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National Capital Region

Canadian Science Advisory Secretariat
Science Advisory Report 2019/020

ADVICE FROM THE ASSESSMENT OF THE RISK TO FRASER RIVER SOCKEYE SALMON DUE TO *PISCIRICKETTSIA SALMONIS* TRANSFER FROM ATLANTIC SALMON FARMS IN THE DISCOVERY ISLANDS AREA, BRITISH COLUMBIA

Net-pen along the coast of British Columbia (photo credit: DFO).

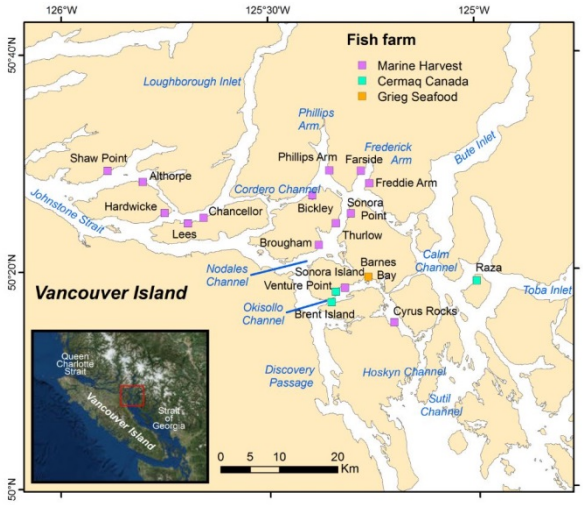

Figure 1. Locations of the 18 Atlantic Salmon farms in the Discovery Islands area stocked at least once between 2010 and 2016.

Context:

Fisheries and Oceans Canada (DFO), under the Sustainable Aquaculture Program, is committed to deliver environmental risk assessments to support science-based decision making related to aquaculture activities. The Aquaculture Science Environmental Risk Assessment Initiative was implemented to assess the risks of aquaculture activities to wild fish and the environment. The risks associated with each environmental stressor validated in the Pathways of Effects for finfish and shellfish aquaculture (DFO, 2010) will be assessed as per the Aquaculture Science Environmental Risk Assessment Framework ensuring a systematic, consistent and transparent process.

DFO's Aquaculture Management Directorate has requested CSAS advice on the risks to Fraser River Sockeye Salmon due to pathogen transfer from marine Atlantic Salmon farms located in the Discovery Islands area in British Columbia. This request supports DFO's role in the management of aquaculture in British Columbia and aligns with recommendations in the final report of the Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River, including recommendations 18 and 19 on risks to wild fish populations related to pathogen transfer from finfish farms (Cohen, 2012).

The advice is provided through a series of pathogen transfer risk assessments, this second series focusing on Aeromonas salmonicida (the causative agent of furunculosis), Piscirickettsia salmonis (the causative agent of salmonid rickettsial septicaemia (SRS)), Renibacterium salmoninarum (the causative

agent of bacterial kidney disease (BKD)) and Yersinia ruckeri (the causative agent of enteric redmouth disease (ERM)). These bacterial pathogens are known to cause disease and have been reported by the industry and/or have been diagnosed through the DFO Fish Health Audit and Surveillance Program on Atlantic Salmon farms in the Discovery Islands area. The risks associated with other pathogens also known to cause disease on marine Atlantic Salmon farms in the Discovery Islands area will be assessed in subsequent processes.

This Science Advisory Report is from the November 6–8, 2018 national advisory meeting on Assessment of the risk to Fraser River sockeye salmon due to bacteria causing systemic infections transferred from Atlantic salmon farms located in the Discovery Islands area, British Columbia. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

Piscirickettsia salmonis transfer risk assessment

- The assessment was conducted using farm-related and environmental data from 2002–2017, based on the current fish health management practices, and considering relevant scientific information.
- The assessment concluded that *P. salmonis* attributable to Atlantic Salmon (*Salmo salar*) farms operating in the Discovery Islands area poses minimal risk to Fraser River Sockeye Salmon (*Oncorhynchus nerka*) abundance and diversity. During this assessment uncertainties were evaluated at each step and ranged from high uncertainty to high certainty (see bullets below and Table 1).
- Two main factors influenced the attribution of minimal risk:
    - in the likelihood steps, it was determined that it is very unlikely that Fraser River Sockeye Salmon would become infected with *P. salmonis* released from an Atlantic Salmon farm in the Discovery Islands area. The uncertainties for the different steps ranged from high certainty to high uncertainty; and
    - in the consequence steps, it was determined in the very unlikely event that Fraser River Sockeye Salmon would become infected with *P. salmonis* due to Atlantic Salmon farms in the Discovery Islands area, the infection would not be expected to spread within wild populations, hence the magnitude of consequences to both Fraser River Sockeye Salmon abundance and diversity would be negligible. The associated uncertainties ranged from reasonable uncertainty to high uncertainty.
- The overall likelihood assessment, including separate farm infection, release, exposure, and infection assessments, was supported by the following key findings:
    - *Piscirickettsia salmonis* and/or salmonid rickettsial septicaemia (SRS) has been detected on Atlantic Salmon farms in the Discovery Islands area;
    - there is temporal overlap of migrating juvenile and adult Fraser River Sockeye Salmon with reports of *P. salmonis* on farms in the Discovery Islands area; and
    - although there is no vaccine available for SRS in BC, there has been limited spread of *P. salmonis* between Atlantic Salmon net pens.
- Uncertainty: Certainty in this assessment is limited by the lack of knowledge about:
    - how long and how close populations of wild juvenile and adult Pacific salmon are in the vicinity of Atlantic Salmon farms;

  - shedding rates in *P. salmonis*-infected salmon;
  - susceptibility and pathogenesis of *P. salmonis* in Sockeye Salmon;
  - the survival of *P. salmonis* in the marine environment;
  - the minimum infectious and lethal dose of *P. salmonis* for any of the susceptible salmonid species (Chinook (*Oncorhynchus tshawytscha*), Coho (*Oncorhynchus kisutch*), Pink (*Oncorhynchus gorbuscha*), Sockeye (*Oncorhynchus nerka*), Chum (*Oncorhynchus keta*), Atlantic salmon (*Salmo salar*) or Rainbow Trout (*Oncorhynchus mykiss*));
  - SRS mortality in wild Sockeye Salmon and other susceptible wild fish; and
  - the consequences to abundance and diversity of Fraser River Sockeye Salmon resulting from sub-lethal effects of *P. salmonis* infection.

- For the purpose of the assessment, a number of key assumptions were made:
  - positive detection of the pathogen on an Atlantic Salmon farm in the Discovery Islands area is evidence of *P. salmonis* infection on that farm;
  - Sockeye Salmon are susceptible to *P. salmonis* infections and SRS;
  - infected Atlantic Salmon shed *P. salmonis* into the surrounding environment; and
  - susceptible fish in wild populations could become infected and die at similar rates to farmed Atlantic Salmon.

Additionally, this risk assessment was informed by a summary of the current state of knowledge related to *P. salmonis* and SRS (Jones, 2019) of which the most relevant elements are summarized below.

Characterization of *Piscirickettsia salmonis* and salmonid rickettsial septicaemia (SRS)

- Infection with *P. salmonis* can lead to the development of SRS in a broad range of host-species including several salmonid and non-salmonid species.
- Sockeye Salmon susceptibility to *P. salmonis* infection and SRS remains to be determined. Laboratory data suggests that Coho Salmon are more susceptible than Rainbow Trout and Atlantic Salmon. There are insufficient data to assign different susceptibilities to different life history stages of salmonids.
- *Piscirickettsia salmonis* is transmitted horizontally, therefore, susceptible fish can become infected through contact with infected fish, contaminated water and/or contaminated equipment. There is little evidence of vertical transmission.
- The incubation period *of P. salmonis* ranges from 10 to 20 days and is dependent on environmental conditions, dose, strain of *P. salmonis,* and the condition of the susceptible host species.
- Disease associated with *P. salmonis* infection is strongly influenced by environmental factors and other stressful events.
- There are no morbidity or mortality data associated with *P. salmonis* infection in wild fish.
- There are no data on shedding rates or minimum infectious dose in any species.
- There is limited information about the survival of *P. salmonis* in the marine environment.

INTRODUCTION

This risk assessment was conducted under the DFO Aquaculture Science Environmental Risk Assessment Initiative, implemented as a structured approach to provide risk-based science advice to further support sustainable aquaculture in Canada. Risk assessments conducted under this initiative follow the Aquaculture Science Environmental Risk Assessment Framework which is consistent with international and national risk assessment frameworks (GESAMP, 2008; ISO, 2009). Details about the initiative and the framework are available on the DFO Aquaculture Science Environmental Risk Assessment Initiative webpage. All risk assessments conducted under the Initiative do not include socio-economic considerations.

This advisory report is one of four summarizing the consensus advice developed during the November 6–8, 2018 Canadian Science Advisory Secretariat (CSAS) scientific peer-review meeting that included international and national scientific experts. Information and current scientific knowledge about *P. salmonis* and salmon rickettsial septicaemia (SRS) and the draft risk assessment were presented in the following documents:

- The characterization of *Piscirickettsia salmonis* and salmonid rickettsial septicaemia (SRS) to inform pathogen transfer risk assessments in British Columbia (Jones, 2019);
- Assessment of the risk to Fraser River Sockeye Salmon (*Oncorhynchus nerka*) due to *Piscirickettsia salmonis* on Atlantic Salmon (*Salmo salar*) farms in the Discovery Islands area, British Columbia (Mimeault et al., 2019b)

The two supporting research documents were reviewed and used to reach the following objectives of the meeting, specifically:

- Review the qualitative risk assessment on Fraser River Sockeye Salmon abundance and diversity due to *P. salmonis* transferred from Atlantic Salmon farms located in the Discovery Islands area.
- Review and assess the uncertainties associated with the estimation of the risk to Fraser River Sockeye Salmon abundance and diversity.
- If risk assessment outcomes warrant, provide advice on additional measures that would reduce the risk to Fraser River Sockeye Salmon abundance and diversity due to pathogen transfer from Atlantic Salmon farms in the Discovery Islands area.

ANALYSIS

Characterization of *Piscirickettsia salmonis* and salmonid rickettsial septicaemia (SRS)

SRS is caused by infection with *P. salmonis*, a Gram-negative bacterium that occurs individually or in groups, and intracellularly in susceptible fish hosts. *P. salmonis* has been isolated from or identified in cases of SRS in Chile, Scotland, Ireland, Norway and in Eastern and Western Canada.

Piscirickettsia salmonis has a broad range of host-species including salmonid and non-salmonid species. Salmonid species susceptible to infection and that have had reported clinical signs of SRS include: Pink (*O. gorbuscha*), Coho (*O. kisutch*), Chinook (*O. tshawytscha*), Atlantic salmon and Rainbow Trout (*O. mykiss*). There are no reports from Sockeye or Chum (*O. keta*) salmon. Laboratory data suggests that Coho Salmon are more susceptible than Rainbow Trout and Atlantic Salmon. There are insufficient data to assign different susceptibilities to different life

history stages of salmonids. No species have been identified as natural reservoirs of the infections in farmed Atlantic Salmon.

As with any salmon pathogen, the incubation period will depend on the age and species of salmon and on its general condition, on the dose and strain of the pathogen and its route of inoculation and on environmental conditions, especially temperature, at the time of exposure. For *P. salmonis,* incubation periods of 10 to 20 days, depending on bacterial strain, have been estimated based on laboratory studies and clinical evidence using Coho Salmon in freshwater (Smith et al., 2004).

No studies have estimated the minimum (infectious or lethal) doses of *P. salmonis* necessary to cause SRS or mortality in fish through exposure routes that mimic natural transmission pathways. Nor are there studies describing shedding rates or timing of shedding during infection.

The survival of *P. salmonis* in the marine environment is influenced by the presence of particulate matter (e.g., mucus and feces), as well as physical processes (e.g., temperature and salinity). A laboratory study reported that a Chilean strain of *P. salmonis* could survive in seawater (32‰) for a period of 10 to 15 days at 5 °C, 10 °C or 15 °C, but at 20 °C no viable bacteria were detected after one week (Lannan and Fryer, 1994).

Laboratory and epidemiological data from Chile and Norway support horizontal transmission as the mode of transmission among wild salmon populations and among farms (Cvitanich et al., 1991; Garces et al., 1991; Almendras et al., 1997; Rees et al., 2014; Price et al., 2017).

There is evidence of virulence differences among different strains of *P. salmonis*; it is also useful to recognize that SRS outbreaks appear to be triggered by environmental stressors, whether of environmental or farm origin.

Occurrence on Atlantic Salmon farms in BC

Data on the occurrence of SRS on Atlantic Salmon farms in BC were obtained from: Fish Health Events (FHE), Fish Health Audit and Surveillance Program (FHASP) and mortality events reports. See Wade (2017) for further details regarding these sources of data. Supplementary industry data on fish health and environmental parameters were also included in the analysis (Wade, 2017).

Between 2002 and 2017, a total of 36 FHEs attributed to SRS were reported on Atlantic Salmon farms in BC. Audit-based farm-level diagnoses of SRS on BC Atlantic Salmon farms were made in nine of 15 years (2002 to end of 2016). There was a total of 36 farm-level diagnoses of SRS in BC, of which three occurred in the Discovery Islands area.

Piscirickettsia salmonis transfer risk assessment

Mimeault et al. (2019b) provide the complete assessment of the risk to Fraser River Sockeye Salmon abundance and diversity due to *P. salmonis* transferred from Atlantic Salmon farms in the Discovery Islands area of British Columbia. The risks were assessed using fish health data and environmental conditions from 2002–2017 and applying current fish health management practices. The elements most relevant to inform the *P. salmonis* transfer risk assessment are summarized here.

Current fish health management practices include regulatory requirements (e.g., Salmonid Health Management Plan (SHMP) and accompanying proprietary Standard Operating

Procedures (SOPs) and regulation of movement of live fish) and additional voluntary industry practices (e.g., additional surveillance and testing).

Conceptual model

The risk assessment followed three main steps outlined in Figure 2, which included the likelihood assessment, consequence assessment and estimation of risk.

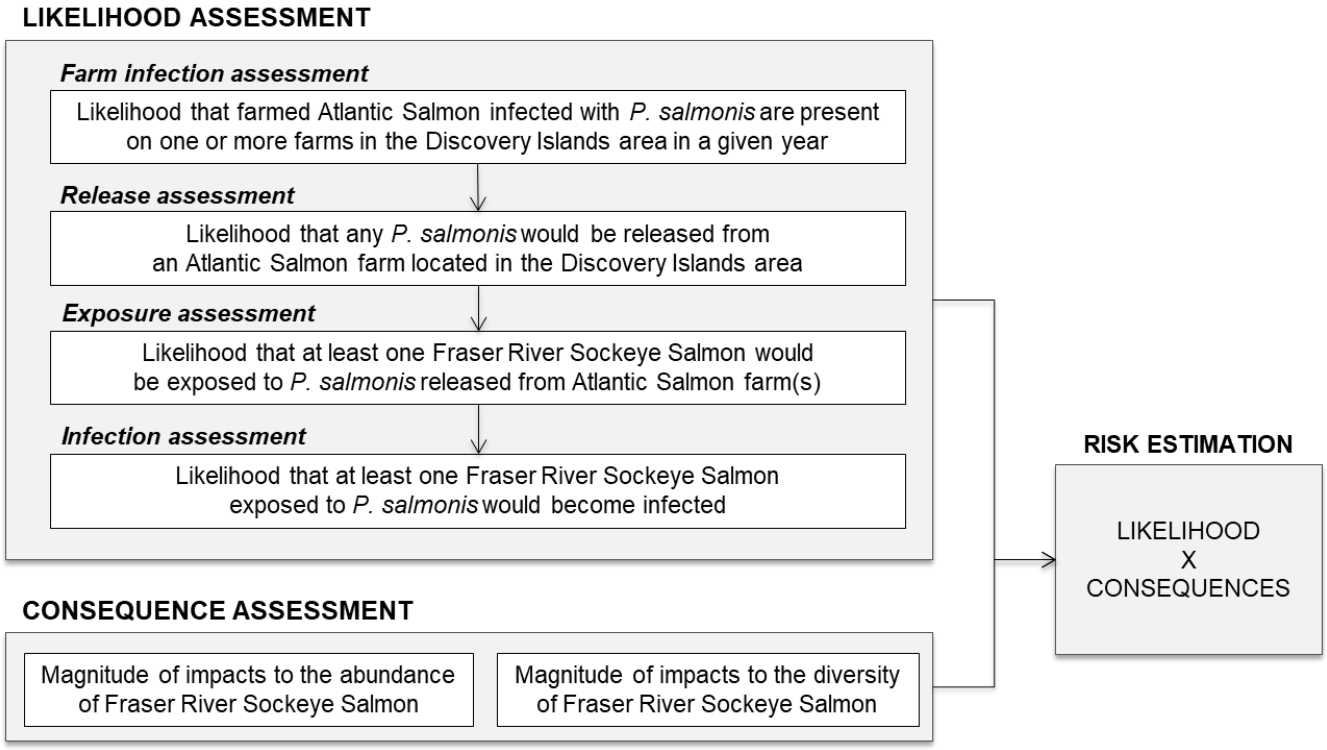

Figure 2. Conceptual model for risk assessment of Piscirickettsia salmonis *transferred from Atlantic Salmon farms located in the Discovery Islands area, BC.*

Likelihood assessment

The likelihood assessment was conducted through four sequential steps: farm infection, release, exposure and infection assessments. Each step of the likelihood assessment assumes that current management practices on Atlantic Salmon farms are followed and will be maintained. The main considerations and conclusions are reported here.

Farm infection assessment

Results from industry surveillance and screening (2011–2017), regulatory fish health reporting (FHE's and Mortality Events) and the Fish Health Audit and Surveillance Program (2002–2017) demonstrate that there is evidence of *P. salmonis* and/or SRS on a total of nine Atlantic Salmon farms in the Discovery Islands area in five different years (2009, 2012, 2015, 2016 and 2017).

Given evidence of *P. salmonis* and/or SRS in five of 16 years (2002–2017), it was concluded that it is unlikely that farmed Atlantic Salmon infected with *P. salmonis* could be present on one or more Atlantic Salmon farms in the Discovery Islands area under the current farm practices.

This conclusion was made with reasonable certainty as it is based on the abundant and robust data about screening and detections on farms over a 16-year time period.

Release assessment

Notwithstanding the likelihood from the farm infection assessment, the release assessment determined the likelihood that any *P. salmonis* would be released from an infected Atlantic Salmon farm located in the Discovery Islands area into an environment accessible to Fraser River Sockeye Salmon. Two potential release pathways were considered: release through infected farmed Atlantic Salmon and release through mechanical vectors (e.g., personnel, visitors and wildlife) and fomites (e.g., farm equipment and vessels).

Piscirickettsia salmonis is horizontally transferred and it is assumed both clinically and sub-clinically infected Atlantic Salmon shed *P. salmonis* into the surrounding environment. As Atlantic Salmon are reared in net pens, it is extremely likely for infected Atlantic Salmon to release *P. salmonis* into the environment. The likelihood was concluded with high certainty.

There are low levels of operational deficiencies on Atlantic Salmon farms in the Discovery Islands area, particularly those relating to relevant biosecurity practices. It was therefore concluded with reasonable certainty that the likelihood of release through vectors or fomites is unlikely under current fish health management practices.

The overall likelihood of release was obtained by adopting the highest likelihood of the release pathways. It is therefore extremely likely that *P. salmonis* would be released from an Atlantic Salmon farm should it become infected.

Exposure assessment

The exposure assessment determined the likelihood that at least one Fraser River Sockeye Salmon would be exposed to *P. salmonis* attributable to an Atlantic Salmon farm in a given year, assuming that *P. salmonis* has been released from at least one Atlantic Salmon farm in the Discovery Islands area.

Two exposure groups were considered: juvenile and adult Fraser River Sockeye Salmon occurring in the Discovery Islands area. Waterborne exposure was considered the most relevant exposure route for wild susceptible species in the context of this risk assessment. Other potential exposure routes, including the indirect exposure to *P. salmonis* through infection of other susceptible species infected from Atlantic Salmon were determined to be negligible in the context of this risk assessment.

The exposure assessment compared the overlap in time and space between when *P. salmonis* has been detected on Atlantic Salmon farms in the Discovery Islands area and when juvenile or adult Sockeye Salmon migrate through the Discovery Islands area.

Juvenile lake-type Fraser River Sockeye Salmon migrate through the Discovery Islands area from approximately mid-May through to mid-July, whereas returning adults migrate through from approximately late-June to early-October reviewed in Grant et al. (2018). To account for annual variations in migration timing, it was assumed that juveniles could be present in the Discovery Islands area from the beginning of May through the end of July. Similarly, for returning adults, it was assumed that adult Sockeye Salmon could be present in the Discovery Islands area from the beginning on June through to the end of October.

In the five years when *P. salmonis* was reported on at least one Atlantic Salmon farm in the Discovery Islands area, it was detected in all months except March and May. These detections

are from the industry surveillance and screening and the Fish Health Audit and Surveillance Program. Evidence in January, April, June, July, September and December are limited to positive molecular tests for *P. salmonis*. No Fish Health Events or mortality events attributed to SRS have been reported on Atlantic Salmon farms in the Discovery Islands area.

While there can be interannual differences in the migration timing of Fraser River Sockeye Salmon, the data underlying the estimates of the presence of juvenile Fraser River Sockeye Salmon in the Discovery Islands area from May-July are extensive. It was concluded that itis unlikely for at least one juvenile Fraser River Sockeye Salmon to be exposed to *P. salmonis* released from Atlantic Salmon farm(s) in the Discovery Islands area. There was reasonable certainty with the conclusion since there is limited temporal overlap with reports of *P. salmonis o*n the farms when juvenile FRSS are present.

For adult Fraser River Sockeye Salmon, however, since the timing of *P. salmonis* reported on farms overlaps with adult Fraser River Sockeye Salmon migrating through the Discovery Islands area, it was concluded that it is very likely that at least one adult Fraser River Sockeye Salmon will be exposed. This was concluded with reasonable certainty because of the robustness of the data supporting the timing of adult migration and the detection of *P. salmonis* both by industry during regular surveillance and through random audit sampling.

Infection assessment

The infection assessment determined the likelihood that at least one Fraser River Sockeye Salmon would become infected, assuming at least one Fraser River Sockeye Salmon has been exposed to *P. salmonis* released from Atlantic Salmon farm(s) operating in the Discovery Islands area at a concentration and duration sufficient to cause an infection.

As shedding rates and minimum infectious or lethal concentrations and exposure times are unavailable for the BC strain of *P. salmonis,* the observations from a SRS outbreak on a farm in BC in 1991, which had net pens of both Atlantic and Chinook salmon, were used to inform the infection assessment. During this SRS outbreak, mortalities occurred in two of the eight Atlantic Salmon net pens and remained negligible in the four Chinook Salmon pens on the farm. The daily mortality rate in the Atlantic Salmon pens increased steadily during the month of October from 0.01% to 0.06% in two of the eight pens (Brocklebank et al., 1993).

Atlantic Salmon farms in the Discovery Islands area are not located in all channels, and do not occupy a large volume of the area (Mimeault et al., 2017). Therefore, it is anticipated that not all juvenile Fraser River Sockeye Salmon will migrate through channels that have Atlantic Salmon farms. Additionally, a recent telemetry study (Rechisky et al., 2018) reported observations with tagged Sockeye Salmon suggesting transient interactions with farm infrastructure. Assuming constant migration speed and unidirectional movement, juvenile Fraser River Sockeye Salmon could encounter farms over three to eight days (Mimeault et al., 2017). Similarly, adult Fraser River Sockeye Salmon, while having a highly variable diversion rate (either northern or southern route to the Fraser River), migrate through the farming area over a two to three-day period (Mimeault et al., 2017).

Therefore, given the low reported mortalities within the farm during an SRS outbreak in BC, and that not all pens were affected during the outbreak as described in Brocklebank et al. (1993), this suggests limited spread of infection over a longer exposure time than what either juvenile or adult Fraser River Sockeye Salmon would experience. It was concluded with high uncertainty that the likelihood of at least one juvenile or adult Fraser River Sockeye Salmon to become

infected with *P. salmonis* released from Atlantic Salmon farm(s) in the Discovery Islands area through waterborne exposure is very unlikely.

Overall likelihood assessment

Table 1 summarizes the likelihood assessment. It was concluded that the likelihood that Atlantic Salmon farms in the Discovery Islands area release *P. salmonis* into an environment and subsequently expose Fraser River Sockeye Salmon at a concentration and for a period of time sufficient to cause infection and disease is very unlikely for both juveniles and adults. Refer to Mimeault et al. (2019b) for more details on the combination of likelihood rankings.

Uncertainties for each step in the likelihood assessment are not combined but are rather reported separately for clarity and transparency.

Table 1. Summary of the likelihood and uncertainty rankings for the likelihood assessment of the Piscirickettsia salmonis *risk assessment. Estimates are reported in white cells and likelihood combination results are reported in shadowed cells under the "Rankings" column.*

Steps		**Rankings**	
Farm infection assessment	**Likelihood**	Unlikely *(reasonable certainty)*	
Release assessment	**Release pathways**	**Farmed Atlantic Salmon**	**Vectors and fomites**
	Likelihoods	Extremely likely *(high certainty)*	Unlikely *(reasonable certainty)*
	Combined likelihoods of release	Extremely likely	
Exposure and infection assessments	**Exposure groups**	**Juvenile Fraser River Sockeye Salmon**	**Adult Fraser River Sockeye Salmon**
	Likelihood of exposure	Unlikely *(reasonable certainty)*	Very likely *(reasonable certainty)*
	Likelihood of infection	Very unlikely *(high uncertainty)*	Very unlikely *(high uncertainty)*
Combined exposure and infection likelihoods for each exposure group		Very unlikely	Very unlikely
Combined likelihoods (farm infection, release, exposure and infection) for each exposure group		Very unlikely	Very unlikely

Consequence assessment

The consequence assessment determined the potential magnitude of impacts on the abundance and diversity of Fraser River Sockeye Salmon, assuming that at least one Fraser River Sockeye Salmon has been infected with *P. salmonis* released from infected Atlantic Salmon farm(s) in the Discovery Islands area.

Based on the likelihood assessment, it was determined that it is unlikely that Atlantic Salmon infected with *P. salmonis* would be present on farms in the Discovery Islands area. In years without *P. salmonis* infections, there would be no consequence to the number of returning adults or the diversity of Fraser River Sockeye Salmon. However, during a year with *P. salmonis* infections, fish health records indicate that there can be up to three farms with *P. salmonis* infections.

Figure 3 illustrates the potential outcomes resulting from the infection of at least one Fraser River Sockeye Salmon with *P. salmonis* released from Atlantic Salmon farms located in the Discovery Islands area.

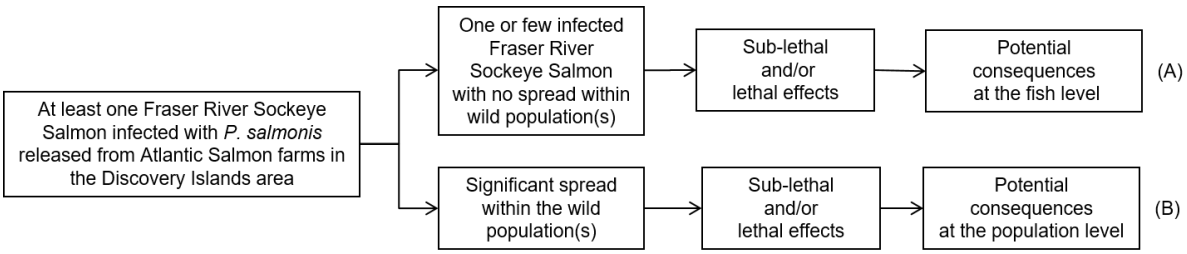

Figure 3. Potential outcomes resulting from at least one Fraser River Sockeye Salmon infected with Piscirickettsia salmonis *released from Atlantic Salmon farms located in the Discovery Islands area.*

Prior hydrodynamic modelling and particle tracking estimates of IHNV concentrations from an outbreak on a farm in the Discovery Islands area (Garver et al., 2013; Chandler et al., 2017; Mimeault et al., 2017) did not predict localized increases in released viral or bacterial concentrations due to currents or eddies. Reported survival of *P. salmonis* in seawater is up to 14 days between 5 °C and 15 °C (Lannan and Fryer, 1994). Combined with the limited on-farm spread observed during the 1991 SRS outbreak (Brocklebank et al., 1992; Brocklebank et al., 1993) the concentration of *P. salmonis* released from multiple farms with infected Atlantic Salmon, once dispersed away from the infected farm, is not anticipated to be higher than the concentration within an infected farm.

Adult Fraser River Sockeye Salmon would be exposed outside the net pens, whereas juvenile Fraser River Sockeye Salmon could be exposed either within an infected net-pen or outside of infected farms.

Based on the limited exposure time and low estimated concentrations outside of the net pens it was concluded that only a few Fraser River Sockeye Salmon would be infected. Should one or a few fish become infected no spread within the population is expected and the sub-lethal and or lethal effects of infection with *P. salmonis* may result in consequences at the fish level (Pathway A), rather than the population level (Pathway B).

As there is no reported evidence of disease in Sockeye Salmon in the literature (Jones, 2019), surrogate data were used for the consequence assessment. The 1991 SRS outbreak in BC on a mixed Atlantic and Chinook salmon farm was used specifically for the range of spread of *P. salmonis* and SRS (Brocklebank et al., 1992; Brocklebank et al., 1993). This data are applicable

as there is no vaccine available for *P. salmonis* in Canada. On-farm densities are higher than the estimated densities of juvenile Fraser River Sockeye Salmon (estimated to be ~0.03 fish/m^3 (Neville et al., 2013; Freshwater et al., 2017)), through the Discovery Islands area, which are anticipated to be higher than densities at sea. It was concluded that it was not plausible that the density of Fraser River Sockeye Salmon would be sufficiently high for a few infected individuals to support the spread of *P. salmonis* infection within the population. As this is based on data from a past outbreak in BC and data from Atlantic and Chinook salmon, it is concluded with reasonable uncertainty that the potential magnitude of consequences to the population abundance Fraser River Sockeye Salmon would be negligible.

Adult Fraser River Sockeye Salmon exposed to up to three Atlantic Salmon farms with *P. salmonis* infected fish in the Discovery Islands area (maximum number infected per year based on fish health data) will have approximately a month between exposure and spawning. Based on the lack of spread between the cages in the 1991 outbreak, infection would not be expected to spread within the wild Fraser River Sockeye Salmon population. Similar to what was modelled for *A. salmonicida* (Mimeault et al., 2019a), for there to be spread of *P. salmonis* to 1% of the returning population within this timeframe from day of farm exposure, the transmission potential (basic reproduction rate (R_0)) would have to be unrealistically high, particularly given what is known about the spread and virulence of *P. salmonis* (Mimeault et al., 2019a). It was therefore concluded with high uncertainty that the potential magnitude of consequence to the population abundance of Fraser River Sockeye Salmon would be negligible.

Impacts on diversity were considered based on a negligible (i.e., <1% reduction in return adult Fraser River Sockeye Salmon) consequence to abundance, the cumulative effect of successive years of exposure to farm-origin *P. salmonis* will also be negligible.

Risk estimation

The estimated risks to the abundance and diversity of Fraser River Sockeye Salmon are based on the results of the likelihood and consequence assessments. The risk categorization of minimal, moderate and high were determined and defined in collaboration with DFO's Ecosystem and Oceans Sciences and Fisheries Management sectors (Mimeault et al., 2017). They are aligned with relevant scales of consequences for fisheries management and policy purposes, existing policy and current management risk tolerance relevant to the risk assessments.

Likelihood							
	Extremely likely						
	Very likely						
	Likely						
	Unlikely						
	Very unlikely	X					
	Extremely unlikely						
		Negligible	Minor	Moderate	Major	Severe	Extreme
		Consequences to Fraser River Sockeye Salmon abundance					

Figure 4. Risk matrix for combining the results of the assessment of the likelihood of Piscirickettsia salmonis *infection in Sockeye Salmon attributable to Atlantic Salmon farms in the Discovery Islands area and magnitude of consequences to Fraser River Sockeye Salmon abundance. Green, yellow and red, respectively, represent minimal, moderate and high risk. The X indicates the risk estimate.*

Under the current fish health management practices, the risk to the diversity of Fraser River Sockeye Salmon as a result of a *P. salmonis* infection attributable to Atlantic Salmon farms operating in the Discovery Islands area is minimal (Figure 5).

Likelihood							
	Extremely likely						
	Very likely						
	Likely						
	Unlikely						
	Very unlikely	X					
	Extremely unlikely						
		Negligible	Minor	Moderate	Major	Severe	Extreme
		Consequences to Fraser River Sockeye Salmon diversity					

Figure 5. Risk matrix for combining the results of the assessment of the likelihood of Piscirickettsia salmonis *infection in Sockeye Salmon attributable to Atlantic Salmon farms in the Discovery Islands area and magnitude of consequences to Fraser River Sockeye Salmon diversity. Green, yellow and red, respectively, represent minimal, moderate and high risk. The X indicates the risk estimate.*

Sources of Uncertainty

Uncertainty remains in both the likelihood and consequence assessments. Total uncertainty includes both variability, which is a function of the system and is not reducible with additional measurements, and the lack of knowledge that can be reduced with additional data or expert opinion (Vose, 2008).

Uncertainties in the likelihood assessment

The main uncertainties related to the likelihood assessment are attributed to:

- the lack of confirmation of susceptibility and pathogenesis of *P. salmonis* in Sockeye Salmon;
- the lack of information about shedding rates in *P. salmonis*-infected healthy and diseased salmon;

- survival of *P. salmonis* in the marine environment;
- the minimum infectious and lethal doses of *P. salmonis* in Sockeye Salmon; and
- lack of data to estimate the proportion of the population that would be exposed and infected with *P. salmonis* released from an Atlantic Salmon farm in the Discovery Islands area in the event of an SRS infection.

Uncertainties in the consequence assessment

The main uncertainties in the consequence assessments for both abundance and diversity resulted from the absence of data on susceptibility to *P. salmonis* and SRS mortality in wild Sockeye Salmon. This resulted in the reliance on mortality rates observed on farms as proxies for mortality rates in wild populations, and the lack of knowledge of the consequences at the individual and at the population levels resulting from sub-clinical infection with *P. salmonis.*

CONCLUSIONS

Characterization of *Piscirickettsia salmonis* and salmonid rickettsial septicaemia (SRS)

Although *P. salmonis* has been diagnosed in farmed salmon in the Discovery Islands region of BC (Jones, 2019), the vast majority of information on *P. salmonis* and SRS is derived from research related to salmon aquaculture in Chile. While this is informative with respect to understanding the biology of the bacterium and its interactions with the host, important differences between Chile and BC with respect to the magnitude and operation of the industry will limit the extent to which risk may be extrapolated to the BC context. The wide host range of *P. salmonis* indicates a high likelihood that Sockeye Salmon will be susceptible, despite the absence of direct evidence of infection in this species. It is useful to recognize that SRS outbreaks appear to be triggered by environmental stressors, whether of natural sources or farm origin.

Important information that will inform the assessment of risk is still lacking. These include the confirmation of susceptibility and pathogenesis in Sockeye Salmon, salmon species-specific bacterial shedding rates and characteristics of the attenuation of bacterial viability under natural conditions. Furthermore, the entire Fish Health Event dataset should be examined more carefully to test the hypothesis that SRS outbreaks tend to follow stressful events such as algal blooms, hypoxic conditions or sea lice treatments, for example.

Piscirickettsia salmonis transfer risk assessment

The risk assessment concluded that *P. salmonis* attributable to Atlantic Salmon farms operating in the Discovery Islands area poses minimal risk to Fraser River Sockeye Salmon abundance and diversity under the current fish health management practices.

Two main factors influenced the attribution of the minimal risk. First, it was determined that it is very unlikely that Sockeye Salmon would become infected with *P. salmonis* released from an Atlantic Salmon farm located in the Discovery Islands area. Second, even in the very unlikely event that Sockeye Salmon would become infected, the infection would not be expected to spread, hence the magnitude of consequences to both Fraser River Sockeye Salmon abundance and diversity would be negligible.

There are considerable sources of uncertainties associated to the determination of the risk to Fraser River Sockeye Salmon due to *P. salmonis* attributable to Atlantic Salmon farms in the Discovery Islands area. The main uncertainties are related to the assessments of the likelihood of infection of Sockeye Salmon for which there is a lack of information about shedding rates in *P. salmonis*-infected healthy and diseased fish; the lack of information about the survival of *P. salmonis* in the marine environment; and the lack of information about the minimum infectious and lethal dose of *P. salmonis* in Sockeye Salmon; and consequence assessment for which there is absence of data on SRS mortality in Fraser River Sockeye Salmon and the consequences at the individual and at the population levels resulting from sub-clinical infection with *P. salmonis*. Conclusions of this risk assessment should be reviewed as new research findings fill knowledge gaps.

OTHER CONSIDERATIONS

The long-term impacts of changing climatic conditions on the bacteria, farmed salmon and wild salmon will need to be better understood and investigated.

The Discovery Islands area is not the only area along the migration route of Fraser River Sockeye Salmon where Atlantic Salmon farms are located.

An analysis of the risks associated with infection with more than one pathogen was not undertaken but will be examined in a future risk assessment.

The application of laboratory studies of pathogens to the assessment of risk is influenced by the experimental methods and design, particularly as it relates to the determination of shedding rates and minimum infectious and lethal doses.

This risk assessment is based on current pathogenicity of *P. salmonis,* industry size and practices. Further analysis would be required If there is a change in the pathogenicity, size or practices of the Atlantic Salmon aquaculture industry in the Discovery Islands area.

LIST OF MEETING PARTICIPANTS

Name	Affiliation
Ackerman, Paige	Fisheries and Oceans Canada
Bianucci, Laura	Fisheries and Oceans Canada
Boily, France	Fisheries and Oceans Canada
Bruneau, Nathalie	Canadian Food Inspection Agency (CFIA)
Bruno, David	Marine Scotland Science
Burgetz, Ingrid	Fisheries and Oceans Canada
Byrne, Philip	Fisheries and Oceans Canada
Fuller, Chad	First Nations Fisheries Committee of BC
Gardner, Ian	Atlantic Veterinary College UPEI
Garver, Kyle	Fisheries and Oceans Canada
Hewison, Tim	Grieg Seafood
Higgins, Mark	Fisheries and Oceans Canada
Holt, Carrie	Fisheries and Oceans Canada
Jakob, Eva	Aqua Nutrition Cargill
Johnson, Stewart	Fisheries and Oceans Canada

Name	Affiliation
Jones, Simon	Fisheries and Oceans Canada
Malcolm, Gabrielle	Fisheries and Oceans Canada
Milligan, Barry	Cermaq Canada
Mimeault, Caroline	Fisheries and Oceans Canada
Olivier, Gilles	Fisheries and Oceans Canada
Parsons, Jay	Fisheries and Oceans Canada
Paylor, Adrienne	Fisheries and Oceans Canada
Peterman, Randall	Simon Fraser University
Powell, Mark	Institute of Marine Research
Proboszcz, Stan	Watershed Watch
Rhodes, Linda	National Oceanographic Atmospheric Administration
Roth, Myron	BC Ministry of Agriculture
Saksida, Sonja	Canadian Food Inspection Agency (CFIA)
Siah, Ahmed	BC Centre for Aquatic Health Sciences
Struthers, Alistair	Fisheries and Oceans Canada
Trudel, Marc	Fisheries and Oceans Canada
Wade, Joy	Fundy Aqua Services
Wan, Di	Fisheries and Oceans Canada
Werring, John	David Suzuki Foundation

(comments only):

Name	Affiliation
Dalsgaard, Inger	Technical University of Denmark
Davies, Robert	University of Glasgow
Purcell, Maureen	U.S. Geological Survey
Stevenson, Roselynn	University of Guelph
St-Hilaire, Sophie	Atlantic Veterinary College UPEI

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This Science Advisory Report is from the November 6–8, 2018 national advisory meeting on Assessment of the risk to Fraser River sockeye salmon due to bacteria causing systemic infections transferred from Atlantic salmon farms located in the Discovery Islands area, British Columbia. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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Canadian Science Advisory Secretariat (CSAS)
National Capital Region
Fisheries and Oceans Canada
200 Kent Street
Ottawa, ON K1A 0E6

Telephone: 613-990-0293
E-Mail: csas-sccs@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

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