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) **inside** Georgia Strait	Overall	Fair					
	2009	Good					
3b. Ocean conditions (physical and biological) **outside** 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) **inside** Georgia Strait	Overall	Fair					
	2009	Good	X				
3b. Ocean conditions (physical and biological) **outside** 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.