Addendum to Technical Report 6

Implications of Technical Reports on Salmon Farms and Hatchery Diseases for Technical Report 6 (Data Synthesis and Cumulative Impacts)

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Prepared for

The Cohen Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River
ADDRESS

Prepared by

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1.0 Introduction

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

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

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

The potential for negative interactions between salmon farms and sockeye salmon is, as demonstrated by public submissions to the Cohen Commission, an issue with a high level of public interest. The sentiment that this issue is "highly polarized" is echoed by all of the authors and most of the reviewers in Project 5. In response to the unique context of this particular topic, the Cohen Commission contracted two reports to evaluate the potential impacts of salmon farms, by two respected experts, both tasked with identical statements of work. The two authors (Noakes 2011 and Dill 2011) were provided with two additional reports intended to provide a common foundation for their investigations, a report synthesizing the data compiled specifically for this project (Korman 2011) and a report performing statistical analyses of these data (Connors 2011). Noakes (2011) and Dill (2011) each applied different analytical methods, reviewed substantially different sets of literature1, and reached divergent conclusions on some issues. Furthermore, peer reviews of these two reports differed substantially amongst the three reviewers.

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

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

2.0 Complexity, Caveats, and Overall Approach

Ecological systems are highly complex and dynamic over time and space. The ability to make definitive conclusions attributing natural or human causes to observed effects is constrained by gaps in the availability and reliability of relevant data as well as by our fundamental understanding of these systems. Large uncertainties can result from the compounding of natural variability, multiple interacting factors, data gaps for most of these factors, time lags between causes and effects, and differing analytical methods. This creates considerable space for a range of potential conclusions or interpretations of the available evidence. We further discuss these concepts in Sections 3.1 and 3.2 of TR6.

For the factors investigated in this memo, data limitations are a particularly important issue. As described by Korman (2011), the disease data compiled for evaluating potential effects of salmon farms are only available starting in 2003[2]. Since productivity data for Fraser River sockeye salmon are only available up to brood year 2004 (i.e., coastal migration of post-smolts in 2006, returns in 2008 or 2009), overlapping data only exists for four years (i.e. brood years 2001-2004, ocean entry 2003-2006). Korman (2011, Appendix 2) explains how so few years of overlapping data will greatly increase the chances of finding a spurious relationship when no true relationship exists as well as the chances of failing to find a relationship when one truly does exist. Either way, the ability to confidently make conclusions about the relationship between two variables or lack thereof is severely limited when based on only four years of overlapping data. For hatchery diseases, the situation is even worse as Stephens et al. (2011) reveal that although there have

[2] Disease data is available for 2002 as well, but because the reporting program was not fully operation, fewer farms reported in 2002 and these data are not directly comparable to data from subsequent years (Korman, 2011).

been cases documenting the release of diseased hatchery fish into the wild, there are simply no reliable data over space and time with which to evaluate the effect such actions may have had on the productivity of wild sockeye salmon.

In this memo, we use a weight of evidence (WOE) approach to retrospective ecological risk assessment, as described in TR6 (Sections 3.3.5 and A3.5.1). Similar to TR6, we apply this WOE approach to synthesize evidence presented within Projects 1a and 5 and assess the overall likelihood that a particular factor has made a substantial contribution to the decline in productivity of Fraser River sockeye salmon. The specific factors evaluated in this memo include waste, escapees, sea lice, and disease from salmon farms, as well as hatchery diseases. The results of these analyses are then incorporated into the previous findings on other stressors within each life history stage, focusing on where these new results alter or modify the existing conclusions or recommendations of TR6. Where necessary, the analysis follows two alternate tracks, respecting the differences between the findings of Noakes (2011) and Dill (2011), rather than trying to reconcile them. In this memo, we highlight the implications that these new results have on the conclusions of TR6. We also examine whether these new results affect the recommendations in TR6 for future research and monitoring, either by adding new items or strengthening the rationale underlying existing ones.

3.0 Results, Synthesis, and Discussion

3.1 Historical Changes in Sockeye Productivity and Salmon Farm Production

Section 4.1 of TR6 summarizes the significant changes observed in sockeye salmon productivity over time and space, in both Fraser and non-Fraser stocks (analysis from Peterman and Dorner 2011). These changes in productivity represent the patterns we are ultimately trying to explain. The productivity of all Fraser River sockeye salmon stocks as an aggregate has been decreasing steadily since the early 1990s. Korman (2011) summarizes the spatial and temporal trends in the data compiled for the Commission for its evaluation of the potential effects of salmon farms on the productivity of sockeye salmon. The total marine salmon production of farms in B.C. increased substantially from the mid-1980s through to the early 2000s, after which it has remained somewhat constant. The majority of production occurs from farms located between Vancouver Island and the mainland, with the majority of all production in B.C. occurring in or near Johnstone Strait, in the areas known as the Discovery Islands and the Broughton Archipelago.

Both Connors (2011, also summarized in Dill 2011) and Noakes (2011) performed statistical analyses evaluating the potential relationship between these two variables (i.e. salmon farm production and the productivity of sockeye salmon), but arrived at seemingly opposing conclusions regarding whether or not they are correlated.

Table 1 summarizes the findings of Connors (2011) and Noakes (2011), noting which stocks, response variables and explanatory variables were included in their analyses. Connors (2011) found statistical support for a negative correlation between the long term patterns in sockeye salmon productivity and the long term patterns in salmon farm production, ocean temperature, and pink salmon. After pre-screening the sockeye productivity and farm production data to remove trends and autocorrelation, Noakes (2011) found that year-to-year changes in the productivity of sockeye salmon are uncorrelated with year-to-year changes in the total production of salmon on farms. The differences in the results of Connors (2011) and Noakes (2011) relate to the different statistical methods applied. As noted by one of the reviewers (R. Routledge review, pg. 108 in Noakes (2011) and pg. 61 in Dill (2011)) the two analyses examine different questions: Connors (2011) evaluates the correlation between the long-term trend in the productivity of sockeye salmon and the long-term trend in salmon farm production, whereas Noakes (2011) evaluates the correlation between the short term, year-to-year fluctuations of pre-screened transformations of these two variables. All of the Technical Reports within Project 5 emphasize that the time series of detailed information on the potential impacts of salmon farms are too short to detect long term effects, and that monitoring of diseases in both salmon farms and wild salmon needs to continue (Connors 2011, Dill 2011, Korman 2011, Noakes 2011).

Table 1. Summary of statistical analyses by Connors (2011) and Noakes (2011) examining the overall relationship between salmon farms and sockeye salmon productivity. R=recruits; S=spawners; Ln=natural logarithm (see Section 4.1 of TR6 for explanations of R and S)

Report	Response Variable	Explanatory Variables	Length of Time Series	Key Findings
Connors (2011)	Ln (R/S) for 32 sockeye stocks (19 Fraser and 13 non-Fraser)	(a) farm salmon production (tonnes) across management areas traversed by sockeye, (b) average sea surface temperatures from Jan-May for marine entry points of each stock, (c) abundance of pink salmon with distributions that overlap N. American sockeye	58 years (1950 – 2007)	- **long term patterns** in the productivity of sockeye salmon are negatively correlated with long term patterns in the production of farmed salmon, sea surface temperatures and pink salmon abundance - large uncertainty around estimated effects
Noakes (2011)	Ln (R/S) after removing autocorrelation and trend in time series	(a) farm salmon production (tonnes) across management areas traversed by sockeye after removing autocorrelation and trend in time series	27 years (1980-2006)	- **year-to-year changes** in sockeye survival uncorrelated with year-to-year changes in farm salmon production

Connors (2011) and the reviewers of his report, suggest several ways in which the analyses of the potential relationship between salmon farm production and sockeye salmon productivity might be further improved, including alternate analyses, additional variables, updated data, and experimental approaches. Future analyses should also consider non-linear analytical methods, as supported by substantial evidence in epidemiology (Connors 2011). Developing independent measures of salmon farm variables for each stock would strengthen the analyses, whereas the current analyses compare multiple stocks to a single measure of farm impact, increasing the probability that the observed relationship represents a confounding factor (Connors 2011). Connors (2011) and two of the peer reviewers of his report recommend that his statistical analyses should be revisited once the data on the very strong 2010 sockeye returns are available. Two of the peer reviewers of Connors' report suggest that experimental manipulation of salmon farm production may be required to get strong enough contrast in treatment effects to reliably detect effects, if such effects truly exist.

3.2 Potential Interactions between Salmon Farms and Sockeye Salmon

Salmon farms could potentially affect sockeye salmon during both the coastal migration of post-smolts and the migration of adults returning to the Fraser River. The vast majority of sockeye salmon post-smolts migrate through the Strait of Georgia and Johnstone Strait on their way to the Gulf of Alaska, whereas a small portion of post-smolts from some stocks in some years may exit the Strait of Georgia through the Strait of Juan de Fuca (see McKinnell et al. 2011). Returning adults use both of these pathways, though the proportional distribution varies from year to year and has changed over time (see Section 4.5.2 in TR6, and Section 4.6 in McKinnell et al. 2011). **Figure 1** illustrates where these two potential interactions are situated within the context of the life history of Fraser River sockeye salmon and other potential stressors examined by the other Technical Reports of the Cohen Commission. All stressors can potentially have delayed impacts on later life history stages (see Figure 2.3-1 in TR6).

The potential interactions between salmon farms and Fraser River sockeye salmon are more complex than those represented in **Figure 1**. Noakes (2011) and Dill (2011) examine four hypothetical mechanisms in which salmon farms might theoretically have an effect on sockeye salmon, including waste, escapees, sea lice, and disease. **Figure 2** illustrates the detailed pathways by which salmon farms might change their immediate environment and consequently effect sockeye productivity (as described in Noakes (2011) and Dill (2011)), regardless of the plausibility, strength, or likelihood of effect. The potential pathways related to structural impacts of salmon farms (e.g. lights used on farms or backeddies created by the physical presence) are not included in the model since they are not one of the primary mechanisms under consideration and are only discussed briefly by Dill (2011).

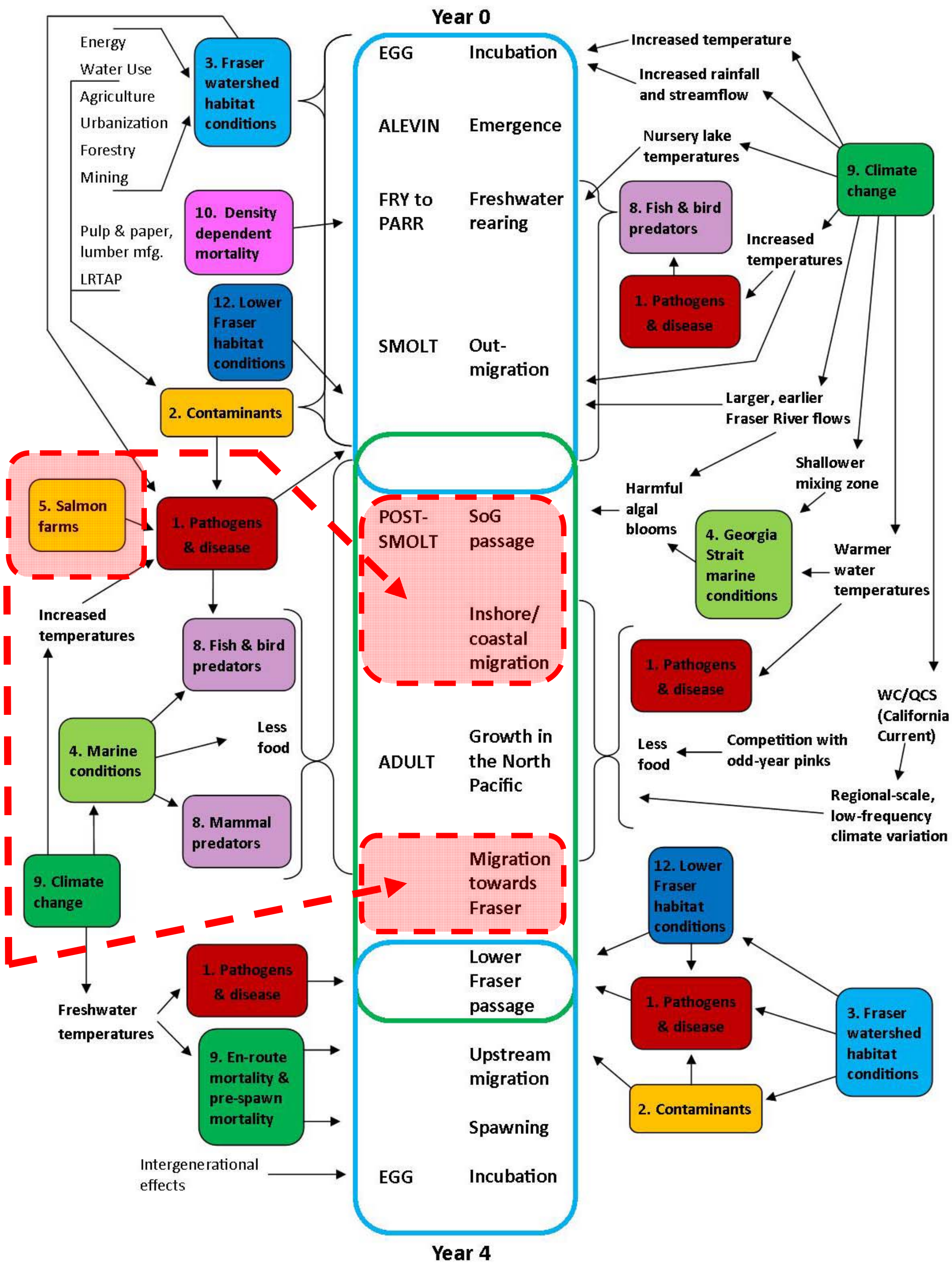

Figure 1. Conceptual model of the life history of Fraser River sockeye salmon and potential stressors affecting each life stage, as previously presented in TR6 (Section 3.3.2), supplemented by pink highlighting to indicate life history stages that could potentially be affected by exposure to disease from salmon farms. Figure 2 provides a more detailed conceptual model with other hypothetical mechanisms of impact. As discussed in TR6 (Figure 2.3-1), impacts at any life history stage may have delayed effects at later life history stages.

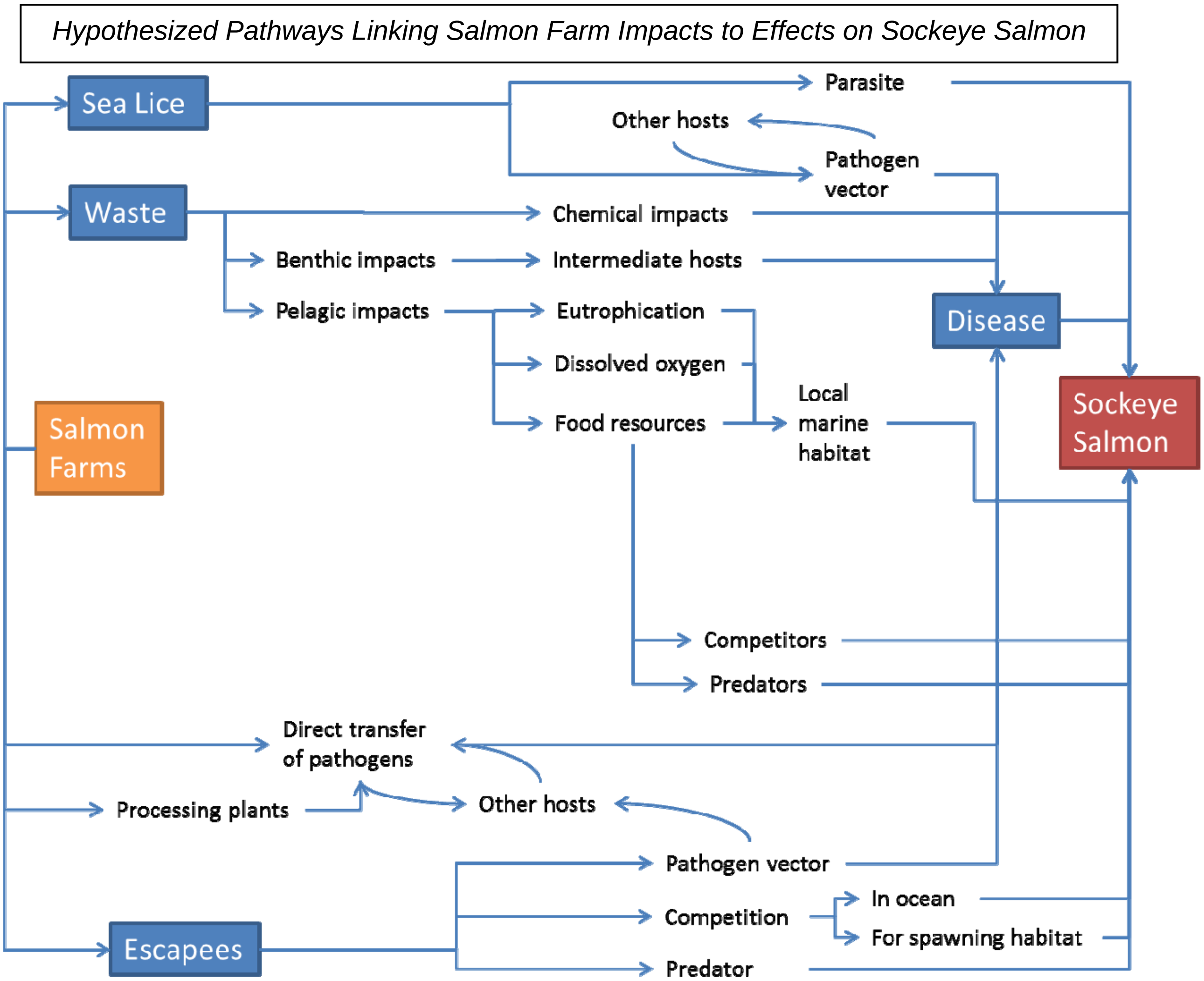

Figure 2. Conceptual diagram of the hypothesized pathways by which the four major mechanisms (blue boxes) evaluated by Noakes (2011) and Dill (2011) could potentially link direct impacts of salmon farms to negative effects on sockeye salmon. The pathways shown are not necessarily proven or supported by evidence. This diagram simply illustrates the pathways discussed in the two reports, regardless of the ultimate conclusions by either report on the plausibility or likelihood of being a significant factor.

3.3 Weight of Evidence Analysis

3.3.1 Waste

Salmon farms produce biological and chemical waste in the form of excretions from salmon, unprocessed food, and chemicals associated with salmon farm activities (e.g., antibiotics, chemotherapeutants, antifoulants, food additives, and disinfectants).

PLAUSIBILITY:

Waste can potentially affect sockeye salmon through three hypothesized mechanisms (see **Figure 2**; summarized from Noakes 2011 and Dill 2011). First, biological waste could change the biophysical conditions and composition of benthic communities immediately below and adjacent to salmon farms. Second, biological waste could change nutrient concentrations, oxygen levels and/or the biological productivity of the water column in the vicinity of salmon farms. Both of these pathways are hypothesized to affect the survival of migrating salmon. Lastly, chemical waste could directly and indirectly (through impacts on food availability) affect sockeye salmon growth and survival. See Section 3.3.5 for a discussion of the benthic environment acting as a pathogen vector.

EXPOSURE & CORRELATION / CONSISTENCY:

The evidence of exposure presented by both Noakes (2011) and Dill (2011) is based on studies investigating the impacts of waste from salmon farms on benthic and pelagic environments, not sockeye salmon directly. Though some sockeye salmon could be exposed to environments altered by salmon farms, both Noakes (2011) and Dill (2011) conclude that the effects of waste from salmon farms will likely be small and localized (i.e., within metres) in part due to high flushing and mixing of waters within the Discovery Islands. Consequently, both Noakes (2011) and Dill (2011) determined that the localized scale of potential exposure is inconsistent with the observed declines in total productivity.

OTHER EVIDENCE:

Noakes (2011) and Dill (2011) do not present any other evidence that would support or refute the hypothesis that waste from salmon farms is responsible for the declines in productivity of Fraser River sockeye salmon.

CONCLUSION:

Despite following different logic paths, the evidence presented by Noakes (2011) and Dill (2011) both lead to the same conclusion, that it is *unlikely* that waste from salmon farms are a primary factor in explaining the observed declines in the productivity of Fraser River sockeye salmon (see **Table 2**). Dill (2011) recognizes the plausibility of the mechanisms and potential for exposure, but concludes that waste is an unlikely contributor due to an inconsistency in the scale of anticipated effects and observed population level declines. Noakes (2011) concludes that the mechanisms are not plausible and exposure is unlikely because any adverse effects on benthic and pelagic environments will be extremely localized. The only other major difference between these authors is that Dill (2011) considers the pathways of effects associated with chemical waste, while Noakes (2011) does not.

THINGS TO KNOW BETTER:
Both Noakes (2011) and Dill (2011) recognize the need to monitor water quality so as to better understand the impacts of waste on the marine environment. Dill (2011) notes the need to understand the cumulative impact of repeated exposure to poor water quality and pathogens when passing multiple farms in succession. Noakes (2011) recommends regular and routine monitoring and reporting of both water quality and oceanographic data, and the establishment of a system for ensuring public access to these data.

3.3.2 Escapees

Adult and juvenile Atlantic salmon are known to escape from salmon farms, which have the potential to interact with Pacific salmon, including sockeye.

PLAUSIBILITY:
Possible impact pathways include predation on sockeye by Atlantic salmon, and competition between Atlantic and Pacific salmon in marine and/or freshwater environments (see **Figure 2**; summarized from Noakes (2011) and Dill (2011)). See Section 3.3.5 for a discussion of Atlantic salmon escapees as a pathogen vector.

EXPOSURE:
Although Atlantic salmon escapees have been documented in the Strait of Georgia and Fraser River basin, both Noakes (2011) and Dill (2011) conclude that exposure has been insufficient to pose a significant concern to sockeye via predation or competition. The authors are confident in this assessment despite some concerns over the quality of data available to describe the numbers, historical trend, and spatial extent of Atlantic salmon escapees. Noakes (2011) notes that the lack of exposure is due, in part, to the inability of Atlantic salmon to colonize the Pacific Northwest despite deliberate attempts to do so in the early 1900s, as well as being farmed for several decades more recently. Similarly, in the Great Lakes Atlantic salmon have failed to re-establish themselves following the introduction of Chinook salmon in the region. Dill (2011) adds that predation on sockeye is unlikely given that Atlantic salmon captured in the ocean have shown few signs of feeding and no confirmed cases of juvenile sockeye in their gut contents.

CORRELATION / CONSISTENCY:
Both Noakes (2011) and Dill (2011) indicate there is no evidence of a correlation between Atlantic salmon escapees and effects on sockeye salmon. They note that few Atlantic salmon have been found in the Fraser River basin, their spatial distribution has been limited, and colonization of freshwater areas has been lacking despite an availability of suitable habitats and their continued presence over several decades.

OTHER EVIDENCE:
Neither Noakes (2011) nor Dill (2011) present further evidence supporting or refuting the hypothesis that Atlantic salmon escapees are having an adverse effect on sockeye salmon.

CONCLUSION:
Noakes (2011) and Dill (2011) differ greatly in the amount of evidence they use to assess the effects of escapees on sockeye salmon. Dill (2011) considers only a few pieces of evidence. Noakes (2011) is more thorough in assessing the number of escapees, their behavioural characteristics, the availability and status of habitats for spawning and rearing, and ecological interactions with other salmonids. Despite these differences, the evidence presented by Noakes (2011) and Dill (2011) each lead to the same conclusion, that it is *unlikely* that Atlantic salmon escapees are a primary factor in explaining the observed declines in the productivity of Fraser River sockeye salmon (see **Table 2**).

THINGS TO KNOW BETTER:
Neither Noakes (2011) nor Dill (2011) identify any knowledge or data gaps that are needed to improve our understanding of the impacts of Atlantic salmon escapees on sockeye salmon.

3.3.3 Sea Lice

Atlantic salmon in farms are infected by two species of sea lice – herring louse (*Caligus clemensi*) and salmon louse (*Lepeophtheirus salmonis*) – which can act as parasites and potentially interact with Pacific salmon, including sockeye.

PLAUSIBILITY:
A direct and plausible concern is that salmon farms are a source of sea lice infestation, which can affect survival of juvenile sockeye salmon along their coastal migration as driven by direct changes in survival, swimming performance, endurance, and behaviour (see **Figure 2**; summarized from Noakes (2011) and Dill (2011)). Though not stated explicitly, by their detailed consideration of the evidence both authors imply that this pathway of effect is plausible. See Section 3.3.5 for a discussion of sea lice as a pathogen vector.

EXPOSURE:
Both Noakes (2011) and Dill (2011) recognize that sockeye and other species of Pacific salmon are exposed to sea lice. However, the presence of sea lice along the coastal migration on its own does not imply that salmon farms are key sources of infestation, and that exposure poses a significant additional stressor on survival, in part because sea lice have been present in the Pacific Northwest prior to the development of salmon farms.

Dill (2011) states there is evidence that sockeye salmon in areas adjacent to salmon farms in the Discover Islands are infested with sea lice, which appear to be at higher levels than areas along the North Coast without salmon farms. Moreover, evidence of exposure is supported by a study that documents increases in infestation of sockeye by sea lice that migrate past the Discovery Islands. However, Dill (2011) also states that there have been no experimental studies that examine the relationship between exposure to sea lice and survival of sockeye salmon, though studies on other salmon species suggest that salmon farms are a likely source of infestation.

Noakes (2011) explicitly considers a larger body of evidence to evaluate the potential impacts of sea lice from salmon farms on Fraser River sockeye. The author recognizes that sea lice, if present in large numbers, can cause mortality on sockeye salmon and other species of Pacific salmon. However, Noakes (2011) has concerns about the interpretation of data from studies examining the relationship between sea lice and Pacific salmon in the Discovery Islands, which have led some researchers to the conclusion that salmon farms are a likely source of exposure. Among the reasons for concern are that the available studies are incomparable due to differences in measurement methods and / or do not properly account for environmental covariates when attributing elevated abundance of sea lice on salmon to salmon farms. Likewise, Noakes (2011) has a variety of concerns about extrapolating findings from studies examining salmon farm – sea lice interactions in the Atlantic to the Pacific Ocean.

Thus, given the conflicting assessment of evidence there remains some uncertainty as to whether exposure to sea lice from salmon farms is affecting survival of Fraser River sockeye salmon.

CORRELATION / CONSISTENCY:

Both Noakes (2011) and Dill (2011) indicate that there is no evidence of a correlation between sea lice abundance and survival of sockeye salmon. This determination is based in part on the Connors (2011) analysis, which did not find a relationship between four measures of sea lice abundance and survival of Fraser River sockeye. Noakes (2011) further cites an overall decrease in average number of sea lice per fish within the last decade, and a lack of consistency between low levels of sea lice abundance in 2007 and 2008, the years of juvenile coastal migration that are associated with extremely low and extremely high adult returns in 2009 and 2010, respectively.

OTHER EVIDENCE:

Noakes (2011) considers three further pieces of evidence which suggests there is a lack of specificity in the way sea lice from salmon farms would have impacts on sockeye salmon. In particular, this evidence suggests that: (1) wild Pacific salmon are the likely source of infestation on salmon farms (not vice versa); (2) juvenile sockeye salmon are likely more tolerant to sea lice infestation than other salmon species because they are larger; and (3), Pacific salmon are likely more resistant to lice than Atlantic salmon.

CONCLUSION:
Although, Noakes (2011) and Dill (2011) differ in their consideration and interpretation of the evidence (summarized above), the evidence they present leads to the same conclusion, that it is *unlikely* that sea lice, acting as a parasite, is a primary factor in explaining the observed declines in the productivity of Fraser River sockeye sockeye salmon (see **Table 2**). See Section 3.3.5 for a discussion of sea lice as a pathogen vector.

THINGS TO KNOW BETTER:
Both Noakes (2011) and Dill (2011) provide guidance on knowledge or data gaps that would improve our understanding about the impacts of sea lice as a parasite on sockeye salmon. In particular, Dill (2011) suggests a need to improve our understanding of:

- the cumulative impact of repeated exposure to poor water quality and pathogens (including lice) when passing multiple farms in succession;

- the impact of both species of lice (*Lepeopthierus salmonis* and *Caligus clemensi*), and of other pathogens, on feeding, vulnerability to predators and survival of sockeye smolts; and

- the interaction of lice and other pathogens with other stressors in the marine environment, such as low food availability and pollutants.

Noakes (2011) recommends a need to:

- maintain the scope and level of fish health and sea lice monitoring and reporting currently in place for the salmon aquaculture industry;

- maintain the 3 lice/fish trigger for treating sea lice but only for the period March – June when the juvenile Fraser River sockeye salmon are migrating past salmon farms;[3] and

[3] Noakes (2011) notes that adult salmon returning to spawn carry high levels of lice. Treating sea lice on farms during the late summer and fall will not substantially reduce the risk of sea lice infection from *L. salmonis* but increases the risk of the sea lice developing a resistance to SLICE.

- examine the lethal and sub-lethal effects of sea lice (*L. salmonis* and *C. clemensi*) on juvenile sockeye salmon.

3.3.4 Disease

Salmon farms can be a source of infectious (and endemic) diseases that infect wild Pacific salmon, including sockeye.

PLAUSIBILITY:
A plausible concern is that known pathogens found on salmon farms (which include "high risk" diseases identified by Kent (2011)) could be directly transferred, or indirectly transferred through an intermediate vector / host which then infects, causes death, and/or impairs physiological function of Fraser River sockeye salmon (see **Figure 2**; summarized from Noakes (2011) and Dill (2011)).

EXPOSURE:
Noakes (2011) and Dill (2011) have opposing views on the exposure of Fraser sockeye salmon to diseases from salmon farms.

Dill (2011) presents evidence that the "high risk" diseases that have been documented on salmon farms can be directly or indirectly (through an intermediate host or vector) transferred to sockeye salmon. Evidence in support of exposure through direct transfer is based on studies that document the abilities of diseases to transfer through the water column or susceptibility of sockeye salmon to infection from other fish. Dill (2011) also hypothesizes that sockeye salmon can be exposed to pathogens from salmon farms that are transferred through intermediate hosts in the benthic environment or waste from processing plants, or carried by pathogen vectors such as Atlantic salmon escapees or sea lice.

Though not stated explicitly, Noakes (2011) implies that exposure of Fraser sockeye to the "high risk" diseases found on salmon farms is unlikely because fish health within the industry is closely monitored, industry and government health reports over the last decade show few cases of "high risk" diseases, diagnostic tests are very accurate (meaning underreporting is unlikely), and a latent form of the disease is unlikely without an active outbreak.

CORRELATION / CONSISTENCY:
Again Noakes (2011) and Dill (2011) differ in their interpretation of the presence of a correlation between fish farm origin diseases and Fraser sockeye salmon.

Dill's (2011) overall concern with salmon farms is based on: (1) Connors' (2011) analysis that found a negative correlation between salmon farm production and sockeye productivity; and (2) other studies which demonstrate concerns associated with salmon farms. Connors (2011) could not find a relationship between the variables representing the underlying mechanisms (i.e., sea lice or diseases) due to a limited number of years of data. However Dill's (2011) examination of further evidence led him to believe that disease transfer from salmon farms is the most likely mechanism of concern that could explain the negative correlation between salmon farm production and sockeye productivity described by Connors (2011).

Noakes (2011) does not accept Connors' (2011) analysis, and asserts that based on his own analysis no correlation exists between salmon farm production and observed declines in productivity of sockeye salmon. These opposite conclusions reflect different statistical methods (see Section 3.1). Noakes (2011) also presents three other points against the disease hypothesis: Connors (2011) disease-specific analyses fail to identify a correlation between disease and sockeye productivity[4]; Korman's (2011) summary of industry and government data show that the incidence of "high risk" diseases on salmon farms is limited in time and space and could therefore not be responsible for observed declines in sockeye productivity; and the number of salmon farms reporting disease concerns has been small, geographically clustered, and declining in recent years (suggesting the spatial distribution of disease concerns is limited).

OTHER EVIDENCE:

No other evidence is presented by Noakes (2011) and Dill (2011) that would support or refute the hypothesis that diseases from salmon farms are having an adverse effect on Fraser River sockeye salmon.

CONCLUSION:

Noakes (2011) and Dill (2011) differ in both their interpretation of the evidence (summarized above), which leads to divergent conclusions about the likelihood that diseases from salmon farms are related to observed declines in productivity of Fraser River sockeye salmon (see **Table 2**). Both Noakes (2011) and Dill (2011) agree that there is a plausible link, but disagree in their assessment of the exposure of Fraser sockeye to fish farm diseases, and whether a correlation exists between diseases of farm origin and Fraser sockeye productivity. These differences in the interpretation of the available evidence lead to divergent conclusions regarding the likelihood that diseases from salmon farms are a primary factor in explaining the observed declines in the productivity of Fraser River sockeye salmon. The evidence as presented by Dill (2011) leads to a

[4] As discussed in section 2.0, Korman (2011, Appendix 2) explains how having only four years of overlapping data on disease and sockeye productivity greatly increases the chances of finding a spurious relationship when no true relationship exists, as well as the chances of failing to find a relationship when one truly does exist.

conclusion of *possible* and the evidence as presented by Noakes (2011) leads to a conclusion of *unlikely*.

THINGS TO KNOW BETTER:

Among the pathways of effects that are potentially relevant to salmon farms (see **Figure 2**), the greatest knowledge and data gaps are associated with diseases. Both Noakes (2011) and Dill (2011) recognize these uncertainties by devoting the greatest attention to this issue in their recommendations. In particular, Dill (2011) recommends improving our understanding of:

- the cumulative impact of repeated exposure to poor water quality and pathogens (including lice) when passing multiple farms in succession;
- the possible presence of a retrovirus on farmed Atlantic and chinook salmon, and the relationship (if any) of this to the causative agent of salmon leukemia (aka marine anemia) found in Chinook;
- the infective state of apparently healthy salmon in net pens (i.e., their potential to be sources of shed viruses and bacteria);
- the potential for lice to act as vectors of high risk pathogens causing such diseases as BKD, IHN and furunculosis;
- the impact of both species of lice (Lepeopthierus salmonis and Caligus clemensi), and of other pathogens, on feeding and anti-predator abilities and survival of sockeye smolts;
- the potential for bloodwater from processing plants to be a source of infection;
- the evolution of resistance and/or increased virulence in sea lice treated with SLICE®;
- interactions of lice and other pathogens with other stressors in the marine environment, such as low food availability and pollutants;
- disease incidence and levels in wild sockeye; and
- the potential for biological control of pathogens on farms (perhaps using mussels, which have been shown to effectively remove *Renibacterium salmoninarum* from seawater; Paclibare et al. 1994).

Noakes (2011) adds that there is a need to:

- maintain the scope and level of fish health and sea lice monitoring and reporting currently in place for the salmon aquaculture industry;

- develop long-term disease monitoring programs for wild fish to provide data to the same level of quality and detail as available from the aquaculture industry (including monitoring the abundance and prevalence of sea lice and pathogens of concern for salmon);

- develop fish health management plans for all federal and provincial hatcheries including all CEDP (Community Economic Development Program) facilities comparable to and consistent with those required for the salmon farming industry; and

- mandatory fish health monitoring and reporting programs for all federal, provincial and CEDP hatcheries consistent with the standards applied to the salmon farming industry.

3.3.5 Hatchery Disease

Facilities that enhance production of all five species of Pacific salmon can be a source of infectious (and endemic) diseases that infect wild Pacific salmon, including sockeye.

PLAUSIBILITY:
Given documented cases of infectious diseases at enhancement facilities within the Fraser River basin and /or Strait of Georgia (including some of the “high risk” diseases identified by Kent (2011)) and evidence of releases of those diseases into fish bearing waters, it is plausible that hatchery origin diseases could infect, cause death, and /or impair physiological function of Fraser River sockeye salmon (as indicated by Stephen et al. (2011)).

EXPOSURE:
Stephen et al. (2011) considered exposure to an infectious disease as a function of the geographic distribution of the escaped pathogen, the abundance of the pathogen in the receiving environment, and the number of transmissions relative to the total number of fish exposed to a pathogen. As no data were available to describe any of these factors, Stephen et al. (2011) were unable to assess exposure of Fraser River sockeye salmon to hatchery origin diseases.

CORRELATION / CONSISTENCY:

Due to a lack of information on the frequency and prevalence of infectious diseases in sockeye salmon, Stephen et al. (2011) could not assess whether any correlations exist or consistency of patterns between hatchery origin diseases and observed declines in productivity of Fraser River sockeye salmon.

OTHER EVIDENCE:
No other evidence was considered in Stephen et al.'s (2011) assessment of impacts of hatchery origin diseases.

CONCLUSION:
Although deemed plausible by Stephen et al. (2011), based on a lack of available data describing exposure and a lack of evidence of a correlation, it is not possible to reach a conclusion on the likelihood of impacts of hatchery origin diseases on observed declines in productivity of Fraser sockeye salmon (see **Table 2**).

THINGS TO KNOW BETTER:
Stephen et al. (2011) provide a comprehensive list of management and research recommendations, some of which will help address critical gaps in our ability to understand the impacts of hatchery origin diseases on sockeye salmon. These recommendations include:

- adopting an adaptive management approach that uses systematic monitoring and ongoing evaluation of DFO and FFSBC fish health services and programs to assess the effectiveness, efficiency and acceptability of not only the following recommendations but ongoing program activities;
- developing consistent and transparent processes for assessing the risk of releasing enhanced salmonids into fish bearing waters;
- improving capacity for auditing and oversight of fish health, especially in terms of risks to wild fish (salmonids and non-salmonids); and
- identifying the health standard for acceptable risk.

3.3.6 Summary

The results of the weight of evidence evaluation of the potential contributing factors considered in this memo are shown in **Table 2**. The evidence presented by both Noakes (2011) and Dill (2011) on **waste**, **escapees**, and **sea lice** suggest that these three potential stressors are each *unlikely* to have made a significant contribution to the observed declines in Fraser River sockeye salmon. Although the evidence from these two reports leads to similar conclusions for these three factors, the pathway by which those conclusions are reached differ between the two reports for waste and sea lice, as described in Sections 3.3.1 and 3.3.3. For **waste**, the two reports disagree on whether the mechanism for impacting sockeye salmon is even plausible but agree that, if such an effect existed, the exposure of sockeye salmon to it would be insignificant. The two reports agree that the mechanism for sea lice having impacts on sockeye salmon is plausible, disagree on whether sockeye salmon are or have been subject to significant exposure to sea lice as a parasite, but agree that the available evidence does not suggest a correlation between sea lice and sockeye salmon productivity. Noakes (2011) presents other forms of evidence that further support the common conclusion. Both reports agree that **escapees** represent a plausible mechanism but that exposure to this factor is insignificant.

Both Noakes (2011) and Dill (2011) agree that **diseases of salmon farm origin** represent a plausible mechanism for salmon farms to adversely affect wild sockeye salmon. However, they completely disagree in their interpretation of the literature and available data regarding whether Fraser River sockeye salmon are exposed to this potential stressor and whether there exists any correlation between salmon farm diseases and sockeye salmon productivity. As a result of these divergent interpretations of the available evidence, each of the reports leads to a different assessment of the overall likelihood that diseases of salmon farm origin have been a primary factor in the observed declines in productivity – the evidence as presented by Noakes (2011) leads to a conclusion of *unlikely* and the evidence as presented by Dill (2011) leads to a conclusion of *possible*. **Figure 3** illustrates the potential pathways that remain *possible* according to the evidence presented by Dill (2011). The evidence presented by Noakes (2011) leads to the conclusion that all of the pathways in Figure 3 are *unlikely*.

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

Table 2. Determination of the relative likelihood that the potential stressors considered in this memo have been primary factors in the observed declines in productivity of Fraser River sockeye salmon.

Factor	Author(s)	Mechanism	Exposure	Correlation/ Consistency	Other Evidence	Likelihood
Waste	**Dill**	Yes	No	No	-	Unlikely
	Noakes	No	No	No	-	Unlikely

Factor	Author(s)	Mechanism	Exposure	Correlation/ Consistency	Other Evidence	Likelihood
Escapees	**Dill**	Yes	No	No	-	Unlikely
	Noakes	Yes	No	No	-	Unlikely
Sea Lice	**Dill**	Yes	Yes	No	-	Unlikely
	Noakes	Yes	No	No	No	Unlikely
Disease – salmon farm origin	**Dill**	Yes	Yes	Yes	No data	Possible
	Noakes	Yes	No	No	-	Unlikely
Disease – hatchery origin	**Stephen et al.**	Yes	No data	No data		No conclusion possible

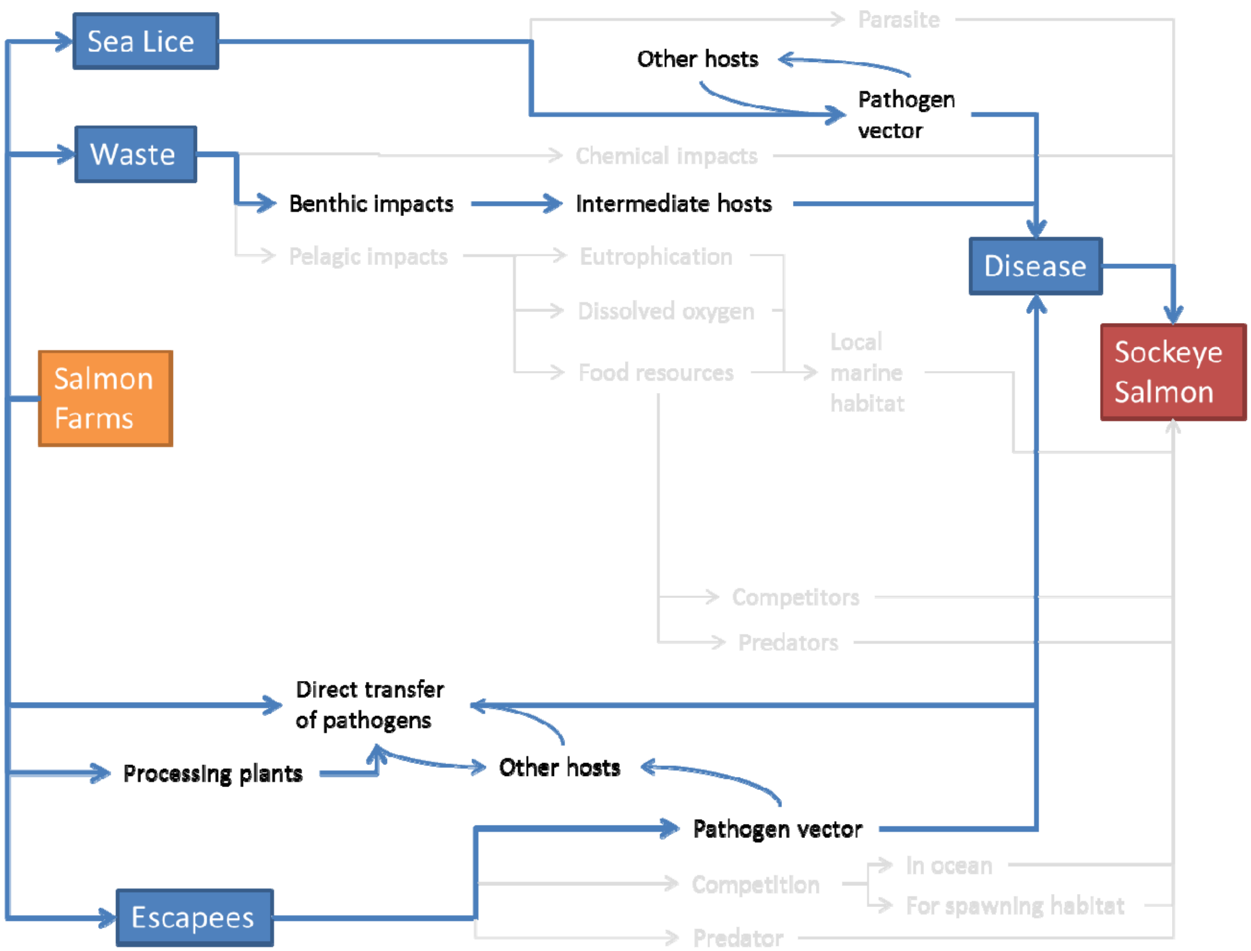

Figure 3. Mechanisms identified as possible or no conclusion possible, ***based on Dill (2011)***. These factors remain as possible influences on sockeye salmon survival, with an uncertain magnitude of effect (including the possibility of no effect), but cannot be definitively rejected or assigned a relative likelihood of "unlikely" with the evidence currently available, as presented by Dill (2011).

4.0 Implications for Cumulative Effects Analysis

4.1 Effects over Entire Life Cycle

Section 4.7 in the TR6 provides qualitative discussion of the potential for cumulative effects over the entire life cycle, and summarizes the results of both our qualitative and quantitative analyses assessing the relative importance of different potential stressors. In this section, we integrate the results from Section 3.3 into the results of the TR6 (Section 4.7) and discuss the implications that these new results have on our previous conclusions. **Table 3** represents the final results table from TR6, expanded to include the new results for hatchery diseases and the four salmon farm mechanisms.

One of the major conclusions of TR6 is that, "We found only two factors (**marine conditions** and **climate change**) which were *likely* to have been a primary factor in the observed declines in Fraser sockeye productivity (recruits/spawner) over the last two decades." (TR6 Section 4.7.1, p. 88, emphasis added). This conclusion specifically applies to the two factors as they affect sockeye salmon during their "coastal migration and migration to rearing areas" life history stage. This conclusion remains unchanged by the new results, which do not add any further *likely* candidates, though the importance of marine conditions (i.e., sea surface temperature) is further supported by the results of the analyses by Connors (2011).

TR6 also identified three stressors which were *possible* primary factors in the observed declines in the productivity of Fraser River sockeye over the last two decades: **marine conditions** subsequent to the outgoing migration; **climate change** as affecting multiple life history stages; and **predators** during both marine stages. The results summarized in this memo expand the conclusions of the TR6 by adding **diseases of salmon farm origin** as another *possible* factor (when based on the available evidence as presented and interpreted by Dill (2011), though considered *unlikely* when based on Noakes (2011) as discussed below). Kent (2011; pgs. 21-22) notes that warming temperatures can potentially increase both the susceptibility of salmon to disease, as well as the abundance of certain pathogens.

The results from this memo add **waste**, **escapees**, and **sea lice** from the operations of salmon farms to the list of factors previously identified as being *unlikely* to have been primary factors in the observed declines in the productivity of Fraser River sockeye salmon. However, these conclusions are based on the impacts of each of these factors that do not include their potential role in disease transfer – all disease related pathways associated with these factors are considered within the disease mechanism. The new results also add **diseases of salmon farm origin** as an *unlikely* factor (when based on the available evidence as presented and interpreted by Noakes (2011), though considered *possible* when based on Dill (2011) as discussed above). However, we must reiterate that all of these factors "…were judged to be *unlikely* as primary causes of long term productivity declines, though they may still have been contributory factors. That is, stressors that we consider unlikely to be primary causes of productivity declines may combine with other factors to create sufficient cumulative stress to kill salmon (i.e., through additive or greater than additive (synergistic) interactions) in some stocks in some years." (TR6 Section 4.7.1, p. 88). A conceptual discussion of cumulative effects, including how relatively minor factors can interact or compound to produce cumulative stress appears in Section 2.0 of TR6.

The only factor previously assessed as *no conclusion possible* was **pathogens and disease**. The results of this memo arrive at the same conclusion for **diseases of hatchery origin**. These factors may play an important role in the observed declines in productivity, or a moderate role, or no role. The lack of reliable data simply precludes the ability to make any conclusions regarding the likelihood that either of these factors have been primary factors. The independent analyses by Kent (2011) and Stephen et al. (2011) both concluded that there were insufficient data on how diseases affect sockeye salmon populations, emphasizing the importance of filling this data gap. Furthermore, disease was the only salmon farm factor in which disagreement between Noakes (2011) and Dill (2011) in the interpretation of the available evidence ultimately led to divergent conclusions, which further underscores the importance of this knowledge gap.

Table 3. Evaluation of the relative likelihood that potential stressors encountered by Fraser River sockeye salmon during each life history stage have contributed to overall declines in productivity in recent decades, based on Sections 4.2 to 4.6. in the TR6 and Section 3.3 in this memo. The new results from this memo are highlighted in grey. n.a. = not applicable to or not assessed at a given life history stage.

Factor	Life History Stage				
	1. Incubation, Emergence and Freshwater Rearing	2. Smolt Outmigration	3. Coastal Migration and Migration to Rearing Areas	4. Growth in N. Pacific and Return to Fraser	5. Migration back to spawn
Forestry[a]	Unlikely	Unlikely	n.a.	n.a.	Unlikely
Mining	Unlikely	Unlikely	n.a.	n.a.	Unlikely
Large hydro	Unlikely	Unlikely	n.a.	n.a.	Unlikely
Small hydro	Unlikely	Unlikely	n.a.	n.a.	Unlikely
Urbanization above Hope	Unlikely	Unlikely	n.a.	n.a.	Unlikely
Agriculture	Unlikely	Unlikely	n.a.	n.a.	Unlikely
Water Use	Unlikely	Unlikely	n.a.	n.a.	Unlikely
Contaminants	Unlikely	Unlikely	n.a.	n.a.	Unlikely
Density Dependent Mortality	Unlikely	Unlikely	Unlikely[b]	Unlikely[b]	Unlikely[b]
Pathogens	No conclusion possible	No conclusion possible	No conclusion possible	No conclusion possible	No conclusion possible
Predators	Unlikely	Unlikely	Possible	Possible	Unlikely[b]
L. Fraser land use	Unlikely	Unlikely	n.a.	n.a.	Unlikely

Factor	Life History Stage				
	1. Incubation, Emergence and Freshwater Rearing	2. Smolt Outmigration	3. Coastal Migration and Migration to Rearing Areas	4. Growth in N. Pacific and Return to Fraser	5. Migration back to spawn
Strait of Georgia human activity & land uses	n.a.	n.a	Unlikely	Unlikely	n.a.
Climate Change	Possible	Possible	Likely	Possible	Definitely [c] Unlikely [d]
Marine Conditions	n.a.	n.a.	Likely	Possible	n.a.
Waste	n.a.	n.a	Unlikely	n.a.	n.a
Escapees	n.a.	n.a	Unlikely	n.a.	n.a
Sea Lice	n.a.	n.a	Unlikely	n.a.	n.a
Disease – salmon farm origin	n.a.	n.a	Unlikely to Possible [e]	n.a.	n.a
Disease –hatchery origin	No conclusion possible	No conclusion possible	No conclusion possible	No conclusion possible	No conclusion possible

[a] Forestry includes logging, Mountain Pine Beetle and log storage.
[b] Not addressed directly for these life stages but conclusions from section 4.2 apply across the whole life cycle.
[c] definitely affected harvest and escapement
[d] life cycle and post-juvenile productivity indices already incorporate en-route mortality in definition of recruits, so en-route mortality cannot explain trends in recruits / spawner. Available (limited) data does not show that en-route stress has intergenerational effects.
[e] based on assessments relying on Noakes (2011) and Dill (2011)

4.2 Effects on Knowledge Gaps and Data Limitations

Section 3 of this report summarizes key things that we need to know better for waste, escapees, sea lice, salmon farm diseases and hatchery diseases. The purpose of this section is to integrate the recommendations in Section 3 of this memo (and others contained in the Project 5 reports on salmon farms) with the research and monitoring priorities contained in section 5.2 of TR6.

In Section 5.2 of TR6 we recommended 23 research and monitoring activities, organized by life history stage, and highlighted 12 of these 23 recommendations as particularly high priority. These recommendations were based on four sources: the PSC report (Peterman et al. 2010), the Cohen Commission's research workshop, the Commission's Technical reports (except for the Project 5 reports on salmon farms which were not available at that time), and the cumulative effects assessment in TR6. As we stress in TR6 (section 5.2.2, page 107), more work is required to prioritize, sequence, define and integrate our recommended activities.

The results of this memo on salmon farms reinforce the three dominant themes in section 5.2 of TR6: 1) coordinated, multi-agency collection of data on sockeye stock abundance, survival and stressors for each life history stage; 2) development of an integrated database and cumulative assessments both within and across multiple life history stages; and 3) transparent dissemination of information annually to scientists and non-scientists. Furthermore, this memo strongly reinforces two high priority recommendations in TR6 for the coastal migration life history stage (recommendations #11 and 12 in Table 5.2-1, pg. 109 in TR6):

11. **Sockeye pathogen and contaminant levels in SoG, SJF, JS and QCS[5] under different marine conditions and exposures to aquaculture activities; and**
12. **Estimates of the annual relative survival of Fraser sockeye over the period of residency in the SoG, SJF, JS and QCS.**

The lists of things we need to know better for salmon farms (in Section 3 of this memo) are largely an extension of the three above-described dominant themes in TR6, and the specific recommendations 11 and 12. This memo indicates that there are three categories of high-priority data which need to be incorporated into the integrated database and cumulative assessments described above: 1) fish health (disease, sea lice, viruses, bacteria, other pathogens) in farm salmon, hatchery salmon and wild sockeye; 2) water quality in the vicinity of salmon farms; and 3) wild sockeye post-smolt survival estimates before and after passing salmon farms. As stressed by all Project 5 authors, the data on farm salmon health are currently of too short duration to reliably assess associations with sockeye productivity, and collection of these data needs to continue. Noakes (2011) recommends that disease monitoring programs for both wild salmon and hatcheries be maintained at a level equivalent to that required for salmon farms.

As noted by both Drs. McAllister and Carruthers in their independent reviews of Connors (2011)), the data described above should be collected for a range of stocks, locations and time periods that provide strong contrasts in exposures to salmon farms. McAllister recommends using acoustically tagged sockeye salmon smolts, as well as acoustically tagged returning adults, to estimate survival rates in the vicinity of salmon farms[6]. Such data would also provide valuable information on the exact location of sockeye, and their degree of exposure to salmon farms.

Drs. McAllister and Carruthers also each independently recommended that the contrasts in exposures to salmon farms be strengthened by deliberate experimental manipulation of the intensity of salmon farming (e.g., one or two fallow years in different zones followed by a few years of full production, in a temporal pattern which won't be confounded by odd-even cycles of pink salmon). Such manipulations, while undoubtedly controversial, would have considerable benefits for finally resolving long standing scientific disagreements concerning the impacts of salmon farms on both sockeye and other salmon species. The temporary costs of reduced salmon

[5] SoG=Strait of Georgia, SJF=Strait of Juan de Fuca, JS=Johnstone Strait; QCS=Queen Charlotte Sound
[6] The Pacific Ocean Shelf Tracking project (POST; http://www.postprogram.org/) has this capability.

farm production could be shared across multiple private, government and non-government entities, and may ultimately yield considerable biological and financial savings in the management of both salmon farms and wild salmon.

Both Noakes (2011) and Dill (2011) recommend controlled experiments to assess the lethal and sub-lethal effects of sea lice and other pathogens on juvenile sockeye. Dill (2011) recommends that the lethal and sub-lethal effects examined in such experiments include changes in feeding and avoidance of predators. He further suggests examining the potential for infection in bloodwater released from processing plants, and the evolution of resistance and/or increased virulence in sea lice treated with SLICE®. Controlled experiments such as these can help to evaluate the likelihood of different hypothesized impact pathways, and focus management on those pathways with potential risks.

As we noted in the introduction to this memo, there are strongly polarized opinions on salmon farms within the scientific community, as evidenced by the contrasting conclusions on some issues between the reports of Noakes (2011) and Dill (2011), and the contrasting opinions among the three reviewers of their reports. Between the two reports, Noakes and Dill cited 260 distinct references (excluding references to Project 5 reports), but only 25 of these references appear in both reports. We strongly endorse the recommendation of Dr. Farrell in his reviews of both the Noakes and Dill reports:

> "Given the perceived importance by the public as well as the highly polarized positions that have been adopted on the issue of the potential aquaculture impacts on wild salmon, I recommend that a working group – not a single individual – assemble existing information in a manner useful for ongoing analyses. The greatest challenge will be the selection of the members of the working group, which must include individuals with a good working knowledge of multivariate statistical analysis, fish stocks, an ability to faithfully represent all existing data, support conclusions with data, have few preconceived ideas other those supported by data, and bring with them a good measure of common sense and willingness to have an open mind to new data and its analysis."

5.0 References

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