1950s have caused earlier snowmelt and, hence, an advance in the spring freshet. It has been suggested that in recent decades increased rain precipitation may have led to an increase in the mortality of eggs due to scouring, especially in the interior. Scouring may be aggravated because returning adult Fraser River sockeye salmon are now smaller than in the past, meaning that their eggs are buried in shallower nests. On the other hand, increased precipitation means an increased

area for spawning, which may result in lower levels of mortality due to egg superimposition. In the absence of quantitative evidence of recent widespread increased scouring of spawning beds, I conclude that it is not possible to evaluate its role in the decline. However, that same absence of evidence means that increased precipitation cannot be ruled out.

The authors of Technical Report 3, Freshwater Ecology, examined six categories of human activities that have potential to affect sockeye salmon during their freshwater life stages; forestry, mining, hydroelectric projects, urbanization upstream of Hope, agriculture, and water use. They identified, in my view, a series of plausible explanations by which such human activities might have contributed to the decline of Fraser River sockeye salmon during incubation (although none of these actual mechanisms was evaluated by the analyses). For example:

- Road construction during forestry operations interferes with the natural patterns of water flow through a watershed. As water drains across exposed road surfaces, increased sediment is carried into streams and can cover spawning redds and reduce oxygenation of incubating eggs.
- Placer mining has a potentially severe impact on sockeye salmon because many alluvial deposits are closely associated with existing streams, and because water is often used to separate placer minerals from the gravel matrix.
- Dams can disrupt the gravel supply to downstream reaches if sediment is trapped in a reservoir. This disruption in gravel supply can have negative effects on channel integrity and the quality of salmon habitat.
- Roads, stormwater runoff, and municipal and industrial effluents have been known to alter water quality in watercourses across the Fraser River basin by changing concentrations of sediments, nutrients, and contaminants.
- Livestock grazing and crop production can lead to physical alterations of streams, riparian zones, and flood plains.
- Extraction of groundwater for irrigation can reduce flows into streams, increasing water temperatures that affect salmon adults and eggs.

I also accept the evidence of several witnesses to the following effect:

- There are a number of potential forestry-related impacts on Fraser River sockeye habitat that can influence stream flow, erosional process, and changes to riparian environments. However, Dr. Peter Tschaplinski, research scientist with the BC Ministry of Environment, testified that forestry practices have improved greatly during the recent 20-year sockeye decline. I conclude from his testimony that these factors are unlikely to have caused the decline.
- Salvage logging in response to the mountain pine beetle epidemic can increase peak water flows, affecting flooding, channel stability, and fish habitat. The evidence indicates that the impacts of the mountain pine beetle epidemic on fish–forestry interactions in the future are unknown.
- Dr. Michael Bradford, research scientist with the Department of Fisheries and Oceans (DFO) and Simon Fraser University, qualified at the hearings as an expert in aquatic habitat ecology, testified that surface water withdrawals limit access to spawning and rearing habitat, interrupt the passage of adults to spawning grounds, and contribute to high water temperatures during summer migration. Similarly, Dr. Steve MacDonald, a research scientist with both DFO and Simon Fraser University, and qualified at the hearings as an expert in aquatic habitat ecology, said that groundwater extraction can aggravate the freezing of streams and, in summer, prevent the cooling influence on spawning grounds.
- Michael Crowe, section head, Oceans, Habitat and Enhancement Branch (OHEB), BC Interior, testified that agriculture affects fish habitat through runoff of pesticides and fertilizers, water extraction, trampling of riparian areas by cattle, ditching, diking, and stream channelization.
- Road and highway construction and other linear development can create fine-sediment pollution that can cause direct mortality, reduce reproductive success, and reduce food availability for fish.

Emergence and freshwater rearing

I heard evidence that coho and chinook salmon potentially prey on small sockeye fry given co-occurrence; that cutthroat trout, steelhead trout, and bull trout are known to prey on sockeye fry in or near Lake Washington; and that a significant proportion of the annual diet of large northern pikeminnows consists of sockeye. However, I accept the evidence of the authors of Technical Report 8, Predation, that some of these species have recently declined in abundance (either naturally or through eradication programs). Their decline makes it unlikely that these species have contributed to the sockeye decline. For the others, there is little available information about abundance and trend in abundance, from which I conclude that it is not possible to quantify their eventual role in the decline of Fraser River sockeye salmon survival. The lack of abundance and trend in abundance estimates for several introduced species known to prey on sockeye salmon, such as smallmouth and largemouth bass and yellow perch, makes it difficult to determine their impact on sockeye survival trends.

During life in nursery lakes, fry may be exposed to warmer water temperatures occasioned by climate change. The authors of Technical Report 9, Climate Change, concluded that if water temperatures in Fraser River rearing lakes have paralleled warming trends of the river in the summer, then fry now experience temperatures approximately 1°C warmer than 20 years ago. There is evidence that, while warmer lake water temperatures may have increased predation rates, sockeye fry are able to move to cooler depths to avoid otherwise lethal temperatures at the surface. I accept this evidence, and conclude that it is unlikely that warming nursery lake temperatures have contributed to the recent decline in Fraser River sockeye abundances, since there is evidence of compensatory measures that sockeye fry can take.

I accept the evidence that infectious diseases and parasites are a known risk to Fraser River sockeye salmon during this life stage. Pathogens can easily be transmitted among fish in the water environment, and the degree of transmission increases with increased density of fish in water (e.g., streams, spawning channels, and nursery lakes). In addition, high water temperature has been documented to cause stress in fish and to reduce their general immune status, and to dramatically increase the replication rate of parasites, all of which lead to increased susceptibility to disease, especially in freshwater. Pollution and contaminants compound these problems.

The author of Technical Report 1, Infectious Diseases, identified several pathogens as posing either high or moderate risk to Fraser River sockeye juveniles – infectious hematopoietic necrosis (IHN) virus (high risk), three bacteria (two high risk and one moderate risk), two protozoa (one high risk and one moderate risk), and one myxozoa (high risk). I accept the evidence that these pathogens have been present in the Fraser River for many years, and that, when outbreaks occur, they can have a devastating impact. For example, a 1989 study documented that an outbreak of the IHN virus caused 50 percent mortality in sockeye salmon in the Weaver Creek spawning channel, in a population of about 17 million fish.

Dr. Kristina Miller's ongoing research into a mortality-related genomic signature found that, in 2008, 82 percent of sockeye smolts left the Fraser River with the signature in at least one tissue.* Her work also found a significant reduction in prevalence of the signature in fish by the fall, suggestive of early marine mortality. The earliest in the life cycle that this mortality-related signature has been identified was in November, in freshwater, before fish were going to smolt. It was believed that the genomic signature associated with elevated mortality is in response to a virus, which she hypothesized to be a parvovirus. At the time of the hearings, Dr. Miller and her colleagues were trying to determine whether the virus is infectious and whether there is a disease associated with the virus.

Life stage 1 findings

I find that there are plausible mechanisms during the incubation, emergence, and freshwater-rearing

* Dr. Kristina Miller is the head of the Molecular Genetics Section, Salmon and Freshwater Ecosystems Division, Science Branch, Pacific Region, DFO. During the hearings, I qualified her as an expert in molecular genetics, immunogenetics, and functional genetics, with a specialty in salmon (Transcript, August 24, 2011, p. 1).

parts of life history stage 1 by which numerous freshwater stressors, such as effluent, contaminants, predators, warming streams and lakes, infectious diseases, agriculture, and surface and groundwater extraction may have contributed to the decline. Although these mechanisms are understood, there is insufficient evidence about the actual impacts these stressors, either singly or cumulatively, have on Fraser River sockeye during this life history stage.

That knowledge gap means it would be premature to eliminate these stressors from a possible role in the decline. It is also possible that, based on the whole of the evidence I heard, the cumulative effect of numerous stressors could have passed a threshold, thereby contributing to the decline directly or by affecting survival at later life history stages.

The evidence does not permit me to conclude whether an outbreak of pathogens triggered the decline in Fraser River sockeye stocks in the early 1990s, or whether they are responsible for the ongoing decline until 2009. Nevertheless, the risk that these pathogens pose is of concern, especially in light of the evidence that warming freshwaters, pollutants, and contaminants in the Fraser River basin can collectively reduce the immunocompetence of the fish host, making sockeye more susceptible to disease.

Dr. Miller's identification of a mortality-related genomic signature in Fraser River sockeye smolts leaving the river (and identified even earlier in the life cycle) and in the marine environment warrants, in my view, further investigation relating to causes and prevalence of this genomic signature. I make other findings related to the genomic signature below.

Life stage 2: smolt outmigration

In May, about 20 months after spawning, fry begin a process called smoltification, a physiological change facilitating the transition from life in freshwater to life in seawater. They move out of their nursery lakes and into the Fraser River, where they migrate downstream to the estuary and into the marine environment of the Strait of Georgia. This downstream migration varies from 40 km to about 1,200 km.

I was told that, of the 420 fry that survive out of a brood of 3,000 eggs, nearly 300 die, leaving only about 120 smolts. Many witnesses regretted the absence of reliable data about rates of mortality during the downstream migration; during residency in the Strait of Georgia; during northward migration through Johnstone Strait and Queen Charlotte Strait, and into Queen Charlotte Sound; and along the continental shelf and into the deep waters of the North Pacific Ocean.

The authors of Technical Report 8, Predation, Dr. Villy Christensen and Dr. Andrew Trites, examined animals that might prey on sockeye salmon smolts. They identified several endemic and introduced fish species known to feed on juvenile salmonids as smolts. However, because there is little information about abundance and trends, I cannot draw any conclusion about whether they have caused or contributed to the decline. The common merganser, the double-crested cormorant, and the Caspian tern are all known predators on juvenile salmon. However, there is no indication that any of these birds has increased in abundance in recent decades, making it unlikely that they have played a major role in the decline. The harbour seal is the only marine mammal that has been documented feeding on salmon smolts in Fraser River freshwater and estuarine habitats, and several public submissions blamed harbour seal predation for contributing to the decline. Increases in harbour seal abundances during the 1990s might suggest that there is a relationship between them and the decline. However, harbour seals also increased in numbers during the 1980s, when Fraser River sockeye salmon abundances increased, which is a confounding pattern. In any event, the researchers reported that direct observations of feeding showed predation on chum, coho, and chinook, but not sockeye, leading me to conclude that harbour seals have not posed an increasing threat to Fraser River sockeye salmon since the early 1990s.

The authors of Technical Report 3, Freshwater Ecology, identified several human activities that have the potential to affect sockeye salmon during their downstream migration. I heard evidence that more than 250 log storage leases cover more than 860 hectares within the Fraser River estuary. Logs can scour nearshore habitats, and wood and bark debris can affect food sources and increase concentrations of potentially toxic log leachates. Although large-scale hydroelectric projects can place great stress on individual Conservation Units (CUs), the two projects that could affect Fraser River sockeye predate the decline. Only a small number of independent power projects have been built close to sockeye salmon spawning grounds or migration corridors. The evidence from this technical report does not support a conclusion that log storage practices, large-scale hydroelectric projects, or independent power projects have had a significant negative effect on the downstream migration of most Fraser River sockeye stocks.

Several pathogens are known to be present in the two types of salmonid enhancement facilities (hatcheries and spawning channels). Technical Report 1A, Enhancement Facility Diseases, identified several ways in which such pathogens can move from salmonid enhancement facilities to wild sockeye salmon, such as through the transfer or release of enhanced fish, or the release of water or wastes contaminated with pathogens from hatcheries and spawning channels into fish–bearing waters. I find that fish with known infectious diseases have been released into fish-bearing waters, and that treated fish have been released without verification that the treatment was effective. However, the data currently collected do not reflect the infection status of a hatchery population as a whole or allow estimates of rates of disease. It is not known what effect, if any, a pathogen of enhancement facility origin might have on Fraser River sockeye salmon productivity. This weak evidence precludes me from concluding that diseases associated with salmonid enhancement facilities have been transmitted to Fraser River sockeye or that, if they have been, disease transmission has affected their production during the past two decades. There is, however, a risk that this transmission has occurred, and it needs to be addressed.

The authors of Technical Report 2, Contaminants, developed an inventory of aquatic contaminants for the Fraser River basin and evaluated the potential effects of those contaminants on Fraser River sockeye. They were satisfied that the greatest potential impact of these contaminants occurs during the smolt downstream migration. Although lead author Don MacDonald testified that there are virtually no data for spawning and rearing areas, Dr. Robie Macdonald, section head, Marine Environmental Quality, Institute of Ocean Sciences, testified that when salmon return to their spawning lake or stream, they bring back contaminants and deposit them in the watershed. The authors identified more than 200 substances that may be released into aquatic ecosystems from the numerous land uses they identified. From these, they identified 23 chemicals of potential concern measured in surface water at concentrations sufficient to pose potential risks to sockeye salmon eggs, alevins, fry, smolts, or adults. Through further refinement, they identified 17 substances in surface water, five substances in sediment, and several other substances with the potential to accumulate in the tissues of sockeye salmon, all of which occur at concentrations sufficient to cause or substantially contribute to adverse effects on the survival, growth, or reproduction of sockeye salmon in the Fraser River basin. However, the authors concluded that the available limited data do not implicate measured water quality conditions as a major factor influencing recent trends in Fraser River sockeye salmon abundance. They also cautioned:

- Numerous contaminants of concern occur in one or more habitats at concentrations sufficient to adversely affect the survival, growth, or reproduction of sockeye.
- Bioaccumulation of contaminants in fish tissues has the potential to adversely affect the productivity of sockeye salmon, although the magnitude and extent of such effects could not be determined with the available data.

The researchers then undertook a qualitative evaluation of potential effects, summarized here.

- *Endocrine-disrupting compounds.* Many of the substances released into the environment as a result of human activities have the potential to disrupt the endocrine system of aquatic organisms, interfering with reproduction, development, and behaviour. In fish, these substances may lead to abnormal thyroid function, decreased fertility, and decreased hatching success. These chemicals are found in pharmaceutical products, industrial chemicals, and pesticides, and are most likely to be observed in municipal wastewater treatment plant effluents, pulp and paper mill effluents, and areas with high industrial / chemical contamination. I accept the researchers' conclusion that it is unlikely that reproductive effects associated with exposure to endocrine-disrupting compounds are sufficient to explain the declines in Fraser River sockeye salmon abundance over the past two decades, for several reasons: pulp and paper mill effluents have decreased; exposure during downstream migration may be insufficient to elicit significant reproductive effects; and there is little evidence for differential response among stocks that possibly receive different exposures to such compounds. Nevertheless, I agree it is possible that exposure to endocrine-disrupting compounds may lead to reduced immunocompetence, which may reduce the capacity of smolts to transition from freshwater to saltwater. That diminished capacity could have contributed to long-term declines in sockeye abundance.

- *Contaminants of emerging concern.* This term refers to a broad group of chemicals described in Technical Report 2, Contaminants, that were previously unknown or not previously recognized as being of concern relative to human or environmental health. They include veterinary and human antibiotics, prescription drugs, sex and steroidal hormones, and wood preservatives. I accept the researchers' conclusion that the paucity of data on toxicity and exposure makes it difficult to evaluate the risks to Fraser River sockeye. However, these contaminants are a significant environmental concern that needs to be addressed, and they could be causing or substantially contributing to the decline of Fraser River sockeye.

The authors of Technical Report 2, Contaminants, have made an important contribution to our understanding of a complex set of issues. They acknowledged that, in many areas, there is insufficient evidence to make definitive findings; and their analysis and conclusions, which were not challenged during the evidentiary hearings, were appropriately cautious. I agree that, based on our limited understanding, exposure to measured contaminants in surface water and sediments does not appear to be a primary factor influencing the productivity or abundance of Fraser River sockeye salmon over the past 20 years. However, risks have been identified concerning endocrine-disrupting compounds and contaminants of emerging concern.

In closing submissions, several participants commented on the role of human activities in freshwater on the decline of Fraser River sockeye. The Province of British Columbia agreed with Technical Report 3, Freshwater Ecology, which stated that recent declines of Fraser River sockeye are unlikely to be the result of changes in the freshwater environment. The province added that gravel removal, forestry, urbanization, municipal wastewater, pulp and paper effluent and mining effluent, hydroelectric projects, and water temperature did not contribute to the decline. The Conservation Coalition stated that the freshwater environment and what may be occurring there ought not to be ignored for the purposes of finding answers, and the First Nations Coalition submitted that the weight of the evidence supports the reasonable conclusion that cumulative or multiple stressors in freshwater environments are contributing to the longer-term decline.

Life stage 2 findings

I find that the evidence has identified numerous stressors to which Fraser River sockeye are exposed during life history stage 2, such as pathogens originating in the salmonid enhancement facilities that can be transmitted to wild salmon stocks; and aquatic contaminants, especially endocrine-disrupting compounds and contaminants of emerging concern. The evidence identifies plausible mechanisms by which these stressors may negatively affect outmigrating smolts, but, as with life stage 1, there are knowledge gaps relating to their actual impact – the research has not been done.

However, as one witness emphasized, absence of evidence should not be interpreted as evidence of absence. It would be premature for me to rule out these stressors in the Fraser River sockeye decline.

One of the glaring data gaps is our ignorance of mortality rates during the downstream migration. Long-term time series data exist for only two smolt populations (Chilko and Cultus lakes), but once smolts leave their nursery lakes, we have no way of knowing how many die before they reach the Strait of Georgia. To identify the greatest risks to survival, it is important to understand rates of mortality on a life stage basis.

We also do not know the health status of many juveniles in rearing lakes or of those smolts that do survive the downstream migration. We know that they are exposed to predators, pathogens, diseases, and contaminants, and although these stressors may not cause immediate death, they may compromise the health of smolts so that they are less able to survive life in the marine environment. Based on Technical Report 2, Contaminants, and other expert testimony, it may be that exposure to contaminants of concern, endocrine-disrupting chemicals, and/or contaminants of emerging concern have contributed to the decline in ways that are not fully understood at this time. I share the researchers' concern that these contaminants may compromise the immune system, that this exposure represents a serious concern for outmigrating sockeye smolts (especially when combined with warmer water temperatures and/or pathogens), and that further research is warranted.

Life stage 3: coastal migration

Environmental conditions and food availability

After leaving the river, it is believed that most Fraser River sockeye juveniles turn north and migrate through the Strait of Georgia, Johnstone Strait, Discovery Passage, and Queen Charlotte Strait, and into Queen Charlotte Sound. There is some evidence that the Harrison River population may spend the remainder of its outward migration year in the Strait of Georgia, and may then migrate south of Vancouver Island through Juan de Fuca Strait to the west coast of Vancouver Island and then northward to Queen Charlotte Sound. Others may migrate through Juan de Fuca Strait immediately. Those that migrate through Queen Charlotte Sound enter the North Pacific Ocean, swimming north and westward in a band within 35 km of the coasts of British Columbia and Alaska, until they reach the overwintering grounds.

The authors of Technical Report 8, Predation, examined several fish species known to prey on sockeye smolts, but concluded that they were unlikely to have been important in the decline either because the abundance of those predators has been in decline over the past decades (chinook and coho) or because there is no evidence that they have recently increased in abundance (spiny dogfish). River lamprey may be an important predator on sockeye postsmolts, but in the absence of abundance and trend estimates, it is not possible to evaluate the effect. The researchers similarly discounted the impact of predation by several bird species, either because there is no evidence of a recent increase in their abundances or because of recent declines in their abundances. Based on their work, it is, in my view, unlikely that predation in the Strait of Georgia has been an important factor in the 1993–2009 decline.

It is clear that human development and activities in the Strait of Georgia have degraded habitat areas and natural environments over the past century through development of residential, recreational, transportation, and industrial lands. Increases in population size and density lead to higher levels of water pollution and to contaminants from wastewater and stormwater runoff. However, what is not so clear is the effect that this habitat degradation has had on migrating sockeye smolts. The authors of Technical Report 12, Lower Fraser Habitat, concluded that there has been a net gain in sockeye habitat during the period 1990–2010, although that conclusion was contradicted by several DFO witnesses who testified that Canada is not achieving no net loss of productive capacity of fish habitat. On this issue, I prefer the evidence of these DFO witnesses over the Technical Report 12 conclusion. In any event, I understand that the Technical Report 12 conclusion is based on the habitat restoration commitments that developers have made as part of development approval processes, rather than on post-development audits and compliance studies. In other words, it is not known how much of the habitat lost as a result of development has actually been restored and, even when restored, how effective the restoration has been. While I am satisfied that there has been a net loss of Fraser River sockeye habitat, the evidence is inconclusive with respect to the effect this has had on sockeye salmon.

I heard evidence (Technical Report 9, Climate Change) that sea surface temperature in the Strait of Georgia has increased at about 0.25°C per decade since the 1950s. Waters are 1.5°C warmer than 60 years ago, and 0.5°C warmer than 20 years ago. I accept that warm sea surface temperatures are associated with reduced upwelling and, hence, potentially low food availability (e.g., zooplankton), which can reduce early marine growth for postsmolts. I also accept that warmer sea surface temperatures can lead to high metabolic rates in sockeye salmon, increase the abundance of non-resident predatory fish, and also increase the metabolic rate of resident predator fish, leading to increased food consumption.

The authors of Technical Report 4, Marine Ecology, and other expert witnesses discussed environmental conditions and their possible impact on food availability during the coastal migration. These discussions lead me to conclude that the initial period of smolt migration could be seen as a race northward to find better feeding conditions in coastal Alaska.

Dr. Richard Beamish, retired research scientist, Salmon and Freshwater Ecosystems, Pacific Biological Station, Science Branch, testified about his initial size / critical period hypothesis: juvenile salmon must grow quickly on entry into the ocean; there are high mortalities in the first six–week period; and the fish that grow the fastest are the larger ones that are able to store more energy in order to survive the harsh winter conditions.

Dr. Jack Rensel, Rensel Associates Aquatic Science Consultants, testified that harmful algal blooms in the Strait of Georgia may have contributed to the long-term decline in Fraser River sockeye.* I accept that exposure of juveniles to *Heterosigma* blooms could result in direct, acute effects or in chronic effects such as infections, making the fish more susceptible to poor food supply conditions and predation.

The author of Technical Report 1, Infectious Diseases, Dr. Michael Kent, reported that the IHN virus has been detected in adult sockeye in seawater and rated the risk as high to Fraser River sockeye. He also identified three bacteria that pose a high risk of serious disease and mortality to juvenile sockeye after migrating to saltwater. The *Parvicapsula minibicornis* parasite is a high risk to smolts shortly after seawater entry but is not detected in older fish in seawater, suggesting that it is linked to parasite-associated mortality in seawater. He rated as moderate the risk from a tapeworm and two sea lice species. I accept his conclusion that the state of the science for understanding the impacts of pathogens on wild salmon in British Columbia is minimal, and it is consequently not possible to conclude that a specific pathogen is the major cause of decline of Fraser River sockeye salmon. However, neither can pathogens be excluded at this time.

In their closing submissions, several participants commented on the role of adverse marine conditions and climate change in the decline. I am including reference to them at this point in my life history stage analysis, although some of them also apply to life history stage 4.

According to Canada, a consensus appears to be emerging among scientists that biophysical changes in the marine environment stand out as the most strongly inferred factors explaining the pre-2010 decline.[2] At the same time, climate change has the potential to affect all life history stages for Fraser River sockeye, which are particularly vulnerable to climate change because the Fraser River watershed is near the southern limit of the distribution of sockeye salmon on the west coast of North America.[3]

The Province of British Columbia, in its submission, stated that the long-term decline in the productivity of Fraser River sockeye is likely attributable to factors related to marine conditions and climate change. It is also likely driven by mechanisms that operate on larger, regional spatial scales (e.g., climate-driven oceanographic changes).[4] This latter point is based on findings in Technical Report 10, Production Dynamics, that most Fraser River and non–Fraser River stocks in Canada and the United States have shown a decrease in productivity, especially over the past decade.

The B.C. Salmon Farmers Association submitted that conditions in the marine environment, including low food abundance, are a likely cause

* Dr. Rensel was qualified as an expert in algal zooplankton and marine and freshwater habitats; harmful algal bloom dynamics; monitoring and mitigation studies; and fish physiology studies, bioassays, and fish kill assessments (Transcript, August 17, 2011, p. 4). His curriculum vitae is Exhibit A to Exhibit 1363.

of the overall Fraser River sockeye decline. The observed decline in sockeye abundance is best explained by climate-driven changes in the marine environment.[5] According to the Seafood Producers Association of B.C., the decline is likely due to a period of poor and declining nearshore and offshore ocean productivity.[6]

The Conservation Coalition said that the current thought is that the decline of Fraser River sockeye can be linked to the marine environment and the early marine survival of the outmigrating smolts.[7] The First Nations Coalition submitted that the weight of the evidence supports the conclusion that the marine environment is a major cause for the overall declining trend in recent years.[8] Climate change is also a contributor to the stressors.

According to the Stó:lō Tribal Council and the Cheam Indian Band, the stressors with the greatest likelihood of being primary factors in the decline of Fraser River sockeye productivity are marine conditions and climate change during the coastal migration and migration to ocean-rearing areas.[9] The Area D Salmon Gillnet Association and Area B Harvest Committee (Seine) submitted that the issue of climate change stands out and deserves special attention, noting that Dr. Scott Hinch, co-author of Technical Report 9, Climate Change, testified that he was hard-pressed to find a greater threat to the stocks than climate change.[10]

Environmental conditions and food availability findings

I find that, during the first four or five weeks after entering saltwater, Fraser River sockeye may encounter a variety of stressors, including predators, pathogens and diseases, harmful algal blooms, low food availability, and degraded habitat. However, in light of the evidence that there are significant gaps in our knowledge about how these stressors actually affect Fraser River sockeye, I am unable to conclude whether these stressors are responsible for the long-term decline.

I heard considerable evidence pointing to marine conditions and climate change during this life history stage as the most likely cause for the decline. It is hypothesized that climate change has resulted in warmer water temperatures in the Strait of Georgia and northward into Queen Charlotte Sound, in increased discharges of freshwater from British Columbia rivers, and in earlier peak timing of the spring freshet. These changes to water properties can affect biological properties. For example, an earlier freshet may result in earlier peak timing of the main zooplankter, while warmer water may mean that the peak duration has shortened. Warmer water can lead to an increase in harmful algal blooms, and to reduced upwelling that in turn can lead to lower zooplankton availability. It also leads to higher metabolic rates that, in times of reduced feeding, result in postsmolts growing more slowly, making them more susceptible to predation. At the same time, warmer water brings in non-resident predators and causes resident predators to consume more.

I find that these are plausible mechanisms that might well lead to increased mortality among Fraser River sockeye during their northward migration, but I do not understand the authors of these technical reports or the other witnesses to assert a cause-effect relationship in relation to the 1993–2009 decline. In the absence of evidence of reliable data concerning rates of mortality during sockeye residence in the Strait of Georgia and in Queen Charlotte Strait and Queen Charlotte Sound, it is not possible to do more than postulate how water and biological properties may have negatively affected smolts over the past 20 years.

Infectious salmon anemia virus

As described in the previous chapter, I find that the evidence does not allow me to conclude whether the infectious salmon anemia virus (ISAv) or an ISAv-like virus currently exists in Fraser River sockeye. I also do not have sufficient evidence to determine whether such an ISAv or ISAv-like virus, if present, is endemic to BC waters or has been introduced.

I accept the opinion of several experts appearing before me that, at present, there has been no evidence that salmon recently tested for ISAv (the virus) suffered from ISA (the disease) as it is now understood. That is not to say that salmon testing positive for ISAv or ISAv-like genetic sequences may not be exhibiting a host response of some form. The results of the research conducted by Dr. Miller and Dr. Brad Davis, a post-doctoral fellow in Dr. Miller's molecular genetics laboratory, indicating a potential influenza-like host response in fish testing presumptively positive for ISAv, suggest that some effect, short of disease and mortality, may be occurring – assuming that what they are detecting is ISAv. However, their research is preliminary, having been completed only one week before the hearings on ISAv. It has not reached a stage that would allow me to make conclusions on whether a host response exists, let alone whether it has contributed to the decline of Fraser River sockeye salmon.

The most that can be said at present is that a plausible mechanism has been identified, creating a risk that ISAv or an ISAv-like virus may have affected the health of Pacific salmon stocks for the past few decades, or that it may mutate in certain circumstances to a more virulent form.

Sea lice

Fraser River sockeye smolts may become infected with sea lice in the marine environment. I accept the evidence of Dr. Simon Jones, research scientist at DFO, and Michael Price, biologist with Raincoast Conservation Foundation, that *Caligus clemensi* (*Caligus*) is the dominant louse species infecting Fraser River sockeye juveniles on their outmigration.* I also accept the evidence of Mr. Price and Dr. Sonja Saksida, a fish veterinarian and executive director of the Centre for Aquatic Health Sciences, that Fraser River sockeye may be more susceptible to infection by the sea lice species *Caligus* than by *Lepeophtheirus salmonis* (*Leps*), with the qualification that more studies need be done to prove this hypothesis.†

The sources of sea lice infecting migrating sockeye juveniles include both wild fish (herring, stickleback) and farmed salmon. I accept the evidence that Atlantic salmon farms may be a significant source of *Leps* infection for outmigrating smolts. The evidence is less clear for *Caligus*. I accept the evidence of Mr. Price that Fraser River sockeye juveniles downstream of salmon farms have a greater *Caligus* lice load than upstream; however, the whole of the evidence before me presents different explanations for why that is so (e.g., increased time spent in seawater, exposure to salmon farms, or exposure to other natural sources of *Caligus* infection). I do accept that salmon farms may be one of many sources of *Caligus* infection.

The evidence establishes that *Leps*, in high numbers, can have a negative effect on sockeye, even causing death, especially in combination with poor environmental conditions, as was shown in the 1990 study of Alberni sockeye returning adults. However, I accept the evidence in Dr. Kent's report and described by Dr. Jones that the most recent (2010) numbers for prevalence and intensity of *Leps* on Fraser River sockeye juveniles are not a cause for concern. So long as *Leps* levels on Fraser River sockeye stay low, they are unlikely to pose a significant threat at a population level.

The evidence also establishes an absence of scientific information about the effect of *Caligus* infection on sockeye. There was a consensus among the scientists from whom I heard that *Caligus* infection presumably has some negative effect on sockeye hosts, but that effect is likely to be of lesser magnitude than *Leps* infection. I accept the evidence of Dr. Jones and Dr. Craig Orr, executive director of Watershed Watch Salmon Society, that more work is needed into the thresholds of sea lice infection and resilience in sockeye generally, and into the patterns of sea lice (especially *Caligus*) distribution and infection on juvenile sockeye.‡

I accept the evidence of Dr. Saksida; Dr. Jones; Dr. Donald Noakes, author of Technical Report 5C, Noakes Salmon Farms Investigation; Dr. Lawrence Dill, author of Technical Report 5D, Dill Salmon Farms Investigation; and Dr. Orr, that sea lice may act as a vector for other pathogens causing disease.§ However, I also accept that this vectoring is

* Dr. Jones was qualified as an expert in parasitology and immunology with a specialty in sea lice and diseases of salmon, including as this relates to farmed and wild salmon (Transcript, September 6, 2011, p. 2), and Mr. Price was qualified as an expert in juvenile salmon ecology in relation to sea lice infestation.

† Dr. Saksida was qualified as an expert in veterinary medicine and veterinary epidemiology with a specialty in fish health.

‡ Dr. Orr was qualified as an expert in ecological sciences with a research focus on sea lice affecting farmed and wild salmon.

§ Dr. Noakes was qualified as "an expert in salmon population dynamics, including wild salmon / farmed salmon interactions, fisheries climate interactions and in statistical analysis including time series analysis" (Transcript, August 25, 2011, p. 69). Dr. Dill was qualified as "an expert in behavioural ecology, predator / prey relationships and ecological factors affecting wild fishes, including parasites and fish farms" (Transcript, August 25, 2011, p. 71).

"accidental" in that it is not necessary for pathogen transfer, and that transmission through water is a more effective means of transmission. I agree with those researchers who told me that, because of its "accidental" nature, vectoring by sea lice is unlikely to have a great impact on Fraser River sockeye.

I also accept the consensus of the witnesses that sea lice acting alone did not cause the decline of Fraser River sockeye salmon. But I cannot ignore the evidence that sea lice acting in combination with other factors (such as other pathogens or poor environmental conditions like increasing water temperature) may have contributed to the decline.

Salmon farms

I accept the evidence of Dr. Dill and Dr. Noakes that wastes and chemicals discharged at salmon farms are unlikely to have any population level effects on Fraser River sockeye. I also accept their evidence that escaped Atlantic salmon are unlikely to have any impact on Fraser River sockeye given that they are not spawning in streams frequented by sockeye and are not competing with sockeye for food. On the subject of diseases on fish farms, there was little agreement between Dr. Dill and Dr. Noakes, other than that both of them said more research is needed into the effects of diseases on wild salmon. I agree. Without such work, scientists and managers alike are left speculating about the real effects that the diseases found on fish farms have on wild stocks such as sockeye.

The potential risk of disease spreading from farmed to wild salmon and how to describe that risk is the main difference between Dr. Dill and Dr. Noakes, and one on which other witnesses also commented. Of all the expert witnesses I heard from, *no one* told me there is no risk to sockeye; indeed, some said the risk could never be "zero," and others told me that salmon farms do increase the risk when compared with no salmon farms. Those (like Dr. Noakes) who ventured to quantify the risk told me it was "low" as a result of proactive policies and practices. Others (like Dr. Dill) did not believe the state of information was such that the risk could be quantified and said that disease on salmon farms could not be ruled out as posing a significant threat to Fraser River sockeye.

I accept the undisputed evidence that there is *some* risk posed to wild Fraser River sockeye salmon from diseases on salmon farms. I also accept that management practices are intended to reduce that risk as much as possible and aim to keep both farmed and wild fish healthy. I agree with Dr. Noakes that the current regulatory data collected for the salmon-farming industry need to be maintained and that future work should focus on understanding diseases in wild fish. However, I am unable to agree with him that salmon farms pose a low risk to wild sockeye: I cannot make that determination on the evidence before me. I accept the evidence of Dr. Josh Korman, author of Technical Report 5A, Salmon Farms and Sockeye Information, and Dr. Dill that scientists need at least another 10 years of regulatory data before they can find relationships (if they exist) in the data.* Although the data available to this Inquiry do not suggest that salmon farms are having a significant negative impact on Fraser River sockeye, I am not prepared to conclude, based on that data, that there is a low risk to sockeye from salmon farms. It is simply too early to reach that conclusion. As well, other than a few studies related to sea lice (mostly in species other than sockeye), DFO has not carried out research to look at the effects of pathogens from fish farms on Fraser River sockeye. In short, there are insufficient data – almost no data – on cause-and-effect relationships, and insufficient data (in terms of a time series) to look for correlations between fish farm factors and sockeye productivity. At the same time, there is no evidence before me that diseases on fish farms are out of control or unusually high by industry standards. So, just as I cannot find the risk from salmon farms to be low, I cannot say the risk is high. Precaution would suggest assuming the risk is not insignificant.

I have considered the theory put forward by Alexandra Morton, executive director of Raincoast Research Society, concerning marine anemia on chinook farms, and I am unable to agree with it in light of the contradictory evidence of Dr. Kent; Dr. Gary Marty, fish pathologist at BC's Animal Health Centre; Dr. Mark Sheppard, lead veterinarian

* Dr. Korman was qualified as "an expert in salmonid stock assessment and in statistical analysis, in particular of population level fisheries data" (Transcript, August 25, 2011, p. 62).

Aquaculture Environmental Operations, DFO; and Dr. Peter McKenzie, a veterinarian and the fish health manager for Mainstream Canada, who are all experts in areas of fish health. I do, however, agree with the premise of Ms. Morton's research – that someone (perhaps more than one person, given the disagreements within the field as shown in the evidence on marine anemia by Dr. Kent, Dr. Stephen, and Dr. Sheppard) with expertise in fish health needs to review fish health data from the farms in order to ask these sorts of big-picture questions and encourage open scientific debates. In my view, those sorts of questions will be better asked and answered if scientists, including those not connected with governments or industry, are able to access and assess data of the same level of detail as was disclosed to this Inquiry.

Virus, sea lice, and salmon farms findings

I find that the evidence does not allow me to conclude whether the infectious salmon anemia virus (ISAv) or an ISAv-like virus currently exists in Fraser River sockeye, or whether such an ISAv or ISAv-like virus, if present, is endemic to British Columbia waters or has been introduced. At most, a plausible mechanism has been identified, creating a risk that ISAv or an ISAv-like virus may have affected the health of Pacific salmon stocks for the past few decades.

I accept the evidence that Atlantic salmon farms may be a significant source of *Leps* infection for outmigrating smolts. However, the most recent numbers for prevalence and intensity of *Leps* on Fraser River sockeye juveniles are not a cause for concern. Salmon farms may also be one of many sources of *Caligus* infection, but there is an absence of scientific information about the effect of *Caligus* infection on sockeye. Sea lice may act as a vector for other pathogens causing disease, but I accept the evidence that transmission through water is a more effective means of transmission. I am satisfied that sea lice acting alone did not cause the decline of Fraser River sockeye, but sea lice acting in combination with factors such as other pathogens or increasing water temperature may have contributed to the decline.

I am satisfied that wastes and chemicals discharged at salmon farms, and escapes from salmon farms, are unlikely to have any population-level effects on Fraser River sockeye. I accept the undisputed evidence that there is some risk posed to Fraser River sockeye from diseases on salmon farms, but I cannot make a determination as to the precise level of risk. Therefore, precaution would suggest assuming that the risk is not insignificant. I accept the evidence that scientists need at least another 10 years of regulatory data before they can find relationships (if they exist) between salmon farm factors and Fraser River sockeye productivity.

Life stage 4: growth to adulthood

Growth in the North Pacific

The distribution and movement of immature Fraser River sockeye salmon along the continental shelf and in the deep North Pacific Ocean is the least understood of all life history stages because it is the least researched.

The authors of Technical Report 8, Predation, identified several predators that are known to prey on immature sockeye salmon. Salmon sharks are known to feed on Pacific salmon in Alaska in the spring and summer (although they are opportunistic feeders that prey on many different species), and there is an indication that their abundance has increased in recent decades. I agree with the researchers' conclusion that the only way to reliably evaluate if salmon sharks have had an increasing impact would be to gather more information about open-ocean abundance and trends in abundance. Although blue sharks are more abundant than salmon sharks, they are not likely to have been a major factor in the decline, since their abundance has not increased in recent decades. It is not possible to know whether daggertooth, walleye pollock, or arrowtooth flounder have contributed to the decline, because of inadequate information about abundance and decline.

Sea surface temperature in the Gulf of Alaska has increased about 1.5°C in the past 60 years and 0.5°C in the past 20 years. The authors of Technical Report 9, Dr. Scott Hinch and Dr. Eduardo Martins, attributed most of this warming to the positive phase of the Pacific Decadal Oscillation.* I agree with their conclusion that increased temperatures in the Gulf of Alaska over the past two decades have possibly resulted in lower survival of Fraser River sockeye during open-ocean residence.

The authors of Technical Report 4, Marine Ecology, stated that oceanic and atmospheric climates of the North Pacific have been described in terms of regimes – periods of persistent anomalies that shift abruptly among phases. The common year of decline of Fraser River and several other sockeye salmon stocks was the 1992 ocean-entry year. I agree that the coincidence of a shared change in sockeye salmon productivity in 1992 suggests that these stocks were affected by a relatively large-scale coastal influence that had a more persistent effect on stocks using Queen Charlotte Sound and Queen Charlotte Strait.

The researchers also reported that the sea provides only limited amounts of food for growing sockeye salmon. For example, a 1990 study found that Bristol Bay sockeye were smaller when the total abundance of sockeye in the Gulf of Alaska was greater, and the same was true for Fraser River sockeye salmon. Dr. Stewart McKinnell, lead author of Technical Report 4, Marine Ecology, testified that the mean size of sockeye gets smaller in two circumstances – when the sea surface temperatures in the Gulf of Alaska get warmer and when sockeye abundance is high.

The researchers referred to evidence that Fraser River sockeye salmon are significantly smaller in brood years that mature in odd years. As the odd / even cycle of abundance of pink salmon in the Fraser River is potentially a source of competition for Fraser River sockeye returning in the same year, a reduction in mean size in odd years may be a consequence of competition for food with pink salmon during the period of overlap in the Gulf of Alaska.

I accept Dr. Peterman's evidence that wild and enhanced salmon can compete for food because their diets overlap and they are thought to generally pass through feeding areas at similar times and places. Food supply in the North Pacific Ocean has diminished as a result of feeding largely by pink salmon.

I rely on the observation of Dr. Peterman and Dr. Dorner that most Fraser River and many non–Fraser River sockeye stocks, both in Canada and the United States, showed a decrease in productivity, especially over the past decade and often also over a period of decline starting in the late 1980s or early 1990s. This includes several stocks that migrate along the west coast of Vancouver Island. The researchers' analyses described the extent to which time trends in productivity are similar across sockeye salmon stocks, but the causes for that similarity were not investigated. I agree with their view that the large spatial extent of similarities in productivity patterns suggests that mechanisms which operate on larger, regional spatial scales, and/or in places where a large number of correlated sockeye stocks overlap, should be seriously examined.

Return to the Fraser River

Fraser River sockeye return by one of two migratory routes: down the west coast of Vancouver Island and through Juan de Fuca Strait to the Strait of Georgia, or through Johnstone Strait and into the Strait of Georgia (the northern diversion route).

I agree that predation may play a role in Fraser River sockeye mortality during the return migration. For example, Steller sea lions have increased in abundance since being protected under the *Fisheries Act* in 1970. According to Technical Report 8, Predation, they stabilized in the mid-1980s at about 10,000 but have since increased to approximately 30,000, although Peter Olesiuk, head of the Pinniped Research Program, Pacific Biological Station, Science Branch, testified that the total Steller sea lion population for British Columbia and southeastern Alaska is estimated to be 60,000. Since daily consumption ranges from at least 17 kg (females) to at least 30 kg (males), Steller sea lions could exert some impact on returning sockeye, even though sockeye appears to be the least favourite salmonid prey.

Harbour seals have also been protected since 1970, and they now number about 108,000 in British Columbia, with about 40,000 of these in the Strait of Georgia. However, salmonids comprise only about 4 percent of their diet, and, of those, chum and coho are preferred over sockeye or pink salmon. They have not increased in abundance over

* The Pacific Decadal Oscillation is a commonly used index to describe inter-decadal variability in the climate of the North Pacific Ocean.

the past decade, making it unlikely that they are a major factor in the decline (unless their diet has recently changed). Since the residency of California sea lions in the Strait of Georgia does not overlap with returning Fraser River sockeye salmon adults, they are unlikely to have contributed to the decline. Southern and northern resident killer whales prefer chinook, and sockeye salmon appear to be insignificant in their diet.

Dr. Miller and her colleagues made a potentially important finding that, in the case of adult sockeye returning to spawn in 2006, 50 percent carried a mortality-related genomic signature. Fish carrying this signature had a 13.5-times lower probability of making it up to the spawning grounds and spawning. Dr. Miller has hypothesized that this signature is in response to a virus, potentially a parvovirus, but it has not been determined whether such a virus is infectious or causes disease.

Life stage 4 findings

I find that two predators deserving attention are salmon sharks in the North Pacific Ocean and Steller sea lions in the coastal waters of British Columbia and southeastern Alaska. However, there are currently insufficient abundance and trend data relating to salmon sharks, and uncertainty about how much sockeye salmon contribute to the diet of Steller sea lions, to be sure of their roles in the decline.

As with life history stage 3, I find that marine conditions and climate change may have contributed to the decline. I heard evidence that sea surface temperatures in the Gulf of Alaska have increased by 0.5°C over the past two decades. Warmer waters can reduce food availability for sockeye salmon, increase the metabolism of predators (causing them to eat more), and attract non-resident predators. However, the contributions of climate change and inter-annual and inter-decadal variations to sea surface temperatures are unclear. Finally, there is evidence that sockeye, pink salmon, and enhanced salmon species compete for food during periods of overlap in the Gulf of Alaska, an occurrence that can result in a reduction in sockeye mean size and possibly abundance, owing to reduced food availability and increased vulnerability to predation and disease.

Data gaps that complicate the analysis for earlier life stages apply with even more force for this life history stage, since so little is known about the life of Fraser River sockeye during their two-year residency in the North Pacific Ocean. Stressors such as predation, reduced food availability, and competition may have singly or cumulatively played a role in the long-term decline. However, identifying such plausible mechanisms falls short of establishing cause-effect relationships.

Important new research that implicates this life history stage in the long-term decline is the finding of Dr. Peterman and Dr. Dorner that most Fraser River and many non–Fraser River sockeye stocks, both in Canada and the United States, show a decrease in productivity, especially over the past decade and often also over a period of decline starting in the late 1980s or early 1990s. Since the continental shelf off southeastern Alaska and the deep North Pacific Ocean are believed to be the two geographical areas where numerous Fraser River and non–Fraser River stocks commingle, it is reasonable to infer that these areas may have at least contributed to the decline. However, because so little is known about Fraser River sockeye salmon life along the continental shelf and in the Gulf of Alaska, it is not possible to be more specific about the stressors that may have contributed to the decline, or how they may have contributed.

Life stage 5: return migration

The four run-timing groups – Early Stuart, Early Summer, Summer, and Late-run – enter the Fraser River at different times between June and September. In most cases, they enter the river with little or no delay. Some parts of the Late-run will, as they have always done, delay at the mouth of the river for 20 to 30 days, or longer in some years. However, since the 1990s, other parts of the Late-run enter the river with little or no delay, at the same time as the Summer-run group. Factors that influence river-entry timing include fish maturity, tides, river flow, and water temperature.

Significant mortality can occur during the upstream migration. Stressors during this life stage include increased river discharge, increased water temperature, and illegal in-river fishing.* It is important to understand that, although these stressors affect harvest and escapement, they do not affect productivity measured as recruits per spawner (discussed previously in Chapter 4) – because productivity is a measure of how successful parents are at producing offspring that mature to come back to the coast, as opposed to how successful parents are at producing offspring that make it back to the spawning grounds. In other words, although these stressors reduce the number of sockeye that reach the spawning ground, they are not responsible for the long-term decline in productivity.

The authors of Technical Report 9, Climate Change, explained that, when river discharge is unusually high, migration rates of some stocks are slowed, extending migration duration by several weeks. This slowdown can deplete energy reserves to levels below critical thresholds, and such energy exhaustion is thought to be responsible for significant mortality in some years. However, river discharge in most years since the early 1990s has not been exceedingly high, so discharge alone is not believed to be the driving factor underlying recent years' trends in en route mortality.

Of greater concern are increasing river temperatures – the Fraser River has experienced approximately 2°C warming in the summer compared with 60 years ago, and river water temperature is frequently between 18 and 20°C during upstream migration. Late-run sockeye that have, since the mid-1990s, been entering the river three to six weeks earlier than normal may encounter temperatures up to 5°C warmer than they normally would. For those migrants affected by temperature, one study showed that 17–18°C was the tipping point, and at 19–20°C stocks were experiencing 20–40 percent mortality. A 2004 study of Weaver Creek sockeye showed that 100 percent of fish perished if they encountered river temperatures exceeding 20°C. I agree with the conclusion of the authors of Technical Report 9, Climate Change, that recent trends in climate change have very likely decreased Fraser River sockeye survival during this life stage over the past 20 years.

Another stressor of concern is endocrine-disrupting compounds, which may be an even greater concern for sockeye returning to the Fraser River than during the outmigration. Fraser River sockeye have been exposed to endocrine-disrupting compounds since their downstream migration and throughout their residence in the marine environment. The rigours of upstream migration can now result in 50–90 percent depletion of somatic energy reserves, increasing concentrations of these contaminants in somatic or gonadal tissues. A 2004 study found that such contaminant magnification was associated with 30 percent mortality in eggs.

Exposure during upstream migration may also compromise immunocompetence. As a result, sockeye could become more susceptible to infection by disease agents, especially when river temperatures are warmer. The author of Technical Report 1, Infectious Diseases, identified several pathogens that are either high or moderate risk to Fraser River sockeye during their upriver migration (fungi and related organisms, protozoa, and myxozoa), although he was not able to determine what impact, if any, these pathogens may have had on the recent Fraser River sockeye decline.

Life stage 5 findings

I find that the single greatest risk to Fraser River sockeye salmon during the upstream migration is increasing river temperatures. Eight of the 10 warmest summer river temperatures on record have occurred in the past 15 years, and Late-run sockeye that enter the river three to six weeks earlier than normal may encounter temperatures up to 5°C warmer than they normally would. Warmer water can lead to significant en route and pre-spawn mortality because compromised immunocompetence makes sockeye more susceptible to pathogens and disease. It can also lead to increased egg mortality through higher concentrations of endocrine-disrupting compounds in gonadal tissues, and to death due to physiological stress. These recent trends in climate change have very likely decreased Fraser River sockeye survival during this life stage

* Illegal in-river fishing was a major focus of the Honourable Bryan Williams's *2004 Southern Salmon Fishery Post-Season Review*. Mr. Williams's report, which evaluated the performance of the Fraser River sockeye fishery, was discussed in the Commission's Interim Report.

over the past 20 years. However, as I noted earlier, although en route mortality can affect harvest and escapement, it does not affect productivity and thus does not assist in identifying stressors that caused or contributed to the long-term decline.

Large spawner abundance

Productivity is a measure of how successful parents are at producing offspring that mature to come back to the coast. One of the measures of productivity is "recruits per spawner," which is the number of recruits, defined as adults that return to the coast before the onset of fishing, produced per spawner. Dr. Peterman testified that, for most Fraser River sockeye stocks, there has been a declining productivity of recruits per spawner since the early 1990s until 2009, to the point where the ratio of returning progeny per spawner was below the replacement level.

It has been hypothesized that allowing too many returning adults to spawn may have caused or contributed to this decline in productivity. For example, a large escapement (spawning population) in a given brood year may cause the number of resulting adults to be extremely low because of competition for limited resources – such as food for fry or oxygen for eggs or alevins in the gravel (simple density dependence). It is also argued that large abundance of spawners in a given brood year would affect not only that brood year's productivity, but also productivity of the subsequent three brood years (delayed density dependence). This latter lag effect could occur through increased incidence of diseases on densely crowded spawning grounds, severe depletion of food supply in rearing lakes for juveniles across successive cohorts, and/or increased reproduction and survival of long-lived predators of juvenile sockeye when their prey are plentiful.

The authors of Technical Report 10, Production Dynamics, sought to test this hypothesis by plotting spawners and resulting recruits and looking for extremely low recruit numbers associated with extremely large previous spawning escapements. They found that for 19 Fraser River sockeye stocks across a total of 977 stock years, there were only 70 instances (7.2 percent) in which the abundance of recruits was less than twice the number of effective female spawners (i.e., roughly below replacement). Further, none of these cases followed an extremely large spawner abundance that subsequently led to chronic low abundance or stock collapse.

Dr. Peterman and Dr. Dorner found that, in the case of Quesnel, Chilko, and Fennell stocks, recent declines in productivity were associated with higher levels of spawner abundance. Similarly, in their testimony, Dr. Carl Walters, professor at the University of British Columbia, and Dr. Brian Riddell, chief executive officer, Pacific Salmon Foundation, cited the Chilko, Quesnel, and Adams stocks as examples of stocks that have experienced a loss of productivity correlated with large escapement in prior years. Dr. Peterman and Dr. Dorner concluded that, although there is evidence of both simple and delayed density dependence for many Fraser River sockeye stocks, their results did not support the general hypothesis that efforts to rebuild Fraser River populations in recent years may have resulted in "over-escapement," thereby causing substantial declines in productivity for these stocks. They acknowledged, however, that the Quesnel stock is an exception to this generalization.

At the June 2010 Pacific Salmon Commission (PSC) workshop, there was some support for the idea that delayed density dependence could have played a role in the long-term decline, with the panellists expressing conclusions ranging from likely to unlikely. In testimony, Ken Wilson, consulting fisheries biologist, expressed the view that large spawner abundance is a fisheries management construct better understood as "under-fishing," and should not be construed as biologically harmful. Dr. Walters disagreed, countering that large spawner abundance could potentially create a strong and synchronous cyclic dominant pattern that would not be conducive to a stable fishery.

In their closing submissions, several participants commented on the role of large spawner abundance (or over-escapement) in the decline. The Seafood Producers Association of B.C. submitted that the decline in productivity of the largest stocks, such as Quesnel and Chilko, is one of the results of excessive spawning populations in several years.[11] The Area D Salmon Gillnet Association and Area B Harvest Committee (Seine) cited Dr. Jim Woodey, former chief biologist at PSC, as saying that the over-escapement problem is not an insignificant issue from the standpoint of future returns and harvest.[12] According to the West Coast Trollers Area G Association and United Fishermen and Allied Workers' Union, DFO's well-intentioned 1987 rebuilding strategy created a situation where excessive spawner density reduced and weakened the outmigrating smolts to such an extent that, by 2009, the resource was unable to replace itself even with the commercial fishery completely closed.[13] According to the B.C. Wildlife Federation and B.C. Federation of Drift Fishers, the evidence shows that density-dependent effects are a likely cause of the decline in production of some stocks and that these stocks are the major components of the Fraser River sockeye.[14] However, the Stó:lō Tribal Council and Cheam Indian Band countered that the best and largest body of evidence in this Inquiry reveals that large spawner abundance is not a cause of the decline of sockeye productivity.[15]

I am unable to conclude, based on the evidence led before the Commission, that large spawner abundance is responsible for the long-term decline in overall Fraser River sockeye productivity. The research of Dr. Peterman and Dr. Dorner found little evidence of extremely low recruit numbers associated with extremely large previous spawning escapements. It is also difficult to reconcile alleged large spawner abundance of Fraser River sockeye with the other significant finding of Dr. Peterman and Dr. Dorner: that most Fraser River and many non–Fraser River sockeye stocks, both in Canada and in the United States, show a decrease in productivity, especially over the past decade and often also over a period of decline starting in the late 1980s or early 1990s.

Conclusions on the long-term decline

When I embarked on this exploration of the possible causes of the decline of Fraser River sockeye salmon, I quoted from Technical Report 1A, Enhancement Facility Diseases:

> It is tempting to think of a cause as a single entity, event or condition which inevitably leads to a specific outcome. This is rarely the case in biomedical situations, especially when population health and disease are being considered. The presence or absence of a disease typically requires a complex interplay of factors.[16]

Unbundling the life cycle of Fraser River sockeye into their five discrete stages has permitted a detailed examination of the various freshwater and marine stressors that sockeye experience during different phases of their life.

This exploration has revealed that researchers have a relatively good understanding of the mechanisms by which many of these stressors may negatively affect Fraser River sockeye. However, what is much less understood is the actual impact that these stressors have, either singly or cumulatively. For example, salmon sharks, as their name implies, are known to prey on salmon, but the extent to which they favour sockeye salmon and the volume they consume is not well understood. Similarly, it is known that some contaminants found in the Fraser River are present at concentrations that can compromise immunocompetence or adversely affect sockeye reproduction, but the extent to which they actually do so remains to be discovered.

This lack of understanding about actual effects not only applies to individual stressors at a single point in time, but also extends to cumulative effects (e.g., the combined effect of contaminants, disease, and warmer waters on the health of a fish) and delayed effects (e.g., a contaminant or parvovirus picked up during the outmigration that leads to mortality during the return migration).

Based on the evidence led during this Commission's hearings, very few (if any) of the potential stressors discussed in this Report can be safely taken off the table with a confident assurance that they have not contributed in some way to the Fraser River sockeye decline. Given the plausible mechanisms that abound, I am satisfied that there is a risk that some of these stressors have a negative impact on sockeye and may have contributed to the long-term decline. However, I accept the testimony of numerous witnesses that a lack of research has resulted in knowledge gaps which have impeded the ability of researchers to move beyond the identification of plausible mechanisms toward the establishment of cause-effect relationships.

Nevertheless, some important research is under way, such as Dr. Miller's identification of a mortality-related genomic signature in Fraser River sockeye that has been found in smolts before they begin their outbound migration and in adults during their return migration. This signature, which Dr. Miller hypothesizes is caused by a parvovirus, is associated with early marine mortality and en route / pre-spawn mortality. At the time of her testimony, however, she had not yet determined whether the cause of the mortality-related genomic signature was infectious or associated with disease.

Although all the stressors referred to above are known to affect Fraser River sockeye salmon specifically, the recent research findings of Dr. Peterman and Dr. Dorner compel us to also look more broadly at regional influences. Their examination of 64 sockeye populations from Washington State, British Columbia, and Alaska revealed that most Fraser River and many non–Fraser River sockeye stocks show a decrease in productivity, especially over the past decade, and often also over a period of decline starting in the late 1980s or early 1990s.

In their view, which I find persuasive, the large spatial extent of similarities in productivity patterns suggests that mechanisms which operate on larger, regional spatial scales, and/or in places where a large number of correlated sockeye stocks overlap, should be seriously examined. In testimony, Dr. Peterman suggested that these could be things such as predators, pathogens, or oceanographic patterns driven by climate processes.

As the author of Technical Report 1A, Enhancement Facility Diseases, so astutely observed, when population health and disease are being considered, causes are rarely a single entity, event, or condition. Rather, they are much more likely a complex interplay of factors. The evidence led before this Commission has identified numerous stressors that may have negatively affected Fraser River sockeye salmon over the past 20 years.

It is not, in my view, a matter of choosing one potential cause over the other. Given our limited understanding of how the many identified stressors actually affect Fraser River sockeye and how regional processes affect many different sockeye stocks, prudence dictates that neither be ruled out. The available evidence has identified a risk that both Fraser River–specific stressors and region-wide influences may have contributed to the long-term decline. Regrettably, that is as far as the evidence takes me. However, there are things that can be done to fill in knowledge gaps and progress toward finding cause-effect relationships. I will explore these options in Volume 3.

The poor return in 2009

The preamble to the Terms of Reference noted that the Fraser River sockeye salmon decline "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." This reference is to the 2009 return, when only 1.36 million fish returned to the river. It not only was the lowest abundance since the 1940s, but also fell far short of the pre-season forecast of 11.4 million (based on the 50 percent probability level).

Earlier in this volume, I summarized the conclusions from four other investigations into the causes of the poor 2009 return of Fraser River sockeye salmon, which were conducted either before or concurrently with this Commission's work. I present these summaries below.

- *September 2009 DFO Science workshop.* Outmigration and early marine mortality is supported by observations of very low sockeye catches in the Strait of Georgia juvenile surveys in July and September 2007. Harmful algal blooms were identified as plausible and under consideration. Low food availability along the marine migration route (Queen Charlotte Sound) was a plausible hypothesis, as were species interactions and competition in southeastern Alaska and the Gulf of Alaska.
- *December 2009 Think Tank of Scientists convened by Simon Fraser University.* Despite incomplete information, the think tank agreed that the problem in 2009 could most likely be attributed to what happened between the time when the fish left the lakes in the spring and their early survival at sea over the next few months.
- *June 2010 Pacific Salmon Commission (PSC) workshop.* The Expert Advisory Panel

concluded that physical and biological conditions inside the Strait of Georgia during the juvenile life stage are very likely the major cause of poor survival of the cohort that returned in 2009. In addition, freshwater and marine pathogens were an important contributor to the poor 2009 return, while harmful algal blooms in the southern Strait of Georgia in 2007 were a possible explanation for the poor returns.

- *April 2011 DFO internal workshop.* Four factors most likely led to sockeye mortality at the scale observed in 2009: low food abundance in the Strait of Georgia in 2007; low food abundance in Queen Charlotte Sound (2007) and the Gulf of Alaska (2008); disease when juvenile sockeye were stressed by low food abundance; and toxic algal blooms in the Strait of Georgia in 2007.

The Terms of Reference do not specifically direct me to make findings of fact respecting the 2009 return. However, it was the subject of consideration in several technical reports and during the evidentiary hearings, where attention was focused on conditions in the Strait of Georgia and Queen Charlotte Sound in 2007 (when postsmolts that would return to spawn in 2009 were migrating north). Many of the scientists who participated in these other investigations were also involved in this Commission's work – as authors or co-authors of the technical reports, as witnesses at the Commission's hearings, or in both capacities.

The authors of Technical Report 4, Marine Ecology, reported that, in the spring of 2007, the daily volumes of freshwater entering the Strait of Georgia were often in the upper quartile but not extreme, and that daily sea surface temperatures were warmer than normal, but that neither temperatures nor salinity was extreme. Phytoplankton and nitrate concentrations during the spring were similar to those of the preceding five years. They increased during the summer, and then dropped during the fall. However, Dr. Beamish testified that, during a 2007 trawl survey in the Strait of Georgia, the researchers encountered extremely low abundances of both herring and the five salmon species, and observed a high percentage of empty stomachs in coho and chinook salmon. He attributed this extraordinary synchronous failure in year-class strength to poor plankton (i.e., food) production due to anomalous physical conditions in the Strait of Georgia (e.g., exceptional freshwater discharge, shallow mixing-layer depth, and winds), although he did not have measurements of plankton or prey abundance.

Dr. Rensel testified that there is evidence that harmful algal blooms in 2007 could have contributed to the poor 2009 return. Blooms can result in direct, acute effects or in chronic effects such as infections, making the sockeye more susceptible to poor food supply conditions and predation.

The authors of Technical Report 4, Marine Ecology, described anomalous conditions in Queen Charlotte Sound during the summer of 2007: the lowest average surface salinity on record (caused by extremely high volumes of river discharge), extreme wind anomalies (resulting in a warm, low-density surface layer to be retained in the sound), and a delay in the spring chlorophyll bloom. Of the areas studied, Queen Charlotte Sound was the only one that had such extreme absolute sea surface temperature.

Several witnesses testified that marine conditions in both the Strait of Georgia and Queen Charlotte Sound were likely to be the primary factor responsible for the poor returns in 2009. Although Dr. Beamish found evidence suggestive of low food availability in the Strait of Georgia during his 2007 trawl survey, other evidence indicates only modestly warmer sea surface temperatures and at least normal concentrations of phytoplankton. In the absence of both juvenile Fraser River sockeye abundance counts on entry into and exit from the Strait of Georgia and zooplankton data, we cannot know for sure the level of mortality that occurred here – plausible explanations for greater-than-usual mortality during this life history stage fall short of cause-effect relationships.

I also heard evidence that abundance of Humboldt squid increased between 2004 and 2009, but, for several reasons, I think it is unlikely that they are responsible for the poor returns in 2009: there is no direct evidence that they prey on sockeye postsmolts; in 2007, Humboldt squid were found off the west coast of Vancouver Island but not farther north; and there is no evidence that they were in the migratory pathways of outbound Fraser River sockeye postsmolts.

Poor return in 2009 findings

In summary, I find that some anomalous conditions (including harmful algal blooms) may have existed in the Strait of Georgia in 2007. When they are combined with the well-documented anomalous ocean conditions in Queen Charlotte Sound that same year, a more persuasive pattern emerges that unfavourable marine conditions in these two areas cumulatively affected Fraser River postsmolt survival. As I stated above, it is not known with certainty exactly what level of mortality occurred in these nearshore areas, but based on the evidence led during the Commission's hearings, these are the areas that most likely presaged the poor Fraser River sockeye salmon return in 2009. It is also possible that sublethal effects from other stressors such as disease or contaminants could have interacted with marine conditions, leading to death during a later life stage.

The authors of several technical reports and several other witnesses cited evidence of significantly more favourable marine conditions for juveniles in 2008 (and a volcanic eruption in Alaska) that may provide a partial explanation for the historically good Fraser River sockeye return in 2010.

Fraser River sockeye salmon stocks: current state and long-term projections

Current state

The Terms of Reference direct me to make independent findings of fact regarding the current state of Fraser River sockeye salmon stocks.

The health of individual Conservation Units (CUs) is the focus of DFO's implementation of the Wild Salmon Policy, as discussed in Volume 1 of this Report. However, when viewed on an aggregate basis, the "current state" of the stocks is at best a snapshot in time. For example, the estimated abundances for 2009, 2010 and 2011 were 1.36 million, 29 million, and 5 million. Given these extreme fluctuations, there is little value in attempting to calculate an average annual value.

What is clear from the Fraser River sockeye abundance chart (Figure 2.5.3) reproduced at the beginning of this chapter is that cyclic dominance has until now produced wide variations in abundance from year to year, and there is no reason to think that this pattern will change. This chart also shows that, after the Hell's Gate rockslide in 1913 and before the dramatic increase in abundances that began in the late 1970s, Fraser River sockeye salmon gradually increased in abundance from about 3 million to about 8 million.

It is too soon to tell whether the recent 30-year phenomenon of exceptional increase and decrease between the late 1970s and 2009 is over, whether we have already embarked on a similar new cycle, or whether there will be a return to more restrained historical norms. Given the four-year cyclic dominance pattern exhibited by several Fraser River sockeye stocks, it will take until at least 2014 to offer even tentative answers to these questions.

Long-term projections

The Terms of Reference also direct me to make independent findings of fact regarding long-term projections for Fraser River sockeye salmon stocks.

As the previous analysis shows, Fraser River sockeye are differentiated CUs. They live in complex freshwater and marine ecosystems and encounter numerous stressors throughout their life stages, the actual impacts of which we have much to learn. Given the challenges involved in attempting to discern the reasons for the recent long-term decline, it would be an unreliably speculative exercise to offer definitive long-term projections for Fraser River sockeye CUs.

What can be said with some confidence is that the stressors that are currently believed to affect sockeye negatively are likely to continue to do so, unless significant remedial measures are introduced in the near future. But because of knowledge gaps, one cannot say with precision what effect those stressors will have on Fraser River sockeye abundance and productivity. As I will discuss in Volume 3, it is important that action be taken to reduce known anthropogenic stressors that we do have control over, such as habitat loss, contaminants, and salmon farms.

One stressor that is of particular concern is climate change. During the evidentiary hearings, Dr. Hinch, co-author of Technical Report 9, Climate Change, was asked whether there is any greater threat to Fraser River sockeye than climate change, and he responded: "I'm hard-pressed to find a greater threat."[17] Fraser River sockeye are particularly sensitive to future warming because they live close to the southern boundary of the sockeye salmon's geographical range.

Climate change impacts will likely be felt throughout all the life stages. Warmer air temperatures may increase the effects of mountain pine beetle infestation and lead to more precipitation in the form of rain and earlier melting of the snowpack. These factors will likely result in increased water runoff and erosion and contribute to earlier spring freshets that will be smaller and of shorter duration. Changes in water flow may affect the timing of zooplankton availability during the outmigration, thereby reducing food availability.

Concerning Fraser River sockeye residence in the North Pacific Ocean, sea surface temperatures are expected to increase by between 2 and 4°C by the end of the century.[18] The authors of Technical Report 4, Marine Ecology, reported that the Intergovernmental Panel on Climate Change (IPCC) anticipates that, under a "business as usual" scenario, there will be a doubling of atmospheric carbon dioxide from the late 20th century concentrations by the mid-2080s. Other IPCC sea surface temperature prediction models suggest that at these concentrations, on average, sea surface temperatures during the month of July of less than 12°C will not be a significant part of the Gulf of Alaska. In other words, current July sea surface temperatures that are considered to be a possible upper thermal limit for sockeye salmon in the Gulf of Alaska will become approximately the average state of nature – with a doubling of carbon dioxide concentrations.

Water temperatures during the upriver spawning migration will also be challenging for Fraser River sockeye salmon. According to Technical Report 9, river waters have warmed approximately 2.5°C in the past 60 years, one degree of which was within the past 20 years. Based on climate models predicting that summer water temperatures in the Fraser River may warm by approximately 2°C over the next century, Dr. Martins, Dr. Hinch, and others in a 2011 paper predicted that spawning migration survival will decrease between 9 and 16 percent (depending on the stock) by the end of the century.[19] They called this prediction "likely optimistic."[20]

Thirteen of the past 20 summers have been the warmest on record, and there has been a progressive increase in peak summer temperatures by approximately 1.8°C during the past 50 years.[21] According to Technical Report 9, it has been predicted that a modest 1°C increase in average summer water temperature over the next 100 years would triple the number of days per year exceeding salmonid critical temperatures.

There is much uncertainty about how Fraser River sockeye salmon will respond to these increasing temperatures and deteriorating environmental conditions. It cannot be assumed that today's most productive populations and regions will sustain that productivity into the future – some habitats will retain the capacity to support salmon more than others. Some populations that are better adapted to warmer water temperatures, such as Chilko Lake sockeye, may persist at higher levels of abundance, while the number of CUs categorized in the Wild Salmon Policy's "red zone" will likely increase. In the future, there will be increasing unpredictability due to climate change.*

There is evidence that, to some extent, salmon are capable of adjusting their adult migration timing in response to warmer water temperatures. According to the authors of Technical Report 9, one of the best examples of phenological changes presumably arising through evolution in response to warming comes from the Columbia River, where sockeye salmon have begun their spawning migration six to 11 days earlier than in the 1940s. However, the rates of river warming have outpaced those of migration timing change, and Columbia River sockeye salmon now experience temperatures on average 2.5°C warmer than in the past. Some stocks have already reached the limit of their capacity to adapt, and the early river entry of some Late-run stocks of Fraser River sockeye shows that some behavioural changes have negative effects.

* The WSP's red zone represents the area beneath the lower benchmark, which is intended to provide a "substantial buffer between it and any level of abundance that could lead to a CU being considered at risk of extinction." See Exhibit 8, p. 17.

In 2011, Michael Healey, of the UBC Institute for Resources, Environment and Sustainability, used a qualitative model to assess the cumulative effects of climate change across life stages and generations of Fraser River sockeye salmon and other salmon species. He concluded:

> Any forecast of the effects of climate change has high uncertainty; however, the evidence presented above shows that global warming will likely have negative effects on productivity of Fraser River sockeye at every life history stage. Although not all environmental and ecological change with global warming will be negative for Fraser River sockeye (warmer temperatures will enhance lake and ocean productivity in some regions, for example, and lower spring and summer discharge may make upstream migration easier), the weight of evidence supports the conclusion that effects at each stage will be predominantly negative. Furthermore, the effects at one stage carry forward to the next.[22]

The authors of Technical Report 9, Climate Change, were more cautious in their conclusions:

> Predicting the responses of Fraser River sockeye salmon, and Pacific salmon more generally, to future climate change will require a much better understanding than we currently have of how evolutionary and ecological mechanisms interact in shaping such responses.[23]

Although climate change predictions give us some indication of the extent of expected warming in the North Pacific Ocean and Fraser River in the decades ahead, there is still much to learn about how these water temperature changes will affect food availability, habitat conditions, predation, diseases, and other stressors.

In general terms, we can expect that adverse ecological effects in freshwater and marine ecosystems that support Fraser River sockeye salmon will lead to reduced productivity in coming decades. With expected Fraser River temperature increases, spawning migration mortality will increase as well. It is likely that there will be an increase in the number of CUs that are categorized in the Wild Salmon Policy's red zone, and CUs that are most sensitive to climate change may face extirpation.

Although northern sockeye populations, like those in Bristol Bay, may survive and possibly thrive under a warmer climate, populations distributed along the southern margin of the sockeye's geographical range, including those in the Fraser River, are vulnerable to the negative impacts of climate change.

This rather bleak prognosis makes the protection of biological diversity all the more compelling. In the words of the Wild Salmon Policy:

> The health of Pacific salmon depends not only on their abundance but also on their biological diversity. That diversity includes the irreplaceable lineages of salmon evolved through time, the geographic distribution of these populations, the genetic differences and life history variations observed among them, and the habitats that support these differences. *Diversity of Pacific salmon represents their legacy to-date and their potential for adaptation to future changes in climate, fishing and habitat. Protecting diversity is the most prudent policy for the future continuance of wild salmon as well as the ecological processes that depend on them and the cultural, social and economic benefits drawn from them.* [Emphasis added.][24]

In Volume 3 of my Report, I will make recommendations for improving the future sustainability of the sockeye salmon fishery in the Fraser River.

Notes

1 Transcript, Randall Peterman, April 20, 2011, pp. 32–33.
2 Canada's written submissions, p. 7, available at www.cohencommission.ca.
3 Canada's written submissions, p. 8, available at www.cohencommission.ca.
4 Province's written submissions, p. 13, available at www.cohencommission.ca.
5 B.C. Salmon Farmers Association's written submissions, p. 141, available at www.cohencommission.ca.
6 Seafood Producers Association of B.C.'s written submissions, p. 2, available at www.cohencommission.ca.
7 Conservation Coalition's written submissions, p. 36, available at www.cohencomission.ca.
8 First Nation Coalition's written submissions, p. 60, available at www.cohencommission.ca.
9 Stó:lō Tribal Council and the Cheam Indian Band's written submissions, p. 10, available at www.cohencommission.ca.
10 Area D Salmon Gillnet Association and Area B Harvest Committee's (Seine) written submissions, p. 70, available at www.cohencommission.ca.
11 Seafood Producers Association of B.C. written submissions, p. 4, available at www.cohencommission.ca.
12 Area D Salmon Gillnet Association and Area B Harvest Committee's (Seine) written submissions, p. 42, available at www.cohencommission.ca.
13 West Coast Trollers Area G Association and United Fishermen and Allied Workers' Union's written submissions, p. 45, available at www.cohencomission.ca.
14 B.C. Wildlife Federation and B.C. Federation of Drift Fishers' written submissions, p. 20, available at www.cohencommission.ca.
15 Stó:lō Tribal Council and Cheam Indian Band's written submissions, p. 12, available at www.cohencommission.ca.
16 Exhibit 1454, pp. 23–24.
17 Transcript, March 9, 2011, p. 20.
18 Exhibit 1320, p. 723.
19 Exhibit 1855.
20 Exhibit 1855, p. 111.
21 Exhibit 561, p. 698.
22 Exhibit 1320, p. 729.
23 Technical Report 9, p. 32.
24 Exhibit 8, p. 2.

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

.../2

P. C. 2009-1860

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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,

.../3

P. C. 2009-1860

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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,

.../4

P. C. 2009-1860

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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,

.../5

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.

CERTIFIED TO BE A TRUE COPY–COPIE CERTIFIÉE CONFORME

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;

CERTIFIED TO BE A TRUE COPY–COPIE CERTIFIÉE CONFORME

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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- Reviewer 2
- Reviewer 3

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 (Early Stuart – Stuart, Takla / Trembleur; Early Summer – Nahatlatch, Anderson, Francois, Taseko, Bowron, Shuswap Complex; Summer –

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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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

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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

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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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Abbreviations and acronyms

AAA	Aboriginal Aquaculture Association
AAROM	Aboriginal Aquatic Resource and Oceans Management
ACFLR	*Aboriginal Communal Fishing Licences Regulations*
ACRDP	Aquaculture Collaborative Research and Development Program
ADM	assistant deputy minister
AEO	Aquaculture Environmental Operations (DFO)
AFE	Aboriginal Fisheries Exemption
AFS	Aboriginal Fisheries Strategy
AHC	Area Harvest Committee
AICFI	Atlantic Integrated Commercial Fisheries Initiative
AIMAP	Aquaculture Innovation and Market Access Program
AMD	Aquaculture Management Directorate (DFO)
ARIMS	Aquaculture Resource Information Management System
ASWP	Atlantic Salmon Watch Program
ATK	Aboriginal traditional knowledge
ATP	Allocation Transfer Program
AVC	Atlantic Veterinary College
BAMP	Broughton Archipelago Monitoring Program
BC	British Columbia
BC Lab	Animal Health Centre, Abbotsford, BC
BCSFA	B.C. Salmon Farmers Association
BKD	bacterial kidney disease
C&E	Compliance and Enforcement
C&P	Conservation and Protection Directorate (DFO)
CAAR	Coastal Alliance for Aquaculture Reform
CAIA	Canadian Aquaculture Industry Alliance
Caligus	*Caligus clemensi* (the herring louse)
CCME	Canadian Council of Ministers of the Environment
CEAA	*Canadian Environmental Assessment Act*
CEDP	Community Economic Development Program
CEPA	*Canadian Environmental Protection Act*
CESD	Commissioner of the Environment and Sustainable Development
CFAR	Canadian Fisheries Adjustment and Restructuring

CFIA Canadian Food Inspection Agency
COSEWIC Committee on the Status of Endangered Wildlife in Canada
CPUE catch per unit effort
CREST catch and release estimation tool
CSA *Canada Shipping Act*
CSAB Commercial Salmon Advisory Board
CSAP Centre for Science Advice (Pacific)
CSAS Canadian Science Advisory Secretariat
CSO combined sewer overflow
CTAC Canadian total allowable catch
CU Conservation Unit
CWL Commonwealth Legal
DBEs differences between in-season and post-season estimates of escapement
DDT dichlorodiphenyltrichloroethane
DEPOMOD depositional modelling
DFO Department of Fisheries and Oceans
DIDSON Dual-Frequency Identification SONAR
DMC Departmental Management Committee (DFO)
DND Department of National Defence
DOE Department of the Environment (Environment Canada)
DOJ Department of Justice Canada
Draft RMAF Wild Salmon Policy Implementation Workplan – Results-based Management and Accountability Framework
DVS Departmental Violation System
EAA BC *Environmental Assessment Act*
EED Environmental Enforcement Directorate
EEM environmental effects monitoring
eLog electronic logbook
EMA BC *Environmental Management Act*
ENGO environmental non-governmental organization
EPMP Environmental Process Modernization Plan
ESSR excess salmon to spawning requirements
ESSRF Environmental Science Strategic Research Fund
EWatch Environmental Watch Program (DFO)
FAM Fisheries and Aquaculture Management
FAO Food and Agriculture Organization of the United Nations
FAWCR BC *Finfish Aquaculture Waste Control Regulation*
FEATS Fisheries Enforcement Activity Tracking System
FFSBC Freshwater Fisheries Society of BC
FHASP BC Fish Health Audit and Surveillance Program
FHE fish health event
FHMP Fish Health Management Plan
FHPR *Fish Health Protection Regulations*
FHV fish health veterinarian
FM&CR fisheries monitoring and catch reporting
FN First Nations
FNC First Nations Coalition
FNFC First Nations Fisheries Council
FPA BC *Fish Protection Act*
FPCA *Forest Practices Code of British Columbia Act*
FPPR *Forest Planning and Practices Regulation*
FRAFS Fraser River Aboriginal Fisheries Secretariat
FREP Forest and Range Evaluation Program
FRIMT Fraser River Sockeye and Pink Salmon Integrated Management Team
FRP Fraser River Panel
FRPA BC *Forest and Range Practices Act*
FRSSI Fraser River Sockeye Spawning Initiative
FSC food, social, and ceremonial
FSWP Fraser River Salmon and Watersheds Program
FTE full-time equivalent
FVAFS Fraser Valley Aboriginal Fisheries Society
GB gigabyte
GDP gross domestic product
GFC Gulf Fisheries Centre
HAB harmful algal bloom
HADD harmful alteration, disruption or destruction of habitat (*Fisheries Act*, s. 35)
HAMP Harmful Algae Monitoring Program
HWG Habitat Working Group
HMU Habitat Monitoring Unit
HSMI heart and skeletal muscle inflammation
IAPF Integrated Aboriginal Policy Framework

IFMP Integrated Fisheries Management Plan
IHN infectious hematopoietic necrosis
IHNv infectious hematopoietic necrosis virus
IHPC Integrated Harvest Planning Committee
IMAP Integrated Management of Aquaculture Plan
IPCC Intergovernmental Panel on Climate Change
IPMA BC *Integrated Pest Management Act*
IPN infectious pancreatic necrosis
IPNv infectious pancreatic necrosis virus
IPP independent power project
IPSFC International Pacific Salmon Fisheries Commission
IQ individual quota
ISA infectious salmon anemia
ISAv infectious salmon anemia virus
ISDF Integrated Salmon Dialogue Forum
ITQ individual transferable quota
JTG joint task group (report of Pearse and McRae)
Leps *Lepeophtheirus salmonis* (the salmon louse)
LKTS Lach-Kwil-Tach Treaty Society
LRP limit reference point
M&C Panel Monitoring and Compliance Panel
MA management adjustment
MAL BC Ministry of Agriculture and Lands
MARPAC Maritime Forces Pacific (DND)
MFLNRO BC Ministry of Forests, Lands and Natural Resource Operations
MMER *Metal Mining Effluent Regulations*
MOE BC Ministry of Environment
MOU memorandum of understanding
MPB mountain pine beetle
MPIRS Marine Pollution Incident Reporting System
MRS mortality-related signature
MSC Marine Stewardship Council
MSY maximum sustainable yield
NAAHLS National Aquatic Animal Health Laboratory System
NAAHP National Aquatic Animal Health Program
NEMISIS National Emergencies and Enforcement Management Information System and Intelligence System
NGO non-governmental organization
NHQ national headquarters
NNFC Northern Native Fishing Corporation
NOAA US National Oceanic and Atmospheric Administration
NPAFC North Pacific Anadromous Fish Commission
NPRI National Pollutant Release Inventory
NSERC National Sciences and Engineering Council of Canada
NWPA *Navigable Waters Protection Act*
OHEB Oceans, Habitat and Enhancement Branch (DFO)
OIE World Organisation for Animal Health
ONA Okanagan Nation Alliance
PA precautionary approach
PacFish Pacific Fisheries Data Initiative
PAH polycyclic aromatic hydrocarbon
PAR *Pacific Aquaculture Regulations*
PARP Pacific Aquaculture Regulatory Program
PARR Program for Aquaculture Regulatory Research
PATH Program Activity Tracking for Habitat database
PBDE polybrominated diphenyl ether
PBS Pacific Biological Station (DFO), Nanaimo
PBT persistent, bioaccumulative, and toxic
PCB polychlorinated biphenyl
PCO Privy Council Office
PCPA *Pest Control Products Act* (federal)
PCR polymerase chain reaction
PDO Pacific decadal oscillation
PFAR Pacific Fisheries Adjustment and Restructuring Program
PFRCC Pacific Fisheries Resource Conservation Council
PICES North Pacific Marine Science Organization
PICFI Pacific Integrated Commercial Fisheries Initiative
PIP Public Involvement Projects
PMRA Pest Management Regulatory Agency (Health Canada)
PNCIMA Pacific North Coast Integrated Management Area
PPER *Pulp and Paper Effluent Regulations*
PPM pulp and paper mill
PPR Policy and Practice Report

Pre-amp	pre-amplification step (used in RT-PCR)
PSAC	Public Service Alliance of Canada
PSARC	Pacific Scientific Advice Review Committee
PSC	Pacific Salmon Commission
PWGSC	Public Works and Government Services Canada
Q and A	questions and answers
QEP	qualified environmental professional
qRT-PCR	quantitative reverse transcriptase polymerase chain reaction
R/EFS	recruits per effective female spawners
R/smolt	recruits per smolt
RACO	Regional Aquaculture Coordination Office
RAR	BC *Riparian Areas Regulation*
RAS	Recirculating Aquaculture System
RDG	regional director general
REET	Regional Environmental Emergency Team
RIAS	regulatory impact analysis statement
RISS	Regulatory Information Submission System
RMA	Riparian Management Area
RMAF	Results-based Management and Accountability Framework
RMC	Regional Management Committee
RSSEPS	Rivers and Smith Salmon Ecosystems Planning Society
RT	reverse transcriptase
RT-PCR	reverse transcriptase polymerase chain reaction
RWA	Regional Working Agreement
S-R	stock-recruitment
SAFE	Salmon and Freshwater Ecosystems Division of DFO Science
SAFF	Sustainable Aquaculture Fisheries Framework
SAP	Sustainable Aquaculture Program (2008)
SAR	1997 Salmon Aquaculture Review (by BC Environmental Assessment Office)
SARA	*Species at Risk Act*
SARCEP	Species at Risk Coordination / Espèces en péril
SBM	share-based management
SCORE	Sub-Committee on Options for Review and Evaluation (CSAB)
SDC	Strategic Directions Committee
SEP	Salmonid Enhancement Program
SFAB	Sport Fishing Advisory Board
SFC	Secwepemc Fisheries Commission
SFF	Sustainable Fisheries Framework
SFU	Simon Fraser University, Burnaby, BC
SLICE	trade name of in-feed therapeutant used to treat fish for sea lice; with active ingredient emamectin benzoate
SLIPP	Shuswap Lake Integrated Planning Process
SOP	standard operating procedures
SST	sea surface temperature
TAC	total allowable catch
TAM	total allowable mortality
TAPGD	Treaty and Aboriginal Policy and Governance Directorate
TEK	traditional ecological knowledge
TR	Technical Report
TRP	target reference point
UBC	University of British Columbia, Vancouver
UBCM	Union of BC Municipalities
UEWBC	Union of Environment Workers British Columbia
UFAWU	United Fishermen & Allied Workers Union
UFFCA	Upper Fraser Fisheries Conservation Alliance
UN	United Nations
UNCLOS	*United Nations Convention on the Law of the Sea*
UNFSA	United Nations Fish Stock Agreement (also UNFA)
USTAC	US total allowable catch
VEC	valued ecosystem components
VHS	viral hemorrhagic septicemia
VPN	virtual private network
VSCs	Valued Social Components
WCCSFN	Western Central Coast Salish First Nations
WSER	Wastewater Systems Effluent Regulations
WSP	Wild Salmon Policy
WUP	Water Use Plan

Glossary

Cross-references are given in italic type.

abundance: the number of fish; the size of the stock.[1]

Aboriginal fishery guardian: fishery guardians employed by First Nations who engage in enforcement activities in accordance with Aboriginal fishing agreements.[2]

acute: in reference to infections, marked by a sudden onset of detectable symptoms that are usually followed by complete or apparent recovery.[3]

adult: *mature* (includes life stages 4 and 5). See *life cycle*.

aerobic scope: level of oxygen available for activities between basal (resting) and maximal metabolic rates; a characteristic describing the fish's ability to allocate energy to essential tissues.[4]

age class: *ecotype* designation based on the number of winters in freshwater after hatching and the number of winters in saltwater.[5]

alevin: sockeye *life stage* that occurs just after hatching from the egg, with *yolk sac* still present; alevins live in gravel until they emerge as *fry*.[6]

amphipod: group of small, mostly planktonic crustaceans belonging to the order Amphipoda.[7]

anadromous: fish that spend most of the growing phase of their *life cycle* in the sea, but return to freshwater to breed.[8]

anthropogenic: caused by humans.

aquaculture: farming of aquatic organisms in the marine environment or freshwater;[9] unless otherwise stated, in this Report the term "aquaculture" refers specifically to marine salmon aquaculture, or "salmon farms."

Atlantic salmon: species of salmon originating from the northern Atlantic Ocean; commonly used in *aquaculture*.[10]

back eddies: places where water flows past an obstacle, which can create a reverse current or cause the water to move in an otherwise different direction or at a different speed.[11]

benthic areas: areas of the seafloor.[12]

bioassay: controlled experiment for the quantitative estimation of a substance by measuring its effect in a living organism.[13]

biodiversity: full range of variety and variability within and among living organisms and the ecological complexes in which they occur; encompasses diversity at the *ecosystem*, community, species, and genetic levels as well as in the interaction of these components.[14]

biota: all the organisms living in a particular region, including plants, animals, and micro-organisms.[15]

bloodwater: wastewater from facilities where fish are processed.[16]

brailing: using a long-handled "net" scoop to take fish out of the *seine* net.

brood year: year when salmon eggs are laid.[17]

brood-year returns: See *total returns*.

bycatch: refers to non-target species (e.g., sockeye salmon when fishing for pink salmon) that become entangled or caught in fishing gear.[18]

caligid copepod: parasitic *copepod* crustacean of the family Caligidae.[19]

caudal: pertaining to the tail or tail region.[20]

chlorophyll bloom: areas in the ocean with high, sustained chlorophyll-α values in the surface waters.[21]

chronic: *disease* that may persist for many months or years and may not directly kill the host.[22]

ciliate: single-celled organism that uses a number of short cell appendages for locomotion.[23]

closed containment facility: facilities that use a range of technologies which attempt to restrict and control interactions between farmed fish and the external aquatic environment, with the goal of minimizing impact and creating greater control over factors in *aquaculture* production.[24]

compass orientation: ability to move in a fixed direction without reference to local landmarks.[25]

conservation: protection, maintenance, and rehabilitation of genetic diversity, species, and *ecosystem*s to sustain *biodiversity* and the continuance of evolutionary and natural production processes.[26]

conservation (of habitats): planned management of human activities that might affect fish habitats in order to prevent destruction and the subsequent loss of fisheries.[27]

Conservation Unit: group of *wild salmon* sufficiently isolated from other groups that, if *extirpated*, is very unlikely to recolonize naturally within an acceptable time frame.[28]

continental shelf: gently sloping offshore zone that usually extends to approximately 200 m in depth.[29]

copepods: small marine and freshwater crustaceans of the subclass Copepoda; sea lice are parasitic members of this group.[30]

counting fences: high-precision method for fish enumeration used at spawning channels and at some rivers and lakes; fish are counted as they pass the fence.[31]

cyclic dominance: pattern of persistent large *abundance* every four years, followed by a slightly smaller subdominant year, with two extremely low abundances in off-cycle years.[32]

degree days: measurement of thermal exposure; accumulated degree days are calculated by multiplying the number of days that a fish is exposed to water of a certain temperature.[33]

density dependence: feedback mechanism whereby a large *escapement* is thought to create a negative effect on productivity such that subsequent *total returns* of adults could be reduced[34] (simple density dependence and delayed density dependence are described in Volume 2 of this Report).

diatoms: single-cellular algae in the phylum Bacillariophyta that are capable of forming filamentous colonies.[35]

DIDSON: Dual-frequency IDentification SONar, which provides high-definition sonar images.[36]

dip net: fishing technique used in the Fraser River canyon to catch large numbers of chinook and sockeye salmon; while standing above the current in the river narrows, the fisher dips a large net attached to the end of a pole into the water, traps fish inside, and hauls them out.[37]

disease: a host fish is diseased if it is behaviourally or physiologically compromised.[38]

diversion rate: percentage of returning sockeye approaching the Fraser River via the north coast of Vancouver Island and Johnstone Strait (also called the northern diversion rate).[39]

dual fishing: fishing for two purposes at the same time; for example, fishing commercially and also retaining fish for *food, social, and ceremonial* purposes.[40]

Early Stuart run: one of the four *run-timing groups* of Fraser River sockeye; this stock group spawns in the Takla–Trembleur Lake system and arrives in the Lower Fraser River from late June to late July.[41]

Early summer run: one of the four *run-timing groups* of Fraser River sockeye; this stock group spawns throughout the Fraser system and arrives in the Lower Fraser River from mid-July to mid-August; this run includes Bowron, Fennell, Gates, Nadina, Pitt, Raft, Scotch, Seymour, and Early Summer Miscellaneous (Early Shuswap, South Thompson, North Thompson tributaries, North Thompson River, Nahatlach River and Lake, Chilliwack Lake, and Dolly Varden Creek).[42]

economic opportunity fishery: separates commercial fishing allocations from allocations for *food, social, and ceremonial* purposes for First Nations.[43]

ecosystem: community of organisms and their physical environment interacting as an ecological unit.[44]

ecosystem approach: approach to the management of human activity that considers all the components of an *ecosystem* that may be affected by the activity, including populations, communities, and habitat, and their linkages, as well as the impact of the ecosystem on the state of the living resource.[45]

ecotype: distinguishes individuals that spend varying numbers of years in freshwater and in saltwater.[46]

effective female spawner: estimate of female spawner *abundance*, which is further adjusted downward by the proportion of eggs that were not spawned, as determined by sampling on the spawning grounds.[47]

El Niño Southern Oscillation: inter-annual climate variability event that occurs every two to seven years and persists up to 1.5 years, characterized by coupled variations in sea surface temperature and sea level pressure in the tropical Pacific Ocean.[48]

emergence: developmental stage where *juvenile* salmon emerge from their gravel nest.[49]

en route loss (en route mortality): estimate of the number of upstream-migrating adults that die in the river en route to their spawning grounds.[50]

endemic: referring to a pathogen or disease that is constantly present in low numbers in a *population*.[51]

enhancement: application of biological and technical knowledge and capabilities to increase the productivity of fish stocks; this increase may be achieved by altering habitat attributes (e.g., habitat restoration) or by using fish culture techniques (e.g., hatcheries, spawning channels).[52]

enterococci: genus of lactic acid bacteria commonly found in the gastrointestinal tract of fish.

epilimnion: warm upper layer of water in a lake.[53]

escapement: number of *mature* salmon that pass through (or escape) fisheries and return to freshwater to spawn.[54]

estuarine: of or related to the border zone between freshwater and marine environments.[55]

exploitation rate: portion of all *adult* fish returning to their natal streams which are captured in a fishery.[56]

extirpation: local extinction of a species.[57]

fallow: in relation to *aquaculture*, the period of a few weeks between harvesting cycles when fish are absent from a site after harvesting and before the next restocking; also, the practice of site rotation where a site may be left empty for one or more years to allow the sediments to recover.[58]

finfish: freshwater and marine fish species that include salmon and non–salmonid species such as trout and sablefish;[59] also called “true fish,” having a backbone, gills, and limbs in the shape of fins.

fish habitat: spawning grounds and nursery, rearing, food supply, and migration areas on which fish depend directly or indirectly to carry out their life processes.[60]

fish ladder: structure designed to permit fish passage – for example, by providing access to spawning grounds upstream of a dam.[61]

fisheries resources: fish stocks or *populations* that sustain commercial, recreational, or Aboriginal fishing activities of benefit to Canadians.[62]

flagellate: single-celled organism that uses a long cellular appendage for locomotion.[63]

flood plain: flat or nearly flat land adjacent to a stream or river which experiences flood during periods of high water discharge.

food, social, and ceremonial: a fishing allocation for First Nations to fish for consumption for subsistence, social, and ceremonial purposes according to their distinctive culture.[64]

Fraser River Panel: panel created under the Pacific Salmon Treaty which manages the commercial harvest of Fraser River sockeye and pink salmon in Fraser *Panel Area Waters*.[65]

fry: life stage at which sockeye have emerged from gravel into freshwater streams, completed yolk absorption, and are less than a few months old.[66] See *life cycle*.

furunculosis: bacterial disease arising from an infection by the bacterium *Aeromonas salmonicida*.[67]

gear: various equipment used for fishing.

genomic signature: characteristic pattern of gene expression, revealed on a micro-array.[68]

gillnet: rectangular net that hangs in the water and is set from the stern or bow of a fishing vessel; when fish swim headfirst into the net, their gills get entangled in the mesh.[69]

gonadal: referring to the gonads (the organs in an animal that produce eggs and sperm).

***Heterosigma* blooms:** blooms of the fish-killing algae *Heterosigma akashiwo*.

histological analysis: analysis of the microscopic anatomy of cells and tissues.

histopathology: microscopic examination of cells and tissues to study the manifestations of a *disease*; used in diagnosis.

homeostasis: tendency of an organism to maintain a steady state or equilibrium with respect to specific functions and processes.[70]

horizontal transmission: direct transfer of an infection from fish to fish.[71]

hydroacoustics: technology involving vessel and shore-based acoustic transducers to detect fish that are swimming.[72]

hydrograph changes: changes in the rate of water discharge or flow.

immature: sockeye that are older than *postsmolt* but will not *mature* in the current calendar year[73] (includes life stages 2 and 3).

immunocompetence: ability of the body to produce a normal immune response.

immunogenetics: study of the relationship between the immune system and genetics.

immunosuppression: reduction in the ability of the immune system to deal with infection, increasing the susceptibility of the host to other pathogens.[74]

indicator stocks: set of 19 Fraser River sockeye stocks for which a time series of *abundance* estimates has been maintained since 1952.[75]

infectious hematopoietic necrosis (IHN): severe, acute, systemic viral *disease* found in *fry* and *juvenile salmonids*.[76]

in-season management: management of the fishery as fish return to spawn; includes *run size* assessments, managing for *escapement* targets, and setting fishery opening and closing dates.[77]

inter-annual variability: differences that occur from year to year.

inter-decadal variability: differences that are recorded over decades; for example, inter-decadal climate variability in the North Pacific Ocean can be observed as atmospheric and oceanic trends that last for 20–30 years (e.g., *Pacific Decadal Oscillation*).[78]

intergenerational effects: cumulative effects that occur among generations of fish; for example, female sockeye experiencing warm water during egg development may produce offspring with lower fitness.[79]

jacks: male *anadromous* sockeye salmon that mature after one year at sea.[80]

jills: female *anadromous* sockeye salmon that mature after one year at sea.[81]

juveniles: the two sockeye salmon *life stages* at which *abundance* is estimated annually in freshwater – *fry* and *smolts*.[82]

kokanee: *population*s of sockeye salmon that are non-*anadromous* and remain as freshwater residents throughout their *life cycle*.[83]

La Niña: inter-annual climate variability event characterized by anomalous cool sea surface temperature and low sea level pressure; typically La Niña events lead to cool sea surface temperature in the waters off the west coast of North America.[85]

landed value: price paid to the commercial fisher or salmon farmer for the whole fish before processing; in aquaculture, an alternative term is "farmgate value."[84]

Late run: one of the four *run-timing groups* of Fraser River sockeye; the Late run arrives in the Lower Fraser from late August to mid-October and spawns in the Lower Fraser, Harrison-Lillooet, Thompson, and Seton-Anderson systems; this run–timing group includes Cultus, Harrison, Late Shuswap, Portage, Weaver, Birkenhead, Miscellaneous Shuswap, and Late Miscellaneous non-Shuswap sockeye.[86]

leachate: liquid that, in passing through matter, extracts solutes, suspended solids, or any other component of the material through which it has passed.

life cycle: salmon have discrete life phases: life stage 1 – eggs and incubation, *alevin*, *fry*; life stage 2 – *smolt* (downstream migration); life stage 3 – *sub-adult*, transition to marine environment; life stage 4 – *adult* (marine growth); and life stage 5 – adult (return migration, spawning, and death).[87]

life stage: See *life cycle*.

limited entry fishery: fishery where no new licences are created, and the only way to acquire a licence is to purchase one from a current licence holder.[88]

Lower Fraser Area: for the purpose of fisheries management, the Lower Fraser Area includes the mouth of the Fraser River up to Sawmill Creek.[89]

mainstem: primary downstream segment of a river, as distinguished from its tributaries.

mariculture: cultivation, management, and harvesting of marine organisms in their natural habitat or in specially constructed rearing units; the end product is cultivated in seawater.[90]

marine productivity: *productivity* in the marine environment.

mark-recapture: high-precision method for enumeration of *escapement*; a method commonly used in ecology to estimate the size of an animal *population*.[91]

mature: *adult* (includes *life stages* 4 and 5).

maximum sustainable yield (MSY): largest catch (yield) that can be taken on average from a *population* under existing environmental conditions without depleting the population; catch will vary annually because of variation in the survival rate of the population.[92]

meta-analysis: statistical procedure for combining the results of several studies testing the same hypothesis.[93]

metabolites: various compounds that take part in or are formed by metabolic reactions.[94]

metabolism: sum of the chemical reactions that occur within a living organism.[95]

micro-array: arrayed series of thousands of microscopic spots, each containing tiny amounts of a specific DNA sequence used as a probe to screen large numbers of samples.[96]

mixed-stock fishery: fishery in which multiple stocks may be passing through an area in which the fishery is operating; the Fraser River sockeye fishery is generally considered a mixed-stock fishery.[97]

morphology: study of the structure and form of organisms.[98]

mortality: death of fish, or the number of fish killed through harvest or through the act of releasing species that cannot be retained in a fishery.[99]

moult: act of casting off the outer layers of an animal's covering (e.g., hair, scales, feathers).

myxobacteriosis: infection caused by bacteria of the order Myxococcales.

myxozoa: diverse group of microscopic parasites of aquatic origin.

negative phase of the PDO: phase of *Pacific Decadal Oscillation* (a type of *inter-decadal* climate variability) characterized by warm and cool sea surface temperatures over the western and eastern North Pacific Ocean, respectively.[100]

nest: depression dug in the gravel substrate by a spawning female sockeye salmon in which her eggs are deposited.[101]

net-pen facility: *aquaculture* facility that uses a net to contain fish, allowing water to pass through (as distinguished from a *closed containment facility*).

nitrate: ion consisting of one atom of nitrogen and three atoms of oxygen.[102]

No Net Loss: principle by which the Department of Fisheries and Oceans strives to balance unavoidable habitat losses with habitat replacement on a project-by-project basis so that further reductions to Canada's fisheries resources due to habitat loss or damage may be prevented.[104]

non–point source: discharges from a diffuse source; non–point sources include runoff from forest management areas, agricultural operations, municipal stormwater, or linear developments.[103]

northern diversion route: return migration route through Johnstone Strait and the Strait of Georgia to the Fraser River.[105]

nursery lake: See *rearing lake*.

ocean-entry year: the year in which a class of sockeye enters the ocean.

orthomyxovirus: RNA virus from the family Orthomyxoviridae.

osmoregulation: regulation of the levels of water and mineral salts in the blood to maintain *homeostasis*.

outlier: measurement or experimental result outside the expected range.

over-escapement: spawning *population* size that is larger than the optimal *escapement* goal;[106] also referred to as under-fishing.

overflights: aerial surveillance of fishing areas used as a technique to monitor fishing activity.[107]

Pacific Decadal Oscillation: atmospheric and oceanic index used to describe the *inter-decadal* variability in the climate of the North Pacific Ocean.[108]

Pacific salmon: salmon of the Pacific Ocean regions, of which 11 species are currently recognized in the genus *Oncorhynchus*.[109]

Pacific Salmon Commission: commission formed under the *Pacific Salmon Treaty* which is directly involved in managing Fraser River sockeye.[110]

Pacific Salmon Treaty: bilateral agreement between Canada and the United States addressing the allocation and *conservation* of Pacific salmon.[111]

Panel Area Waters: geographical area designated under the *Pacific Salmon Treaty* in which Fraser River sockeye and pink salmon management is subject to provisions of that treaty.[112]

parvovirus: one of a group of viruses with small, single-stranded DNA genomes.[113]

pathogen: agent (such as a virus, bacteria, or sea louse) that causes *disease*.[114]

pathogenicity: ability to cause *disease*.[115]

pelagic: of or relating to the open ocean, as opposed to the ocean bottom.[116]

phenological: an organism's biological response to climatic conditions.

phenols: class of organic compound with a hydroxyl functional group.

phytoplankton: small planktonic organisms, mostly single-celled algae, that manufacture their own food by turning sunlight into chemical energy; this process is called autotrophy.[117]

pilot sales fishery: Aboriginal communal economic fishery licensed under the *Aboriginal Communal Fishing Licenses Regulations*.[118]

placer mining: exploitation of placer mineral deposits (formed by gravity separation during sedimentation processes) for their valuable heavy metals.[119]

plasmacytoid: innate immune cells that circulate in the blood ready to respond to pathogens, but not specific to any particular type.[120]

population: group of interbreeding organisms that is relatively isolated (i.e., demographically uncoupled) from other such groups and is likely adapted to the local habitat.[121]

positive phase of the PDO: phase of *Pacific Decadal Oscillation* (a type of *inter-decadal* climate variability) characterized by cool and warm sea surface temperatures over the western and eastern North Pacific Ocean, respectively.[122]

postsmolt: *juvenile* salmon that has undergone the physiological changes necessary to live at sea, emigrated from freshwater, and in its first calendar year at sea.[123]

pre-spawn mortality: females that have arrived on spawning grounds but die with most of their eggs retained in their body.[124]

prevalence: percentage of individuals of a host species infected with a particular parasite species.[125]

productive capacity: maximum natural capability of habitats to produce healthy fish, safe for human consumption, or to support or produce aquatic organisms on which fish depend.[126]

productivity: numbers of returns per *spawner* by *brood year*.[127]

protozoan: There is no exact definition, but the term often refers to unicellular heterotrophic, usually microscopic, eukaryotic organisms such as amoebas and ciliates.

purse-seine fishery: type of fishery involving the use of *seine* nets that are gathered at the bottom to form a "purse."

rearing lake: freshwater lake used by sockeye *fry* to feed and grow before developing into the *smolt* stage.

recreational fishing (sport fishing): non-commercial fishing to provide food for personal use or as a leisure activity.[128]

recruitment: See *recruits*.

recruits: also referred to as "returns"; the *abundance* of adults of a given sockeye *population*, usually estimated by summing the estimated number of *spawners* with abundances of fish that were caught in various fisheries.[129]

redd: sequential series of *nests* dug by a single female *salmonid*.[130]

refugia: places of refuge for salmon;[131] for example, groundwater upwelling that augments stream flow in dry summer months provides localized cooling or "thermal refugia" for migrating *adults* and rearing *juvenile*s.[132]

resource management: departmental actions, policies, and programs affecting Pacific *wild salmon* directly or indirectly through their habitats and *ecosystems*.[133]

retrovirus: any of a family of single-stranded RNA viruses containing an enzyme that allows for a reversal of genetic transcription, from RNA to DNA (rather than the usual DNA to RNA).[134]

returns: catch plus *escapement*, by *ecotype*.[135]

Ricker and Larkin models: two stock-recruitment models that are frequently used to describe Fraser River sockeye population dynamics.[136]

riparian zone: area of vegetation near streams.[137]

run size: one or more stocks of the same species that survive natural *mortality* agents and return to a given freshwater system in a given year.[138]

run-timing groups: groups of fish characterized by the timing of their return migration: Early Stuart, Early Summer, Summer, and Late-run.

salmonid: a group of fish that includes salmon, trout, and char, belonging to the taxonomic family Salmonidae.[139]

scare permit: permit issued by Environment Canada's Wildlife Service that authorizes the scaring away of migratory birds; used by *aquaculture* operators.[140]

scouring: physical disruption of eggs due to high stream flows generated by rainfall; a factor potentially decreasing the survival of eggs.[141]

sector: DFO sectors are national headquarters organizational divisions based on program activities;[142] fishing sectors refer to and distinguish commercial, *recreational*, and Aboriginal fishers.

seine: fishing net that hangs vertically in the water with its bottom edge held down by weights and its top edge buoyed by floats; seine nets can be deployed from the shore as a beach seine or from a boat.

selective fishing: *conservation*-based management approach that allows for the harvest of surplus target species or *Conservation Units* while aiming to release *bycatch* unharmed or to minimize or avoid the harvest of species or stocks for which there is conservation concern.[143]

senescence: deteriorating changes in a cell or organism with aging.[144]

set net: *gillnet* anchored in position rather than drifted or manipulated by hand.

smolt: *juvenile* salmon that has completed rearing in freshwater and migrated into the marine environment. A smolt becomes physiologically capable of balancing salt and water in the estuary and ocean waters. Smolts vary in size and age depending on the species of salmon.[145]

somatic: the body and its cells (as distinguished from reproductive cells).[146]

spawner success: successful reproduction by *spawners*.

spawners: males and females that reach the spawning grounds.[147]

stewardship: acting responsibly to conserve fish and their habitat for present and future generations.[148]

stock: aggregate of *populations* of a single species that are grouped for management purposes. Stock generally have similar migration patterns and *run timing*.[149]

stock assessment: use of various statistical and mathematical calculations to make quantitative predictions about the reactions of fish *populations* to alternative management choices.[150]

stream walks: method of estimating salmon *spawner abundance* by walking along the banks of a stream and counting the number of fish.[151]

sub-adult: not yet *adult* or *mature*.

Summer run: one of the four *run-timing groups* of Fraser River sockeye; the Summer-run stock group spawns in the Chilko, Quesnel, Stellako, and Stuart systems and arrives in the Lower Fraser River from mid-July to early September; the run includes Chilko, Late Stuart, Stellako, and Quesnel sockeye.[152]

superimposition of eggs: placement of eggs on or over other eggs.

surfactant: compounds that lower the surface tension of a liquid; or the interfacial tension between two liquids, or between a liquid and a solid.

systemic: in relation to disease, pertaining to the body as a whole.[153]

tagging program: program that involves tagging of fish or other animals.

telemetry: science and technology of automatic measurement and transmission of data by wire, radio, or other means from a distance.[154]

thermal stratification: change in temperature at different depths of a lake.

Tier 1, Tier 2, Tier 3: part of a three-tier process, involving discussions and organizational relationships among, respectively, First Nations only; First Nations and the federal government; and First Nations, the federal and provincial governments, and third parties.[155]

total allowable catch: estimated quantity of fish that may be harvested or used in the development of fishing plans.[156]

total return: sum of the estimated numbers of *adult* salmon of a population taken in the catch plus the estimate of the number of *spawners* in that *population*, computed across all life-history types; sometimes called *brood-year* returns.[157]

troll: to fish by trolling; trolling is a method of fishing where one or more fishing lines, baited with lures or bait fish, are drawn through the water.

upwelling: oceanographic phenomenon that involves wind-driven motion of dense, colder, and usually nutrient-rich water toward the ocean surface.

vectors: organisms that carry *disease*-causing micro-organisms from one host to another.[158]

vibriosis: *disease* caused by infection with bacteria of the genus *Vibrio*.

virulence: measure of the severity of a *disease* or parasite's impact on its host's fitness.[159]

visceral: pertaining to organs located in the chest and abdomen.[160]

water mass: identifiable body of water with chemical and/or physical properties distinct from surrounding water.

weak stocks: fish stocks identified as having low *productivity*.[161]

wild salmon: Salmon are considered "wild" if they have spent their entire *life cycle* in the wild and originate from parents that were also produced by natural spawning and continuously lived in the wild.[162]

yolk sac: sac containing yolk (nutritious material contained in an egg) that is attached to an embryo.[163]

zooplankton: weakly swimming and drifting planktonic organisms, mostly *protozoa* and small animals such as crustaceans, which must consume *phytoplankton* (or detritus) to survive in a process called heterotrophy.[164]

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YUKON TERRITORY
NORTHWEST TERRITORIES
ALASKA
BRITISH
COLUMBIA
ALBERTA
PACIFIC
OCEAN
Fort St. James
Burns Lake
Fraser Lake
Vanderhoof
Prince George
McBride
Wells
Quesnel
Valemount
Williams Lake
100 Mile House
Clinton
Cache Creek
Chase
Sicamous
Lillooet
Ashcroft
Kamloops
Salmon Arm
Enderby
Logan Lake
Lumby
Pemberton
Lytton
Whistler
Merritt
Hope
Vancouver
Richmond
Chilliwack
Surrey
Abbotsford
Victoria
VANCOUVER
ISLAND
WASHINGTON
IDAHO
MONTANA
Fraser River Basin
Indian Reserve
Municipality
0 50 100 200 300
km

Fraser River Basin
Fraser River Basin
Indian Reserve
Municipality
0 25 50 100 150 km
ALBERTA
WASHINGTON
VANCOUVER ISLAND
Strait of Georgia
Driftwood River
Takla Lake
Middle R.
Trembleur Lake
Tachie R.
Stuart Lake
Fort St. James
Stuart River
Burns Lake
Francois Lake
Fraser Lake
Nechako River
Nadina R.
Stellako R.
Vanderhoof
Prince George
Fraser River
Bowron River
McBride
Bowron Lake
Wells
Valemount
Quesnel
Quesnel River
Mitchell River
Quesnel Lake
Horsefly River
Williams Lake
Chilcotin River
Chilko River
Taseko River
Taseko Lakes
Chilko Lake
100 Mile House
Raft River
North Thompson River
U. Adams River
Momich R.
N. Barriere Lake
Fennell Cr.
Adams Lake
Seymour River
Shuswap Lake
Sicamous
Mara Lake
Clinton
L. Adams River
Scotch Cr.
Chase
Cache Creek
Kamloops Lake
Kamloops
South Thompson R.
Salmon Arm
Enderby
Marble Lake
L. Shuswap R.
M. Shuswap R.
Lumby
Bridge R.
Portage Cr.
Anderson L.
Lillooet
Ashcroft
Seton L.
Seton Cr.
Birkenhead R.
Gates Cr.
Thompson River
Logan Lake
Nicola River
Merritt
Lillooet River
Pemberton
Lillooet Lake
Lytton
Whistler
Nahatlatch R.
HELL'S GATE
U. Pitt R.
Harrison Lake
Pitt Lake
Weaver Cr.
Hope
Coquihalla R.
Harrison R.
Vancouver
Chilliwack
Richmond
Surrey
Abbotsford
Vedder R.
Chilliwack Lake
Chilliwack R.
Cultus L.
Victoria

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