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

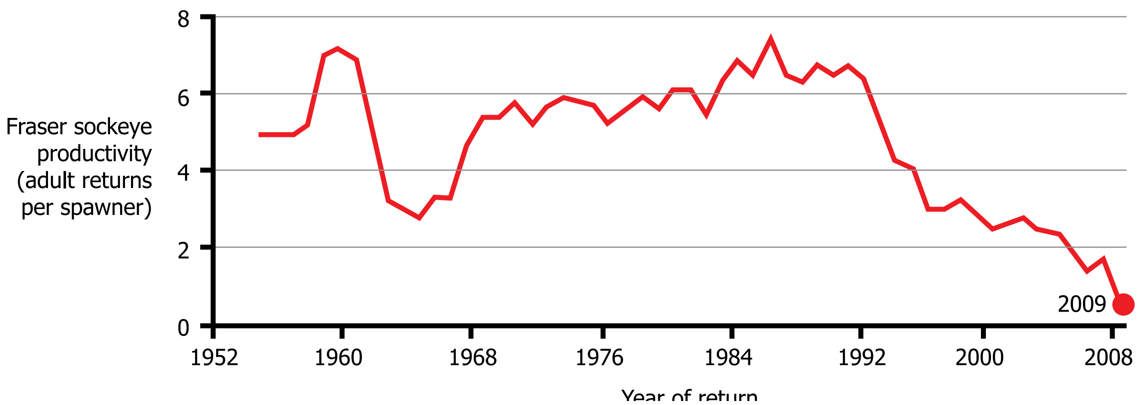


Figure 2.5.1 Fraser River sockeye adult returns per spawner, 1950s–2009

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.

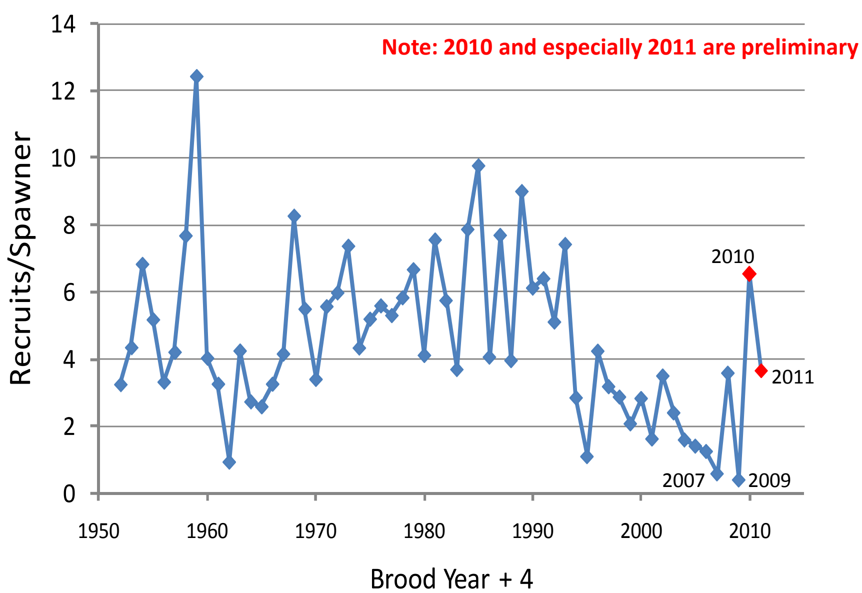


Figure 2.5.2 Annual variation in total Fraser River sockeye productivity, 1952–2011

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.

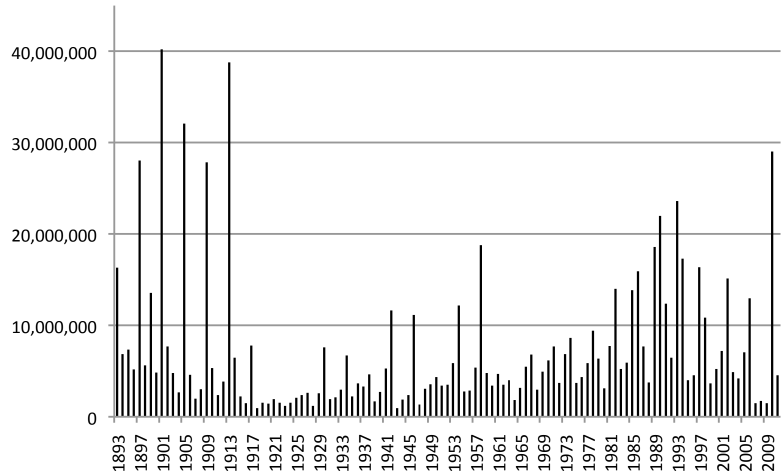


Figure 2.5.3 Total Fraser River sockeye returns, 1893–2011

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

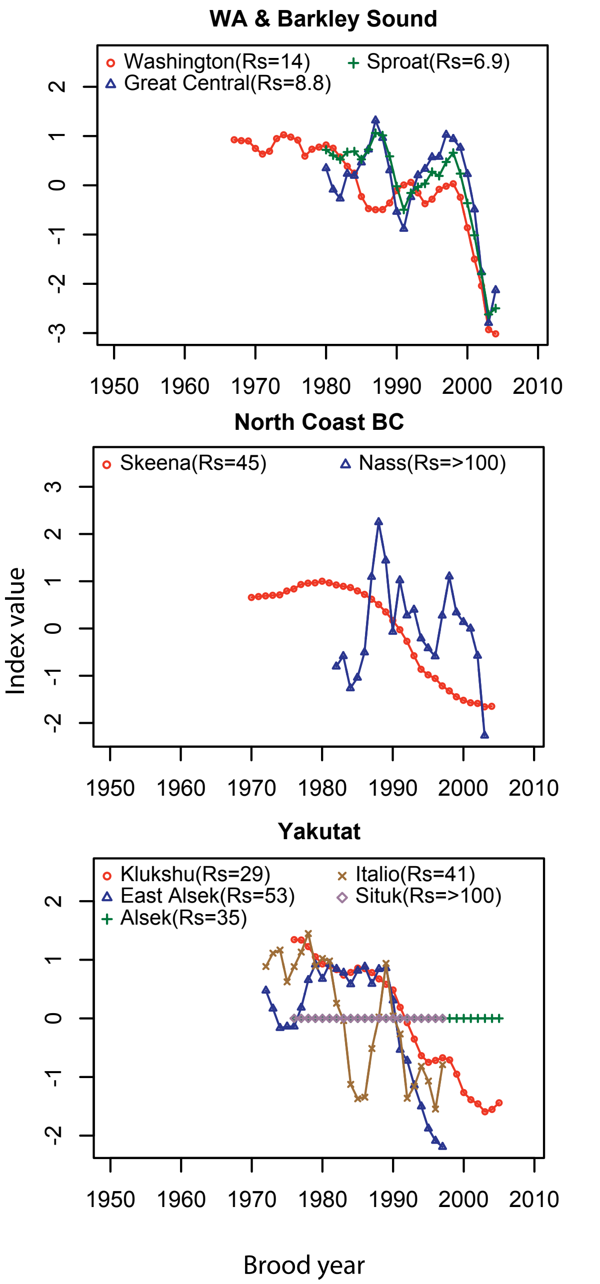
This chart of abundances shows that between 1893 and 1913 there were extraordinarily good returns every four years, but returns of well under 10 million in most intervening years. Since the Hell's Gate rockslide occurred in 1913, returns have gradually increased from about 2 million to about 8 million, 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,



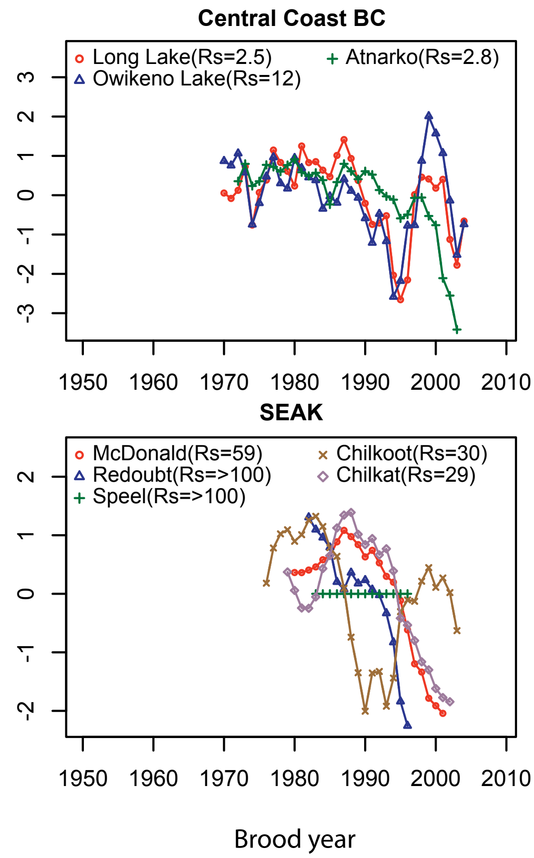


Figure 2.5.4 Scaled Kalman filter time series for non–Fraser River, BC, sockeye salmon stocks, by brood year

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.