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**National Capital Region**

# 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

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**Foreword**

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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# GLOSSARY

**Acute:** characterized by a short and relatively severe course

**Carrier:** an infected animal that sheds pathogenic organisms but shows no sign of disease

**Chronic:** a disease condition that is persistent or long lasting

**Clinical:** outward appearance of a disease in a living organism

**Colony-forming unit (CFU):** a unit used to estimate the number of viable bacterial cells in a sample, where viability is assessed as the ability to multiply on an artificial growth medium (e.g., agar plate)

**Disease:** condition in which the normal function or structure of part of the body or a bodily function is impaired

**Epidemiological unit:** a group of animals that share approximately the same risk of exposure to a pathogenic agent with a defined location

**Fish Health Event (FHE):** a suspected or active disease occurrence within an aquaculture facility that required the involvement of a veterinarian and any measure that is intended to reduce or mitigate impact and risk that is associated with that occurrence or event

**Fomite:** refers to an inanimate object capable of transmitting a disease (e.g., contaminated net or boat)

**Incubation period:** the period of time between infection and onset of clinical signs

**Infection:** growth of pathogenic microorganisms in the body, whether or not body function is impaired

**Infection pressure:** concentration of infective pathogens in the environment of susceptible hosts

**Mortality event:** fish mortalities equivalent to 4000 kg or more, or losses reaching 2% of the current facility inventory, within a 24 hour period; or fish mortalities equivalent to 10,000 kg or more, or losses reaching 5%, within a five day period

**Outbreak:** unexpected occurrence of mortality or disease in a population

**Prevalence:** the number of hosts infected with a pathogen (*infection prevalence*) or affected by a disease (*disease prevalence*) expressed as a percentage of the total number of hosts in a given population at one specific time

**Silver:** fresh mortalities

**Subclinical:** insufficient signs to cause classical identifiable disease

**Susceptible species:** a species in which infection has been demonstrated by the occurrence of natural cases or by experimental exposure to the pathogenic agent that mimics natural transmission pathways

**Vector:** refers to a living organism that has the potential to transmit a disease, directly or indirectly, from one animal or its excreta to another animal (e.g., personal, wildlife, etc.)

## ABSTRACT

Fisheries and Oceans Canada, under the Aquaculture Science Environmental Risk Assessment Initiative, is conducting a series of assessments to determine risks to Fraser River Sockeye Salmon (*Oncorhynchus nerka*) due to pathogens on marine Atlantic Salmon (*Salmo salar*) farms located in the Discovery Islands area in British Columbia (BC).

This document is the assessment of the risk to Fraser River Sockeye Salmon due to *Piscirickettsia salmonis* on Atlantic Salmon farms in the Discovery Islands area, BC under current farm practices. This risk assessment was conducted in three main steps: (i) the likelihood assessment which includes four consecutive steps (a farm infection assessment, a release assessment, an exposure assessment, and an overall infection assessment; (ii) the consequence assessment; and, (iii) the risk estimation which combines the outcomes of the first two steps.

*Piscirickettsia salmonis* is the causative agent of salmonid rickettsial septicaemia (SRS), a disease of marine fish. Based on evidence of infection and disease on Atlantic Salmon farms between 2002 and 2017, it is unlikely, with reasonable certainty, that farmed Atlantic Salmon in the Discovery Islands area will become infected with *P. salmonis* in any given year under the current farm practices. However, when infected, the bacterium is extremely likely, with high certainty, to be released from farmed Atlantic Salmon into the marine environment. Considering the migration window of Fraser River Sockeye Salmon through the Discovery Islands area and the timing of *P. salmonis* infection on farms, it is unlikely that at least one juvenile, but very likely that at least one adult, both with reasonable certainty, would be exposed to the bacterium released from infected farms in any given year. Under such exposure, it is very unlikely that Fraser River Sockeye Salmon would get infected with *P. salmonis* attributable to Atlantic Salmon farms located in the Discovery Islands area. Overall, it was concluded that the likelihood that Fraser River Sockeye Salmon would become infected with *P. salmonis* attributable to Atlantic Salmon farms in the Discovery Islands area is very unlikely under the current fish health management practices.

In the event of a very unlikely infection of Fraser River Sockeye Salmon with *P. salmonis* attributable to Atlantic Salmon farms in the Discovery Islands area, the potential magnitude of consequences to Fraser River Sockeye Salmon abundance and diversity resulting from an infection was determined to be negligible given that: (i) an infection acquired at the juvenile stage would not be expected to spread within the population, and (ii) an infection acquired at the adult stage would not have time to spread before reaching spawning grounds. Those conclusions were reached with reasonable to high uncertainty given significant knowledge gaps.

Overall, the assessment concluded that *P. salmonis* attributable to Atlantic Salmon farms in the Discovery Islands area poses minimal risk to Fraser River Sockeye Salmon abundance and diversity under the current farm practices. This risk assessment should be reviewed as new research findings fill knowledge gaps.

# 1 INTRODUCTION

Fisheries and Oceans Canada (DFO) has a regulatory role to ensure the protection of the environment while creating the conditions for the development of an economically, socially and environmentally sustainable aquaculture sector and is a priority of the Minister of Fisheries, Oceans and the Canadian Coast Guard.

It is recognized that there are interactions between aquaculture operations and the environment (Grant and Jones, 2010; Foreman et al., 2015). One interaction is the risk to wild salmon populations resulting from the potential spread of infectious diseases from Atlantic Salmon (*Salmo salar)* farms in British Columbia (BC) (Cohen, 2012a).

DFO Aquaculture Management Division requested formal science advice on the risk of pathogen transfer from Atlantic Salmon farms located in the Discovery Islands area to wild fish populations in BC. Given the complexity of interactions between pathogens, hosts and the environment, DFO is delivering the science advice through a series of pathogen-specific risk assessments.

This document assesses the risk to Fraser River Sockeye Salmon (*Oncorhynchus nerka*) attributable to *Piscirickettsia salmonis*, the causative agent of salmonid rickettsial septicaemia (SRS), from Atlantic Salmon farms in the Discovery Islands area in BC. This pathogen was selected to undergo a formal pathogen transfer risk assessment given that SRS had been reported at the farm level on Atlantic Salmon farms in the Discovery Islands area.

Risks posed to other wild fish populations and related to other fish farms, pathogens, and regions of BC are not included in the scope of the current risk assessment.

# 2 BACKGROUND

This risk assessment is conducted under the DFO Aquaculture Science Environmental Risk Assessment Initiative (hereinafter referred to as the Initiative) implemented as a structured approach to provide science-based risk advice to further support sustainable aquaculture in Canada. Furthermore, to ensure consistency across risk assessments conducted under the Initiative, the Aquaculture Science Environmental Risk Assessment Framework (hereinafter referred to as the Framework) outlines the process and components of each assessment.

The Framework ensures the delivery of systematic, structured, transparent and comprehensive risk assessments. It is consistent with international and national risk assessment frameworks (GESAMP, 2008; ISO, 2009) and includes the identification of management protection goals, a problem formulation, a risk assessment and the generation of science advice. The management protection goals and problem formulation were developed in collaboration with DFO's Ecosystems and Oceans Sciences and Ecosystem and Fisheries Management sectors and approved by Aquaculture Management Division.

The Framework also comprises risk communication and a scientific peer-review through DFO's Canadian Science Advisory Secretariat (CSAS) that includes scientific experts both internal and external to DFO. Further details about the Initiative and the Framework are available on the DFO Aquaculture Science Environmental Risk Assessment Initiative webpage.

Risk assessments conducted under this Initiative do not include socio-economic considerations and are not cost-benefit or risk-benefit analyses.

## 2.1 MANAGEMENT PROTECTION GOALS

In accordance with the recommendations pertaining to aquaculture and fish health in the 2012 final report of the Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River (Cohen, 2012a), the valued ecosystem component in this risk assessment is the Fraser River Sockeye Salmon and the management protection goals are to preserve the abundance and diversity of the Fraser River Sockeye Salmon.

## 2.2 PROBLEM FORMULATION

### 2.2.1 Hazard identification

In this risk assessment, the hazard is the bacterium *P. salmonis* attributable to Atlantic Salmon farms in the Discovery Islands area.

### 2.2.2 Hazard characterization

Jones (2019) reviewed the relevant characteristics of *P. salmonis* and SRS (e.g., pathogen distribution, virulence, survival in the marine environment, susceptible species, shedding rates in Atlantic Salmon, infectious doses in Pacific salmon) and identified knowledge gaps relevant to this risk assessment. The review includes a summary of the occurrence of *P. salmonis* and SRS on Atlantic Salmon farms in BC. Additional details specific to Atlantic Salmon farms located in the Discovery Islands area are included in this document.

### 2.2.3 Scope

This assessment aims to determine the risk under current farm practices, including regulatory requirements and voluntary practices as described in Wade (2017). It focuses on the risk attributable to active Atlantic Salmon farms operating in the Discovery Islands area (Fish Health Surveillance Zone 3-2) and in close proximity (three farms in Fish Health Surveillance Zone 3-3 to the northwest of Fish Health Surveillance Zone 3-2) (refer to Figure 1 and Table 1) and includes the same 18 farms as in Mimeault et al. (2017).

Other Atlantic Salmon farms located along the migratory routes of Fraser River Sockeye Salmon, such as the ones operating in the Broughton Archipelago, are outside the scope of this risk assessment.

This risk assessment focuses on the potential direct impacts of *P. salmonis* attributable to Atlantic Salmon farms in the Discovery Islands area on Fraser River Sockeye Salmon abundance and diversity. Potential indirect impacts to Fraser River Sockeye Salmon through ecosystem processes resulting from infection of other susceptible Pacific salmon species are not considered.

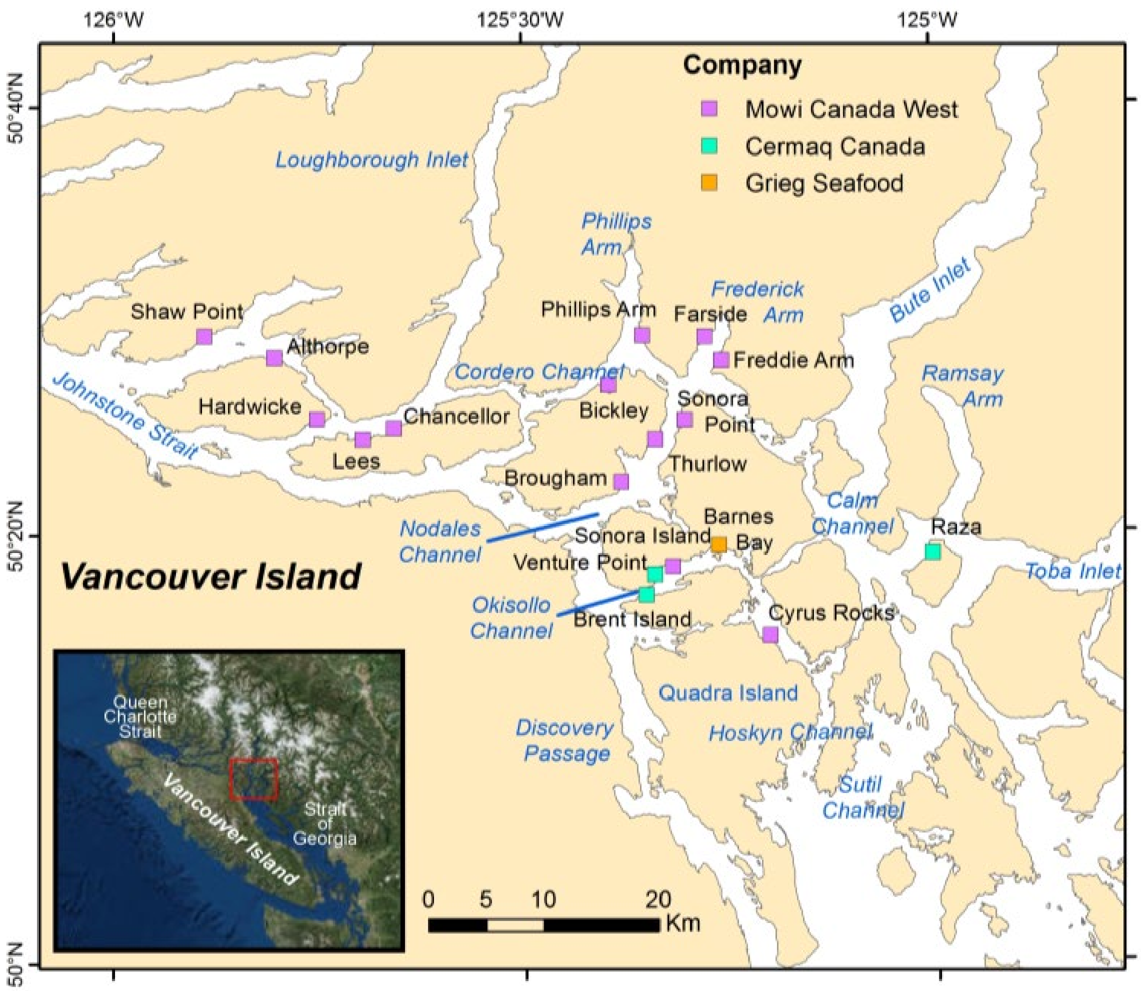


*Figure 1. Locations of Atlantic Salmon farms in the Discovery Islands area (Fish Health Surveillance Zone 3-2 and three farms in Fish Health Surveillance Zone 3-3) included in this risk assessment. Symbol size for fish farms is not to scale. The insert illustrates the location of the Discovery Islands area in BC. Adapted from Mimeault et al. (2017).*

*Table 1. List of the 18 active Atlantic Salmon farms included in the risk assessment.*

| Company | Farm | Fish Health Surveillance Zone |
|---|---|---|
| Cermaq Canada | Brent Island | 3-2 |
| | Raza Island | 3-2 |
| | Venture | 3-2 |
| Grieg Seafood | Barnes Bay | 3-2 |
| Mowi Canada West (formerly Marine Harvest Canada) | Althorpe | 3-3 |
| | Bickley | 3-2 |
| | Brougham Point | 3-2 |
| | Chancellor Channel | 3-2 |
| | Cyrus Rocks | 3-2 |
| | Farside | 3-2 |
| | Frederick Arm | 3-2 |
| | Hardwicke | 3-3 |
| | Lees Bay | 3-2 |
| | Phillips Arm | 3-2 |
| | Shaw Point | 3-3 |
| | Sonora Point | 3-2 |
| | Okisollo | 3-2 |
| | Thurlow | 3-2 |

### 2.2.4 Risk question

What is the risk to Fraser River Sockeye Salmon abundance and diversity due to the transfer of *P. salmonis* from Atlantic Salmon farms located in the Discovery Islands area under current farm practices?

### 2.2.5 Methodology

The methodology is based on Mimeault et al. (2017) which was adapted from the DFO Guidelines for Assessing the Biological Risk of Aquatic Invasive Species in Canada (Mandrak et al., 2012), the World Organisation for Animal Health (OIE) Import Risk Analysis (OIE, 2010), recommendations for risk assessments in coastal aquaculture (GESAMP, 2008) and the Food and Agriculture Organization guidelines on understanding and applying risk analysis in aquaculture (FAO, 2008).

#### 2.2.5.1 Conceptual model

The conceptual model (Figure 2) is adapted from Mimeault et al. (2017) in which the likelihood of an event to take place and its potential magnitude of consequences are combined into a predefined matrix to estimate the risk. The likelihood is assessed in four consecutive steps namely: a farm infection assessment; a release assessment; an exposure assessment; and an infection assessment. The consequence assessment determines the potential magnitude of impacts of *P. salmonis* infection attributable to Atlantic Salmon farms in the Discovery Islands area on the abundance and diversity of Fraser River Sockeye Salmon.

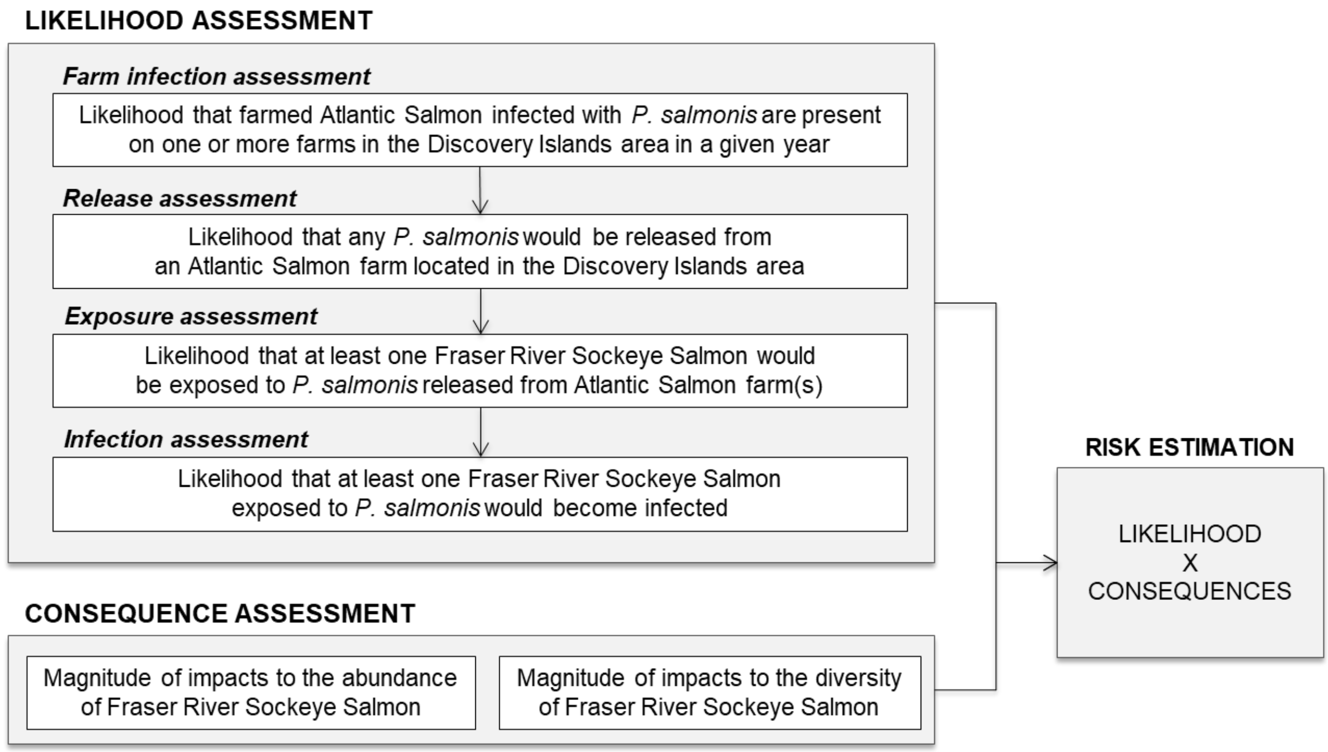


*Figure 2. Conceptual model to assess the risks to Fraser River Sockeye Salmon resulting from* Piscirickettsia salmonis *attributable to Atlantic Salmon farms located in the Discovery Islands area, British Columbia. Adapted from Mimeault et al. (2017).*

#### 2.2.5.2 Terminology

The categories and definitions used to rank likelihood (Table 2), consequences to abundance (Table 3), consequences to diversity (Table 4), uncertainty for data and information (Table 5) and uncertainty for fish health management (Table 6) were adapted from Mimeault et al. (2017).

*Table 2. Categories and definitions used to describe the likelihood of an event over a period of a year. "Extremely unlikely" is the lowest likelihood and "extremely likely" is the highest likelihood.*

| Categories | Definitions |
|---|---|
| Extremely likely | Event is expected to occur, will happen |
| Very likely | Event is very likely to occur |
| Likely | Event is likely to occur |
| Unlikely | Event is unlikely to occur, not likely but could occur |
| Very unlikely | Event is very unlikely to occur |
| Extremely unlikely | Event has little to no chance to occur, insignificant, negligible |

*Table 3. Categories and definitions used to describe the potential consequences to the abundance of Fraser River Sockeye Salmon.*

| Categories | Definitions |
|---|---|
| Negligible | 0 to 1% reduction in the number of returning Fraser River Sockeye Salmon |
| Minor | > 1 to 5% reduction in the number of returning Fraser River Sockeye Salmon |
| Moderate | > 5 to 10% reduction in the number of returning Fraser River Sockeye Salmon |
| Major | > 10 to 25% reduction in the number of returning Fraser River Sockeye Salmon |
| Severe | > 25 to 50% reduction in the number of returning Fraser River Sockeye Salmon |
| Extreme | > 50% reduction in the number of returning Fraser River Sockeye Salmon |

*Table 4. Categories and definitions used to describe the potential consequences to the diversity of Fraser River Sockeye Salmon. CU: Conservation Unit.*

| Categories | Definitions |
|---|---|
| Negligible | 0 to 1% change in abundance over a generation and no loss of Fraser River Sockeye Salmon CUs over a generation |
| Minor | > 1 to 10% reduction in abundance in some CUs that would not result in the loss of a Fraser River Sockeye Salmon CU over a generation |
| Moderate | > 1 to 10% reduction in abundance in most CUs that would not result in the loss of a Fraser River Sockeye Salmon CU over a generation; OR<br>> 10 to 25% reduction in abundance in one or more CUs that would not result in the loss of a Fraser River Sockeye Salmon CU over a generation |
| Major | > 25% reduction in abundance in one or more CUs that would not result in the loss of a Fraser River Sockeye Salmon CU over a generation |
| Severe | Reduction in abundance that would result in the loss of a Fraser River Sockeye Salmon CU over a generation |
| Extreme | Reduction in abundance that would result in the loss of more than one Fraser River Sockeye Salmon CU over a generation |

*Table 5. Categories and definitions used to describe the level of uncertainty associated with data and information.*

| Categories | Definitions |
|---|---|
| High uncertainty | • No or insufficient data<br>• Available data are of poor quality<br>• Very high intrinsic variability<br>• Experts' conclusions vary considerably |
| Reasonable uncertainty | • Limited, incomplete, or only surrogate data are available<br>• Available data can only be reported with significant caveats<br>• Significant intrinsic variability<br>• Experts and/or models come to different conclusions |
| Reasonable certainty | • Available data are abundant, but not comprehensive<br>• Available data are robust<br>• Low intrinsic variability<br>• Experts and/or models mostly agree |
| High certainty | • Available data are abundant and comprehensive<br>• Available data are robust, peer-reviewed and published<br>• Very low intrinsic variability<br>• Experts and/or models agree |

*Table 6. Categories and definitions used to describe the level of uncertainty associated with fish health management. "Some" and "most" are respectively defined as less and more than 50% of relevant data.*

| Categories | Definitions |
|---|---|
| High uncertainty | • No information collected through farm management practices, as specified in Salmonid Health Management Plans, is available<br>• Discrepancy between information/data obtained through farms and farm audits for all farms<br>• Voluntary farm practice(s)<br>• Expert opinion varies considerably |
| Reasonable uncertainty | • Some information collected through farm management practices, as specified in Salmonid Health Management Plans, is available<br>• Discrepancy between information/data obtained through farms and farm audits for most farms<br>• Voluntary company practice(s)<br>• Experts come to different conclusions |
| Reasonable certainty | • Most information collected through farm management practices, as specified in Salmonid Health Management Plans, is available<br>• Corroboration between information/data obtained through farms and farm audits for most farms<br>• Voluntary industry-wide practice(s) agreed through a Memorandum of Understanding or certification by a recognized third party<br>• Experts mostly agree |
| High certainty | • All information collected through farm management practices, as specified in Salmonid Health Management Plans, is available<br>• Corroboration between information/data obtained through farms and farm audits for all farms<br>• Mandatory practice(s) required under legislation and certification by a recognized third party<br>• Experts agree |

#### 2.2.5.3 Combination rules

As described in Mimeault et al. (2017), the combination of likelihoods differs if events are dependent or independent: "An event is dependent when its outcome is affected by another event. For example, infection can only happen if exposure took place, consequently infection is dependent on exposure. Events are independent when the outcome of one event does not affect the outcome of other event(s); for example, a pathogen can be released into the environment via different unrelated pathways."

Likelihoods are combined as per accepted methodologies in qualitative risk assessments adopting the lowest value (e.g., low) for dependent events and the highest value (e.g., high) for independent events (Cox, 2008; Gale et al., 2010; Cudmore et al., 2012). However, when events are independent but not mutually exclusive, i.e., could occur concurrently, the adoption of the highest individual likelihood might underestimate the overall likelihood. Uncertainty is reported individually for each ranking without combination.

#### 2.2.5.4 Risk estimation

As described in Mimeault et al. (2017), two risk matrices were developed in collaboration with DFO's Ecosystems and Oceans Sciences and with DFO's Ecosystem and Fisheries Management sectors to categorize the risk estimates for the abundance (Figure 3) and diversity (Figure 4) of Fraser River Sockeye Salmon. They are aligned with the relevant scale of consequences for fisheries management and policy purposes, existing policy and current management risk tolerance relevant to the risk assessments.

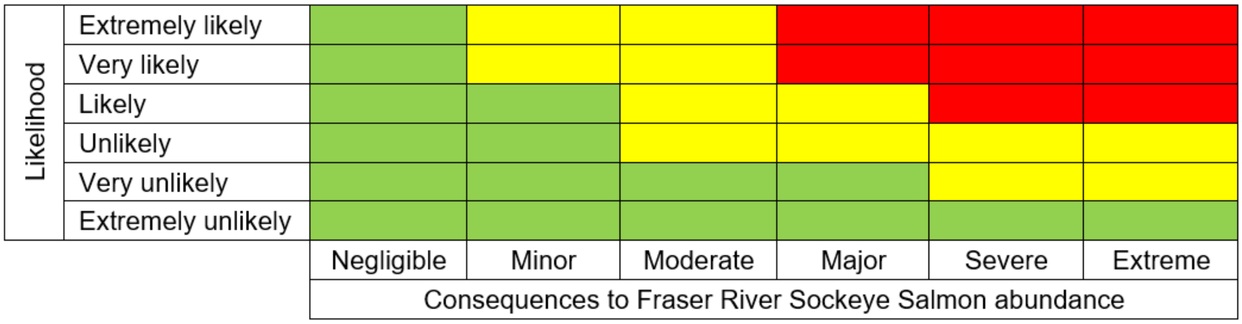


*Figure 3. Risk matrix for combining the results of the likelihood and consequence to Fraser River Sockeye Salmon abundance assessments. Green, yellow and red represent minimal, moderate and high risk, respectively.*

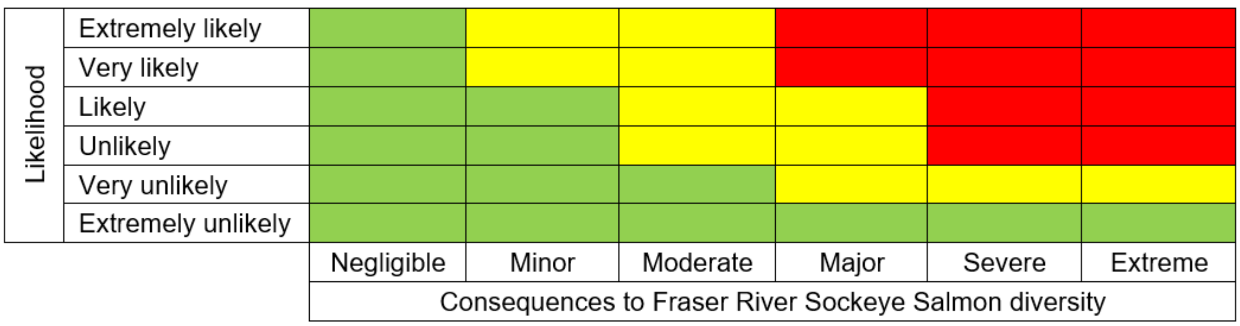


*Figure 4. Risk matrix for combining the outputs of the likelihood and consequence to Fraser River Sockeye Salmon diversity assessments. Green, yellow and red represent minimal, moderate and high risk, respectively.*

# 3 LIKELIHOOD ASSESSMENT

The likelihood assessment consists of determining the likelihood that Fraser River Sockeye Salmon would become infected with *P. salmonis* attributable to Atlantic Salmon farms located in the Discovery Islands area. Each step of the likelihood assessment assumes that current management practices on Atlantic Salmon farms are followed and will be maintained.

## 3.1 FARM INFECTION ASSESSMENT

### 3.1.1 Question

In a given year, what is the likelihood that farmed Atlantic Salmon infected with *P. salmonis* are present on one or more farms in the Discovery Islands area?

### 3.1.2 Considerations

Factors contributing to the detection of *P. salmonis* infections on Atlantic Salmon farms are based both on regulatory requirements and industry practices.

#### 3.1.2.1 Regulatory requirements

##### *3.1.2.1.1 Licensing requirements*

DFO has had the primary responsibility for the regulation and management of aquaculture in BC since December 2010 through the Pacific Aquaculture Regulations (PAR) developed under the Fisheries Act. DFO is therefore responsible for issuing aquaculture licences for marine finfish, shellfish and freshwater operations in BC.

Each farm operating in BC requires a Finfish Aquaculture Licence under the PAR which includes the requirement for a Salmonid Health Management Plan (SHMP) and accompanying proprietary Standard Operating Procedures (SOPs) (DFO, 2015). The SHMP outlines the health concepts and required elements associated with a finfish aquaculture licence (Wade, 2017), while accompanying SOPs detail the procedures to address specific concepts of the SHMP including monitoring fish health and diseases (DFO, 2015; Wade, 2017).

The SHMP includes requirements related to "Keeping Pathogens Out" (section 2.5 of the SHMP) (DFO, 2015) including that particular care be taken to avoid undue fish stress and transmission of pathogens.

##### *3.1.2.1.2 Fish Health Audit and Surveillance Program*

Through the Fish Health Audit and Surveillance Program (FHASP), samples are collected from recently dead fish to audit the routine monitoring and reporting of diseases by the farms (Wade, 2017). Moribund fish can also be sampled (I. Keith, DFO, 103-2435 Mansfield Drive, Courtenay, BC V9N 2M2, pers. comm., 2018). DFO aims to audit 30 randomly selected farms per quarter or 120 farms per year (Wade, 2017).

During an audit, a maximum of 30 fresh fish are selected for histopathology, bacteriology and molecular diagnostics/virology, although in most circumstances eight fresh fish are sampled (Wade, 2017). DFO veterinarians provide farm-level diagnoses based on a combination of farm history, treatment history, environmental factors, mortality records, clinical presentation on farm, and results of diagnostic procedures performed on individual fish (DFO, 2018c).

Under the FHASP, SRS is diagnosed in an Atlantic Salmon population when the site is under treatment for the disease, or when there are significant pathological lesions with characteristic organisms, either in tissues from a sample pool with positive polymerase chain reaction (PCR) screening result for *P. salmonis*, or in central nervous system tissue, and population level losses attributed to the disease (I. Keith, DFO, pers. comm., 2018*).*

Jones (2019) summarized audit-based detections of *P. salmonis* and farm-level SRS diagnoses between 2002 and 2016 in BC. Details of detections and diagnoses specific to Atlantic Salmon farms in the Discovery Islands area are included in Appendix A. Briefly:

- There were no detections of *P. salmonis* in 2002-2008, 2010, 2011, 2013 and 2014;
- Positive detections of *P. salmonis* via PCR were made in a small number of samples[1] (n=1 to 3) in four years (2009, 2012, 2015 and 2016) on a total of five farms;
- SRS and *Piscirickettsia*-like bacteria were diagnosed through histology in a small number of fish (n=1 to 23) in three years (2009, 2012 and 2016) on a total of four farms; and
- SRS was diagnosed at the farm level in one year (2016) on two farms.

[1] Samples consist of a small amount of tissue collected from up to five fish.

Although the DFO FHASP is not designed to capture incidence or prevalence, the above detections are indicative of the presence of the pathogen and/or disease in some individuals on farms. These data provide evidence that low levels of *P. salmonis* may be present in farmed populations that may only be detectable using sensitive diagnostic methods.

As part of a research project, molecular evidence of *P. salmonis* genomic DNA has been reported in audit samples collected between April 2011 and December 2013 on Atlantic Salmon farms in BC including farms in Fish Health Surveillance Zones 3.2 and 3.3 (Laurin et al., 2019).

###### *3.1.2.1.3 Fish Health Events*

Fish Health Events (FHEs) are reported to DFO by the industry. DFO (2015) defines a FHE as "a suspected or active disease occurrence within an aquaculture facility that requires the involvement of a veterinarian and any measure that is intended to reduce or mitigate impact and risk that is associated with that occurrence or event." When a FHE occurs, the licence holder must take action to manage the event, evaluate the mitigation measures, submit a notification of FHE and therapeutic management measures to the Department (DFO, 2015).

Reporting of FHEs has been required since the fall of 2002, with the exception of 2013, 2014 and first three quarters of 2015 during which mortalities had to be reported by cause (Wade, 2017). During this time, FHEs were still reported to the BC Salmon Farmers Association (BCSFA) but were not required to be reported to DFO as a condition of licence. The BCSFA provided the FHEs that occurred on Atlantic Salmon farms in the Discovery Islands area during this period to inform this assessment.

No FHEs attributed to SRS were reported on Atlantic Salmon farms in the Discovery Islands area between 2002 and 2017 (based on data collated from DFO Aquaculture Management, the BC Salmon Farmers Association (2013-2015) and DFO (2018a)).

###### *3.1.2.1.4 Mortality Events*

DFO (2015) defines a mortality event as "a) fish mortalities equivalent to 4000 kg or more, or losses reaching 2% of the current facility inventory, within a 24 hour period; or (b) fish mortalities equivalent to 10,000 kg or more, or losses reaching 5%, within a five day period." As a condition of licence, any mortality event must be reported to DFO no later than 24 hours after discovery with details including facility name, fish cultured, number of dead fish, suspected proportion affected, suspected carcass biomass, probable cause, and action taken (DFO, 2015).

No mortality events attributed to SRS, or to any other infectious disease, were reported on Atlantic Salmon farms in the Discovery Islands area between 2011 and 2017 (DFO, 2018b). Mortality event reporting was required prior to 2011 but details and reports are not available.

###### *3.1.2.1.5 Regulation of movement of live fish*

The movement of live aquatic animals is regulated by the Canadian Food Inspection Agency (CFIA) and DFO. Movement control measures contribute to prevention of the introduction of pathogens on marine farm sites and are hence relevant to determine the likelihood of *P. salmonis* infection on Atlantic Salmon farms.

CFIA grants permits for Aquatic Animal Domestic Movements to contain certain aquatic animal reportable diseases. As SRS is not a reportable disease for finfish in Canada (CFIA, 2018), this form of movement control is not further considered.

DFO grants Introduction and Transfer licences under Section 56 of the Fishery (General) Regulations. The Introductions and Transfers Committee (ITC) assesses the health, genetic and ecological impacts that could occur through the transfer of fish in the province. For the aquaculture industry, the ITC assesses the health of fish to be transferred which includes the diseases and causative agents included in Appendix III of the Marine Finfish Aquaculture Licence under the Fisheries Act (diseases of regional, national or international concern) along with any other concern that may arise during the assessment, which would include clinical signs of SRS. For every aquaculture related transfer application, fish health reports and husbandry records are examined by Aquaculture Management Division staff prior to transfer. If any clinical signs of diseases are seen, or there are any other concerns, the ITC can either recommend that the transfer should not happen, or they can work with the applicant to ensure the transfer is carried out in a safe manner (Mark Higgins, DFO, Pacific Biological Station, 3190 Hammond Bay Road, Nanaimo, BC V9T 6N7, pers. comm., 2018). Licences are required for every transfer.

As a condition of a marine aquaculture licence, companies are required to have Standard Operating Procedures (SOPs) to address the movement of fish between facilities (DFO, 2015; Wade, 2017).

#### 3.1.2.2 Industry practices

Three companies rear Atlantic Salmon on marine sites in the Discovery Islands area: Cermaq Canada, Grieg Seafood and Mowi Canada West. Refer to Wade (2017) for an overview of health management practices on Atlantic Salmon farms in BC.

##### *3.1.2.2.1 Surveillance and testing*

Every active marine production site is monitored daily by on-site trained staff for syndromic surveillance during which mortalities are removed and classified. Staff are required to alert the veterinarian if there are any signs of particular pathogens or diseases (Wade, 2017). Additionally, routine health checks are conducted regularly by all companies during which fresh mortalities and/or silvers are examined for signs of diseases or abnormal conditions and sampled for pathogen screening on an as needed basis based on syndromic surveillance, site history, environmental conditions and professional judgement of the veterinarian and fish health team. The frequency of routine health checks and sampling for pathogen screening varies among companies as described below.

In addition to daily monitoring, every Cermaq Canada active marine production site is visited by fish health staff or the veterinarian a minimum of once every two weeks to confirm on-site mortality classification and to sample up to five moribund or fresh mortalities with no obvious cause of death (e.g., non-performing, algae, handling, low oxygen, matures, deformities). In addition to gross lesion scoring of all major organ systems, full histology on three of these fish plus a pool of kidney tissue (up to five fish) is frozen for potential submission by the veterinarian based on either mortality trends or on-site observations. For the first six weeks after transfer to marine production sites, six fresh silvers per cage are sampled every two weeks for bacteriology testing. Finally, at least once per quarter, a pool of kidney tissue is submitted for PCR testing (for infectious hematopoietic necrosis virus (IHNV), viral hemorrhagic septicaemia virus (VHSV), and *P. salmonis*) and three fish are submitted for full histology examination (B. Milligan, Cermaq Canada, 203-919 Island Highway, Campbell River, BC, Canada V9W 2C2, pers. comm., 2018).

In addition to daily monitoring, every active Grieg Seafood marine production site is visited at least once every quarter by the fish health staff and/or veterinarian where at least five silvers are sampled for bacteriology, histology and PCR testing (P. Whittaker and T. Hewison, Grieg Seafood, 1180 Ironwood St, Campbell River, BC V9W 5P7, pers. comm., 2018).

In addition to daily monitoring, every active Mowi Canada West production site is visited at least once a month by fish health staff or the veterinarian and at least once every quarter by the veterinarian. Fresh mortalities and/or silver samples may be collected for pathogen screening based on syndromic surveillance, site history, environmental conditions and professional judgement of the veterinarian and the fish health team (D. Morrison, Mowi Canada West, 124-1334 Island Highway, Campbell River, BC V9W 8C9, pers. comm., 2018).

Screening and testing for *P. salmonis* by the industry is not limited to routine surveillance. Other reasons for testing include research and development, investigation of mortality events, and when fresh mortalities show gross lesions compatible with SRS or a systemic condition of unknown etiology, and upon instruction by the veterinarian and the fish health team. Detection of *P. salmonicida* is based on molecular tests as the pathogen is difficult to culture. Testing is performed by an external diagnostic laboratory.

*3.1.2.2.2 Movement of live fish*

With the exception of one farm, smolts are not stocked directly from freshwater to marine sites in the Discovery Islands area due to the risk of infection from *Kudoa* sp., a parasite of marine fishes (Wade, 2017). Direct stocking occurs at Raza where *Kudoa* sp. has not been an issue (D. New, Cermaq Canada, 203-919 Island Highway, Campbell River, BC, Canada V9W 2C2, pers. comm., 2018).

In BC, any movement of live fish to fish-rearing facilities requires an Introductions and Transfers licence under section 56 of the *Fisheries (General) Regulations*. The decision to issue a licence is based on the recommendations of the ITC. This includes consideration of the results of the pre-transfer health assessments conducted according to company-specific best practices.

- Six to eight weeks prior to every live fish transfer, Cermaq Canada conducts bacteriology (n=30) and PCR for IHNV, VHSV and piscine orthoreovirus (in pools of five fish) on 30 moribund fish. PCR is also conducted for detection of infectious pancreatic necrosis virus (IPNV), infectious salmon anemia virus (ISAV), *Renibacterium salmoninarum* prior to transfers from freshwater to seawater facilities, and for *P. salmonis* prior to transfers from seawater to seawater facilities.
- Three weeks prior to live fish transfers, Grieg Seafood conducts general necropsy (n=30), bacteriology (n=30) and PCR on 30 fish (six pools of five fish) from the subpopulation (P. Whittaker and T. Hewison, Grieg Seafood, pers. comm., 2018).
- Prior to any live fish transfer, Mowi Canada West conducts bacteriology (n=20), virology (four pools of five fish) and histology (n=5 to 10) testing on 20 randomly selected silver fish (D. Morrison, Mowi Canada West, pers. comm., 2018).

*3.1.2.2.3 Vaccination*

In BC, vaccination of Atlantic Salmon is not a condition of licence and is therefore voluntary (DFO, 2015; Wade, 2017). Although there is currently no commercial vaccine for SRS, Renogen®, a live vaccine developed to protect fish against bacterial kidney disease, has been suggested to also provide protection against SRS. The efficacy of the vaccine against SRS is unknown.

Grieg Seafood has been conducting trials since January 2017 with Renogen® to determine its potency to protect against SRS. Given that the vaccine is currently only used in trials, not all Atlantic Salmon are vaccinated with Renogen® to allow comparisons between trial groups (P. Whittaker and T. Hewison, Grieg Seafood, pers. comm., 2018). Mowi Canada West vaccinates 100% of their Atlantic Salmon with Renogen® prior to transfer to seawater to protect against bacterial kidney disease (D. Morrison, Mowi Canada West, pers. comm., 2018).

#### *3.1.2.2.4 Treatment*

Grieg Seafood and Mowi Canada West may treat Atlantic Salmon on their marine sites with in-feed oxytetracycline for 10 to 14 day or florfenicol for 10 days if clinical signs of SRS are present (P. Whittaker and T. Hewison, Grieg Seafood, pers. comm., 2018; D. Morrison, MOWI Canada West, pers. comm., 2018). The choice of antibiotic depends on the sensitivity of the organism and other factors. The length of the treatment is dependent on the prescribed drug, veterinarian judgement and size of the fish. Treatment appears to be efficacious as evidenced by reduction in mortality rates on marine production sites; however, carrier fish may still be present in the population after treatment. A single treatment is often sufficient, however, in Chile multiple treatments are often required (P. Whittaker and T. Hewison, Grieg Seafood, pers. comm., 2018).

### 3.1.2.3 Detections by the industry

Based on the results of observations and testing conducted by the industry on Atlantic Salmon farms in the Discovery Islands area between 2011 and 2017, *P. salmonis* was detected in at least one fish in 20% of site visits with testing for the bacterium. *Piscirickettsia salmonis* was detected in at least one sample in two farms in 2015, five farms in 2016 and three farms in 2017. Refer to Appendix B for details.

### 3.1.2.4 Summary of *Piscirickettsia salmonis* and salmonid rickettsial septicaemia on Atlantic Salmon farms in the Discovery Islands area

In this risk assessment, evidence of *P. salmonis* infection and/or SRS refers to fish sampled during routine screenings by the industry, regulatory programs, FHEs, or any other diagnostic workups on the farms with: (i) positive laboratory tests results targeting *P. salmonis* (e.g., PCRs), or (ii) indicative of *P. salmonis* and/or SRS (histology), or (iii) clinical signs and gross lesions of SRS recognized by trained personal with or without confirmation by diagnostic testing.

Table 7 summarizes data related to Atlantic Salmon farms in the Discovery Islands area with evidence of *P. salmonis* infections and/or SRS signs and diagnoses by year between 2002 and 2017. Data were separately collated from regulatory reporting requirements (results from the FHASP, FHEs and mortality events reported by the industry to DFO) and from industry syndromic surveillance, testing and diagnoses. Therefore, an infection on the same farm may be captured in more than one category so number of farms cannot simply be added between categories or years.

It is acknowledged that the presence of a pathogen in an individual fish does not always result in clinical signs or disease in a population. *Piscirickettsia salmonis* was confirmed on Atlantic Salmon farms in five different years and resulted in farm-level SRS in one year.

Overall, between 2002 and 2017, *P. salmonis* and/or signs of SRS were detected on a total of nine farms and in a total of five years (2009, 2012, 2015, 2016 and 2017) with most of the detections in recent years.

*Table 7. Number of Atlantic Salmon farms in the Discovery Islands area with evidence of* Piscirickettsia salmonis *infection and/or salmonid rickettsial septicaemia (SRS) summarized by year. Data include polymerase chain reaction (PCR), tissue imprints and histology results from industry testing (2011-2017), results from the Fish Health Audit and Surveillance Program (FHASP) (2002-2016), fish health events (FHEs) (2002-2017) and mortality events (2011-2017) reported by the industry to Fisheries and Oceans Canada (DFO). NA: data not available. Months with evidence of* P. salmonis *and/or SRS are shaded and bolded.*

| Year | Number of active farms | Industry data | FHASP data | | | Reported to DFO by industry | |
|---|---|---|---|---|---|---|---|
| | | Number of farms with positive samples / total number of farms tested | Number of farms with positive PCR samples / total number of farms audited | Number of farms with SRS and *Piscirickettsia*-like bacteria identified through histology / total number of farms audited | Number of farms with farm-level SRS diagnoses / total number of farms audited | Number of farms with FHEs attributed to SRS | Number of farms with mortality events attributed to SRS |
| 2002 | NA | NA | 0/3 | 0/3 | 0/3 | 0 | NA |
| 2003 | NA | NA | 0/4 | 0/4 | 0/4 | 0 | NA |
| 2004 | 14 | NA | 0/9 | 0/9 | 0/9 | 0 | NA |
| 2005 | 15 | NA | 0/11 | 0/11 | 0/11 | 0 | NA |
| 2006 | 16 | NA | 0/12 | 0/12 | 0/12 | 0 | NA |
| 2007 | 16 | NA | 0/13 | 0/13 | 0/13 | 0 | NA |
| 2008 | 17 | NA | 0/15 | 0/15 | 0/15 | 0 | NA |
| 2009 | 18 | NA | **1/14** | **1/14** | 0/14 | 0 | NA |
| 2010 | 16 | NA | 0/4 | 0/4 | 0/4 | 0 | NA |
| 2011 | 17 | 0/1 | 0/8 | 0/8 | 0/8 | 0 | 0 |
| 2012 | 13 | No tests | **1/12** | **1/12** | 0/12 | 0 | 0 |
| 2013 | 8 | 0/3 | 0/7 | 0/7 | 0/7 | 0 | 0 |
| 2014 | 10 | 0/2 | 0/8 | 0/8 | 0/8 | 0 | 0 |
| 2015 | 10 | **2/3** | **1/9** | 0/9 | 0/9 | 0 | 0 |
| 2016 | 11 | **5/10** | **4/11** | **3/11** | **2/11** | 0 | 0 |
| 2017 | 12 | **3/10** | NA | NA | NA | 0 | 0 |

### 3.1.3 Assumptions

- Positive detection of the pathogen is evidence of infection; and
- Diagnostic results can be pooled regardless of the differences between methodologies and test performance characteristics for the purpose of indicating the occurrence of the pathogen on farms.

### 3.1.4 Likelihood of farm infection

Table 8 presents the main factors contributing to and limiting the likelihood of a *P. salmonis* infection occurring on an Atlantic Salmon farm in the Discovery Islands area. These factors were used to determine the likelihood and uncertainty rankings based on definitions in Table 2, Table 5 and Table 6.

*Table 8. Factors contributing to and limiting the likelihood that farmed Atlantic Salmon infected with* Piscirickettsia salmonis *are present on one or more Atlantic Salmon farms in the Discovery Islands area under the current fish health management practices.SRS: salmonid rickettsial septicaemia; FHE: fish health event; PCR: polymerase chain reaction; SHMP: salmonid health management plan.*

| Contributing factors | Limiting factors |
|---|---|
| • Atlantic Salmon are susceptible to *P. salmonis* infections;<br>• Between 2011 and 2017, *P. salmonis* was detected by the industry on two farms in 2015; five farms in 2016 and three farms in 2017;<br>• During fish health audits:<br>  o *Piscirickettsia salmonis* was detected through PCR on one farm in each of 2009, 2012, and 2015 and on four farms in 2016;<br>  o SRS and *Piscirickettsia*-like bacteria were detected through histology on one farm in each of 2009 and 2012 and on three farms in 2016; and<br>  o SRS was diagnosed at the farm level on two farms in 2016;<br>• Overall, from 2002 to 2017, there is evidence of *P. salmonis* and/or SRS:<br>  o on a total of nine Atlantic Salmon farms; and<br>  o on at least one farm in five different years (2009, 2012, 2015, 2016 and 2017);<br>• There is no commercial vaccine against SRS; and<br>• SRS outbreaks appear to be triggered by environmental stressors (Jones, 2019). | • Three farms conduct diagnostic testing for *P. salmonis* through PCR prior to live fish transfers from seawater to seawater while other farms conduct general necropsy or histology prior to any live fish transfer that can detect active SRS or *P. salmonis*; and<br>• SHMPs include requirements for minimizing stress during transfer, handling and harvesting (DFO, 2015). |

It was concluded that, in a given year, the likelihood that farmed Atlantic Salmon infected with *P. salmonis* are present on one or more Atlantic Salmon farms in the Discovery Islands area is **unlikely** under the current farm practices given that *P. salmonis* has been detected in five of 16 years (2002 and 2017). This conclusion was made with **reasonable certainty** given abundant and robust data about screening and detections on farms from different sources and over 16 years.

## 3.2 RELEASE ASSESSMENT

### 3.2.1 Question

Assuming that Atlantic Salmon infected with *P. salmonis* are present, what is the likelihood that any *P. salmonis* would be released from an Atlantic Salmon farm located in the Discovery Islands area into an environment accessible to wild fish populations?

### 3.2.2 Considerations

Considerations include Atlantic Salmon rearing method; shedding of *P. salmonis* from infected fish; and fish health management practices.

#### 3.2.2.1 Atlantic Salmon rearing method

Atlantic Salmon reared on marine sites in the Discovery Islands area are contained in net pens. Under such conditions, water flows freely through the pens and there are no barriers to pathogen exchanges between the net pens and the environment (Johansen et al., 2011).

#### 3.2.2.2 Shedding of *Piscirickettsia salmonis* from infected fish

Laboratory data and epidemiological data from farms in Chile and Norway support horizontal transmission of *P. salmonis* among fish and among farms (Cvitanich et al., 1991; Garces et al., 1991; Almendras et al., 1997; Rees et al., 2014; Price et al., 2017).

Although horizontal transmission is consistent with shedding of *P. salmonis* from infected fish, neither the timing of shedding during infection nor the rate of shedding has been described (Jones, 2019). While it is not unreasonable to expect shedding of *P. salmonis* from apparently healthy infected fish, there is little evidence to support this possibility (Jones, 2019).

#### 3.2.2.3 Fish health management practices

As a condition of licence, all companies must comply with the SHMP which includes biosecurity measures to maintain fish health, prevent pathogen entry and limit the spread of diseases on farm (DFO, 2015), some of which will affect the likelihood of pathogens to be released from an infected farm.

The SHMP requires procedures for collecting, categorizing, recording, storing and disposing of fish carcasses (DFO, 2015). More specifically, procedures must be in place for the regular removal of carcasses to storage containers; the reporting of mortality by category to DFO; a secure location of stored carcasses until transfer to land-based facilities; to prevent contents from leaking into the receiving waters; the secure transfer of stored carcasses to land-based facilities; and sanitization methods for storage containers, equipment and other handling facilities or vessels (DFO, 2015). The SHMP also requires a SOP for fish disease outbreaks or emergency, where an outbreak is defined as an “unexpected occurrence of mortality or disease” (DFO, 2015).

Beyond indicating that a SOP is required and a description of the goal, DFO does not prescribe how elements of the SHMP should be achieved. It is therefore up to the company to address the concepts to the satisfaction of the DFO's fish health veterinarian (Wade, 2017). Consequently, it is assumed that for companies with a valid finfish aquaculture licence, the SOPs submitted are in compliance with the conditions of licence and approved by the DFO veterinarian (Wade, 2017).

Protocols are in place for handling and storing dead fish; for labeling, cleaning, disinfecting and storing gear used to handle dead fish; to restrict visitors who must obtain permission prior to arriving on site; to control on-site visitors through the use of signage, footbaths and site specific protective clothing; net washing procedures, not sharing equipment when possible, cleaning and disinfecting equipment after use and dry storing in proper locations; for cleaning, disinfecting and transferring large and submerged equipment among sites; and biosecurity measures are in place to control vessel movement (Wade, 2017). All companies use Virkon® Aquatic, a broad-spectrum disinfectant (Wade, 2017) which is assumed to be effective against marine bacteria such as *P. salmonis*.

Compliance with these elements is determined through the FHASP. On average, less than one deficiency per audit has been reported between 2011 and 2015 on Atlantic Salmon farms in the Discovery Islands area (Wade, 2017). Most reported deficiencies were related to sea lice protocols; carcass retrieval protocol or incomplete record keeping. See Wade (2017) for a detailed breakdown of deficiencies by category.

### 3.2.3 Assumption

- Atlantic Salmon infected with *P. salmonis* are present on at least one farm; and
- Biosecurity and biocontainment measures are effective against *P. salmonis*.

### 3.2.4 Likelihood of release

Table 9 presents the main factors contributing to and limiting the likelihood of release. These factors were used to determine the likelihood and uncertainty rankings based on definitions in Table 2, Table 5 and Table 6.

*Table 9. Factors contributing to and limiting the likelihood that* Piscirickettsia salmonis *will be released from infected and/or diseased Atlantic Salmon on farms in the Discovery Islands area under the current farm practices.*

| Contributing factors | Limiting factors |
|---|---|
| • In Chile, there is epidemiological evidence that *P. salmonis* can spread between salmon farms (Rees et al., 2014; Price et al., 2017);<br>• It is not unreasonable to expect low-level shedding of *P. salmonis* from apparently healthy infected fish (Jones, 2019); and<br>• Atlantic Salmon in the Discovery Islands area are reared in net pens allowing pathogens, including *P. salmonis*, to be released from farms to the surrounding environment. | • Protocols are in place for handling and storing dead fish; for labeling, cleaning, disinfecting and storing gear used to handle dead fish (Wade, 2017);<br>• Protocols are in place to restrict visitors who must obtain permission prior to arriving on site and to control on-site visitors through the use of signage, footbaths and site specific protective clothing (Wade, 2017);<br>• Protocols are in place to minimize predators and wildlife access (Wade, 2017);<br>• Protocols are in place for net washing procedures, not sharing equipment when possible, cleaning and disinfecting equipment after use and dry storing in proper locations (Wade, 2017);<br>• Protocols are in place for cleaning, disinfecting and transferring large and submerged equipment among sites (Wade, 2017);<br>• Biosecurity measures are in place to control vessel movement (Wade, 2017); and<br>• On average, less than one operational deficiency per audit has been reported between 2011 and 2015 on Atlantic Salmon farms in the Discovery Islands area (Wade, 2017). |

Two pathways were considered in the release assessment: (1) infected farmed Atlantic Salmon and (2) mechanical vectors and fomites.

#### 3.2.4.1 Release through infected farmed Atlantic Salmon

It was concluded that the likelihood that *P. salmonis* would be released from an Atlantic Salmon farm located in the Discovery Islands area into an environment accessible to wild fish populations through infected farmed Atlantic Salmon is **extremely likely** under the current fish health management practices given rearing in net pens and expectation that subclinically infected fish could shed the bacterium. This conclusion was made with **high certainty** given robust, abundant and peer-reviewed data about shedding of *P. salmonis* from infected salmonids.

#### 3.2.4.2 Release through vectors and fomites

It was concluded that the likelihood that *P. salmonis* would be released from an Atlantic Salmon farm located in the Discovery Islands area into an environment accessible to wild fish populations through vectors or fomites is **unlikely** under the current fish health management practices. This conclusion was made with **reasonable certainty** given that the relevant biosecurity practices are part of licence requirements and therefore specified in SHMP and relevant SOPs and low levels of operational deficiencies that could affect fish health on Atlantic Salmon farms in the Discovery Islands area.

#### 3.2.4.3 Overall likelihood of release

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.

## 3.3 EXPOSURE ASSESSMENT

### 3.3.1 Question

Assuming that *P. salmonis* has been released from at least one Atlantic Salmon farm in the Discovery Islands area, what is the likelihood that at least one Fraser River Sockeye Salmon would be exposed to *P. salmonis* in a given year?

### 3.3.2 Considerations

The exposure assessment consists of determining the spatial and temporal concurrence of the released pathogen and susceptible species (Taranger et al., 2015).

Considerations include susceptible species; relative size and volume of Atlantic Salmon farms; occurrence of Fraser River Sockeye Salmon in the Discovery Islands area; survival of *P. salmonis* in the marine environment; and timing of *P. salmonis* infections on Atlantic Salmon farms in the Discovery Islands area.

#### 3.3.2.1 Susceptible species

Jones (2019) summarized the salmonids, non-salmonids and other species known to be susceptible to infection with *P. salmonis.* Salmonid species in which clinical signs of SRS have been reported include Pink (*O. gorbuscha*), Coho (*O. kisutch*), Chinook (*O. tshawytscha*) and Atlantic salmon and Rainbow Trout (*O. mykiss*).

To date, there are no reports of SRS from Sockeye Salmon, however, the wide host range of *P. salmonis* indicates a high likelihood that Sockeye Salmon could be susceptible, despite the absence of direct evidence of infection in this species (Jones, 2019).

#### 3.3.2.2 Relative size and volume of Atlantic Salmon farms

Atlantic Salmon farms operating in the Discovery Islands area occupy 0.007% of the area and 0.0008% of the volume of the overall area (Mimeault et al., 2017). Considering that channel width in the Discovery Islands area varies between approximately 850 and 3,200 m, a farm with dimension of 100 m by 100 m by 20 m depth would span over approximately 3 to 12% of the width of the channel.

#### 3.3.2.3 Fraser River Sockeye Salmon in Discovery Islands area

##### *3.3.2.3.1 Juveniles*

Juvenile Sockeye Salmon have been found in the Discovery Islands area in a number of different locations in several studies throughout many years (Levings and Kotyk, 1983; Brown et al., 1984; Groot and Cooke, 1987; Neville et al., 2013; Beacham et al., 2014; Johnson, 2016;

Neville et al., 2016). Based on these studies, Grant et al. (2018) summarized that juvenile lake-type Fraser River Sockeye Salmon migrate through the Discovery Islands from mid-May to mid-July, with peak catches in early-to-mid June.

Out of the five years with evidence of *P. salmonis* and/or SRS on Atlantic Salmon farms since 2002, two years included evidence during the months of May to July (see Table 10 and Table 11).

*3.3.2.3.2 Adults*

Returning adult Sockeye Salmon have been caught in 98% of the Pacific Salmon Commission test fisheries sets conducted in the Discovery Islands area between 2000 and 2015 (Grant et al., 2018) providing evidence of their presence in the Discovery Islands from mid-July to mid-September. Then, by combining when the earliest and latest returning adult Sockeye Salmon migrate past in the Lower Fraser River at Mission, BC (located 60 km upstream of the Fraser River outlet to the southern Strait of Georgia) with the average swimming speed and the distance from the northwestern and southwestern limits of the Discovery Islands area, Grant et al. (2018) estimated that returning adult Fraser River Sockeye Salmon migrate through the Discovery Islands area from June to October.

Out of the five years with evidence of *P. salmonis* and/or SRS on Atlantic Salmon farms since 2002, four years reported evidence during the months of June to October (see Table 10 and Table 11).

### 3.3.2.4 *Piscirickettsia salmonis* survival in the marine environment

Jones (2019) reviewed the state of knowledge about the survival of *P. salmonis* in the environment. Studies most relevant to survival in the marine environment are reported here.

Knowledge of the survival of *P. salmonis* in the marine environment is limited to studies using a Chilean strain. In a laboratory study, a Chilean strain of *P. salmonis* survived in seawater (32‰) for a period of 10 to 15 days at 5°C, 10°C or 15°C (Lannan and Fryer, 1994). *Piscirickettsia salmonis* can form biofilms which may enhance its survival in marine environments (Marshall et al., 2012).

To date, there is no information about the survival of *P. salmonis* in the marine environment in BC.

### 3.3.2.5 Timing of *Piscirickettsia salmonis* and salmonid rickettsial septicaemia on Atlantic Salmon farms in Discovery Islands area

Table 10 summarizes evidence of *P. salmonis* infection and/or SRS by month between 2002 and 2017 on Atlantic Salmon farms in the Discovery Islands area:

- based on industry surveillance and screening results, *P. salmonis* was confirmed on farms in all months except in March, April and May. In all cases, detections were done by PCR, except in February and one occurrence in November. Over 65% of testing for *P. salmonis* between 2011 and 2017 was conducted between August and December;
- based on FHASP results, *P. salmonis* infections were reported in April, August, September, October, and November; and SRS farm-level diagnoses were only reported in August and November;
- no FHEs were attributed to SRS; and
- no mortality events (2011-2017) were attributed to SRS.

Overall, based on all sources of data available between 2002 and 2017, *P. salmonis* and/or SRS was detected on Atlantic Salmon farms in the Discovery Islands area in all months except March and May. Evidence in January, April, June, July, September and December are limited to a few positive *P. salmonis* PCR test results. No seasonal patterns of infection or disease could be found. Table 11 summarizes evidence from all sources of *P. salmonis* and/or SRS per year and month reported on Atlantic Salmon farms located in the Discovery Islands area.

*Table 10. Number of Atlantic Salmon farms in the Discovery Islands area with evidence of* Piscirickettsia salmonis *infection and/or salmonid rickettsial septicaemia (SRS) summarized by month. The "X" indicates evidence of the presence of Sockeye Salmon in the Discovery Islands area in a given month. Data include histology, tissue imprints and polymerase chain reaction (PCR) tests conducted by industry (2011-2017), results from the Fish Health Audit and Surveillance Program (2002-2016), fish health events (FHEs) (2002-2017) and mortality events (2011-2016) reported by the industry to Fisheries and Oceans Canada (DFO). Letters on the first row of the table represent months of the year from January to December. Months with Fraser River Sockeye Salmon in the Discovery Islands area or months with evidence of* P. salmonis *and/or SRS are shaded and bolded.*

| **Occurrence in the Discovery Islands area** | **J** | **F** | **M** | **A** | **M** | **J** | **J** | **A** | **S** | **O** | **N** | **D** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lake-type juvenile Fraser River Sockeye Salmon | | | | | X | X | X | | | | | |
| Returning adult Fraser River Sockeye Salmon | | | | | | X | X | X | X | X | | |
| **Evidence of *P. salmonis* and/or SRS** | **J** | **F** | **M** | **A** | **M** | **J** | **J** | **A** | **S** | **O** | **N** | **D** |
| Number of farms with positive samples / total number of farms tested (industry data) | **1/5** | **1/3** | 0/4 | 0/4 | 0/7 | **1/5** | **1/4** | **1/6** | **3/9** | **3/6** | **4/9** | **2/8** |
| Number of farms with positive PCR samples / total number of farms tested (audit data) | 0/14 | 0/11 | 0/5 | **1/14** | 0/10 | 0/10 | 0/12 | **4/14** | **1/11** | **1/16** | **5/13** | 0/10 |
| Number of farms with SRS and *Piscirickettsia*-like bacteria identified through histology / total number of farms with histology samples (audit data) | 0/14 | 0/11 | 0/5 | 0/14 | 0/10 | 0/10 | 0/12 | **3/14** | 0/11 | **1/16** | **4/13** | 0/10 |
| Number of farms with farm-level SRS diagnoses / total number of farms audited (audit data) | 0/14 | 0/11 | 0/5 | 0/14 | 0/10 | 0/10 | 0/12 | **1/14** | 0/11 | 0/16 | **2/13** | 0/10 |
| Number of farms with FHEs attributed to SRS (reported by industry) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Number of farms with mortality events attributed to SRS (reported by industry) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

*Table 11. Number of Atlantic Salmon farms in the Discovery Islands area with evidence of* Piscirickettsia salmonis *and/or salmonid rickettsial septicaemia (SRS) summarized per year and month. Data includes results from tests conducted by industry (2011-2017), Fish Health Audit and Surveillance Program (2002-2016), fish health events (2002-2017) and/or mortality events (2002-2017). Between 2004 and 2017, the number of active Atlantic Salmon farms varied between three and 17 in a given month (number of active farms not available for 2002 and 2003). Months with evidence of* P. salmonis *and/or SRS are shaded and bolded.*

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2002** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2003** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2004** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2005** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2006** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2007** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2008** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2009** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** | 0 |
| **2010** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2011** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2012** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** | 0 | **1** | 0 | 0 |
| **2013** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2014** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2015** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** | 0 | **1** | **1** |
| **2016** | **1** | **1** | 0 | **1** | 0 | **1** | 0 | **3** | **2** | **2** | **5** | **1** |
| **2017** | 0 | 0 | 0 | 0 | 0 | 0 | **1** | 0 | **1** | **2** | 0 | 0 |

### 3.3.3 Assumptions

- Sockeye Salmon are susceptible to *P. salmonis* infections;
- *P. salmonis* has been released from at least one Atlantic Salmon farm operating in the Discovery Islands area;
- Positive detections of *P. salmonis* is evidence that the pathogen is present in sampled fish;
- *P. salmonis*-infected fish are shedding the bacterium;
- Evidence of shedding is limited to months with evidence of infection or disease on farms;
- Sockeye Salmon can use all channels in the Discovery Islands area; and
- Wild Sockeye Salmon and Sockeye Salmon produced through enhancement are not differentiated for the purpose of this risk assessment.

### 3.3.4 Likelihood of exposure

Table 12 presents the main factors contributing to and limiting the likelihood of Fraser River Sockeye Salmon to be exposed to *P. salmonis* attributed to Atlantic Salmon farm(s) in the Discovery Islands area. These factors were used to determine the likelihood and uncertainty rankings based on definitions in Table 2, Table 5 and Table 6.

*Table 12. Factors contributing to and limiting the likelihood that Fraser River Sockeye Salmon would be exposed to* Piscirickettsia salmonis *released from infected/diseased Atlantic Salmon farm(s) in the Discovery Islands area under the current fish health management practices.*

| Contributing factors | Limiting factors |
|---|---|
| • Millions of juvenile and adult Fraser River Sockeye Salmon migrate through the Discovery Islands area every year (reviewed in Grant et al. (2018));<br>• There is temporal overlap between Fraser River Sockeye Salmon migration and evidence of *P. salmonis* on Atlantic Salmon farms in the Discovery Islands area; and;<br>• Under laboratory conditions, *P. salmonis* can survive in seawater for 10 to 15 days. | • Atlantic Salmon farms are not found in all channels of the Discovery Islands area; and<br>• Atlantic Salmon farms occupy a relatively small surface area and volume of the Discovery Islands area region (Mimeault et al., 2017). |

This assessment considered two exposure groups (juvenile and adult Fraser River Sockeye Salmon) and one exposure route (waterborne).

The likelihood that at least one Fraser River Sockeye Salmon could be exposed to *P. salmonis* attributable to Atlantic Salmon farms was informed by the number of years with evidence of *P. salmonis* and/or SRS during periods of time when Fraser River Sockeye Salmon are present in the area, divided by the number of years with evidence of *P. salmonis* and/or SRS (five years, see Table 11).

#### 3.3.4.1 Exposure of juvenile Fraser River Sockeye Salmon

It was concluded that the likelihood of at least one juvenile Fraser River Sockeye Salmon to be exposed to *P. salmonis* attributable to Atlantic Salmon farms located in the Discovery Islands area through waterborne exposure is **unlikely** under the current fish health management practices given the temporal overlap in the Discovery Islands area with reports of *P. salmonis* on farms. Out of the five years with evidence of *P. salmonis* and/or SRS on farms since 2002, two years had evidence between May and July which corresponds to when juvenile Fraser River Sockeye Salmon are expected to be present in the Discovery Islands area (see Table 11). This conclusion was made with **reasonable certainty** given abundant and robust data documenting the presence of juvenile Sockeye Salmon in the Discovery Islands area and occurrence of *P. salmonis* and SRS on Atlantic Salmon farms in the Discovery Islands area.

#### 3.3.4.2 Exposure of adult Fraser River Sockeye Salmon

It was concluded that the likelihood of at least one adult Fraser River Sockeye Salmon to be exposed to *P. salmonis* attributable to an Atlantic Salmon farm located in the Discovery Islands area through waterborne exposure is **very likely** under the current fish health management practices given the temporal overlap in the Discovery Islands area with reports of *P. salmonis* on farms. Out of the five years with evidence of *P. salmonis* and/or SRS on farms since 2002, four years had evidence between June and October which corresponds to when adult Fraser River Sockeye Salmon are expected to be present in the Discovery Islands area (see Table 11). This conclusion was made with **reasonable certainty** given abundant and robust data documenting the presence of adult Sockeye Salmon in the Discovery Islands area and 16 years of data from various sources on *P. salmonis* and SRS on Atlantic Salmon farms in the region.

## 3.4 INFECTION ASSESSMENT

### 3.4.1 Question

Assuming that at least one Fraser River Sockeye Salmon has been exposed to *P. salmonis* released from Atlantic Salmon farm(s) located in the Discovery Islands area, what is the likelihood that at least one will become infected?

### 3.4.2 Considerations

Considerations include oceanographic and environmental conditions; minimum infectious and lethal doses; estimated duration of exposure; estimated infection pressure from farms; and mortality attributable to SRS on Atlantic Salmon farms.

#### 3.4.2.1 Oceanographic and environmental conditions

Water temperatures in the Discovery Islands area vary both seasonally and regionally with recorded temperatures ranging between 3 and 24°C (Chandler et al., 2017). Average monthly water temperature measured in the top 15 m of Atlantic Salmon farms in the Discovery Islands area ranges from 7.6 ± 2.3°C to 11.5 ± 3.3°C (Chandler et al., 2017). Given that survival of *P. salmonis* in seawater over a 10 to 15 day period was equal to or greater than in tissue culture medium at 5°C, 10°C or 15°C (Lannan and Fryer, 1994), it appears water temperatures in the Discovery Islands area are suitable for *P. salmonis* survival.

Water salinity in the Discovery Islands area varies considerably by season (due to river runoff of snowmelt), by depth (due to the estuarine circulation) and by location (as some narrow channels are extremely well mixed vertically) ranging from close to zero to 32. Average monthly salinity measured in the top 15 m of Atlantic Salmon farms in the Discovery Islands area ranges from 28.9 ± 7.3 to 29.9 ± 8.7 (Chandler et al., 2017) and there is no evidence to suggest that salinities in this range affect the survivability of *P. salmonis*.

#### 3.4.2.2 Minimum infectious and lethal doses

The infectivity of *P. salmonis* by bath challenge has been demonstrated in Atlantic Salmon with a Scottish isolate (Birkbeck et al., 2004) and in Rainbow Trout with a Chilean strain (Smith et al., 2015). However, to date, 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 (Jones, 2019).

#### 3.4.2.3 Estimated duration of exposure

The potential duration that a susceptible fish species would be exposed to *P. salmonis* released from an Atlantic Salmon farm in the Discovery Islands area depends on the: (i) time Fraser River Sockeye Salmon spend in the area, and (ii) duration of *P. salmonis* infections and SRS on Atlantic Salmon farms in this area.

##### *3.4.2.3.1 Time Fraser River Sockeye Salmon spend in the Discovery Islands area*

Grant et al. (2018) estimated the residence time of Sockeye Salmon in the Discovery Islands area to be five to 14 days for a juvenile and three days for an adult. Atlantic Salmon farms in the Discovery Islands area are located in channels within a portion of the total. The total length of the Discovery Islands area is approximately 140 km, with the farms being located over approximately 75 km of this length. Assuming a constant migration speed and unidirectional movement, Mimeault et al. (2017) then estimated that juveniles could encounter farm(s) over three to eight days and returning adults over two days on their migration through the Discovery Islands area.

In a telemetry study conducted in 2017, the median travel time of juvenile Fraser River Sockeye Salmon (primarily from Chilko Lake) through Hoskyn and Okisollo channels (Figure 1) was approximately 30 hours and the travel time from the eastern to the western end of the Okisollo Channel was approximately six hours (Rechisky et al., 2018). In the same study, receivers were also deployed at two fallowed salmon farms to measure Sockeye Salmon exposure time to a region with salmon farms. The median time that juvenile Sockeye Salmon spent near individual salmon farms was approximately 4.5 minutes, suggesting a short duration of exposure to the fallowed farms (Rechisky et al., 2018).

##### *3.4.2.3.2 Duration of* Piscirickettsia salmonis *infections and salmonid rickettsial septicaemia on Atlantic Salmon farms in the Discovery Islands area*

There have been no FHEs or mortality events attributed to SRS on Atlantic Salmon farms in the Discovery Islands area. Most of the FHEs attributed to SRS and audit-based farm-level SRS diagnoses in BC have been reported on the West Coast of Vancouver Island (Fish Health Surveillance Zone 2.3) and given the different environmental conditions, observations from this region are difficult to extrapolate to the Discovery Islands area.

#### 3.4.2.4 Estimated *Piscirickettsia salmonis* infection pressure from Atlantic Salmon farms

Estimating the potential waterborne concentration of *P. salmonis* on a farm during a SRS outbreak requires an estimate of the number of infected fish during an outbreak, the bacterial shedding rate, the shedding duration and the farm volume.

To date, it is not possible to estimate this concentration given that to date no studies have estimated bacterial shedding rates from *P. salmonis*-infected salmon (Jones, 2019).

#### 3.4.2.5 Mortality attributable to *Piscirickettsia salmonis* and salmonid rickettsial septicaemia on Atlantic Salmon farms

Important differences between Chile and BC with respect to the magnitude and operation of the industry limit the extent to which risk may be extrapolated to the BC context (Jones, 2019). The roles of environmental factors, including farm-level processes, in influencing the apparent virulence heterogeneity among *P. salmonis* isolates in various regions requires further research (Jones, 2019). Consequently, only SRS manifestations in BC are considered relevant to this risk assessment.

The first well-described SRS outbreak occurred in farmed Atlantic and Chinook salmon maintained in separate cage systems at a single site near Vancouver Island in 1991 (Brocklebank et al., 1992; Brocklebank et al., 1993). The site consisted of two net pen systems approximately 100 meters apart. The first system contained eight cages of Atlantic Salmon (1991-S1[2]) and four cages of Chinook Salmon (1991-S1) while the second system consisted of eight cages of Chinook Salmon (1991-S0[3]). All cages were identical. The outbreak occurred in the autumn of 1991, approximately six weeks after an algal bloom in September. The daily mortality rate increased steadily during the month of October from 0.01% to 0.06% in two of the

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[2] An "S1" is a smolt or young salmon that has completed the physiological process of smoltification one year after being hatched from the egg (Brocklebank et al. 1993).

[3] An "S0" becomes a smolt within a year from being hatched from the egg (Brocklebank et al. 1993)

eight pens of Atlantic Salmon (Brocklebank et al., 1993). Each pen contained 8,500 fish of 400 to 500 g. Moribund Atlantic Salmon collected in November displayed clinical signs consistent with a septicaemia. In approximately mid-to-late January, fish were treated with in-feed oxytetracycline. One week after the last day of treatment, Atlantic Salmon daily mortality dropped from 0.66% to 0.015% (Brocklebank et al., 1993). The cumulative mortality reached 8% on the affected site for the Atlantic Salmon while Chinook Salmon mortality remained negligible despite showing internal clinical signs by December (Brocklebank et al., 1993).

Finally, while *P. salmonis* was detected and SRS diagnosed at the farm-level in two consecutive audits at Barnes Bay (three months apart) and in one audit at Okisollo in 2016, no FHE attributed to SRS were reported on Atlantic Salmon farms in the Discovery Islands area suggesting limited spread of SRS among farmed Atlantic Salmon despite a prolonged exposure in close proximity in net pens.

### 3.4.3 Assumptions

- Fraser River Sockeye Salmon entering the Discovery Islands area naïve to *P. salmonis*; and
- Fraser River Sockeye Salmon have been exposed to *P. salmonis* released from Atlantic Salmon farm(s) operating in the Discovery Islands area.

### 3.4.4 Likelihood of infection

Table 13 presents the main factors contributing to and limiting the likelihood that a Fraser River Sockeye Salmon would become infected with *P. salmonis* released from an Atlantic Salmon farm located in the Discovery Islands area. These factors were used to determine the likelihood and uncertainty rankings based on definitions in Table 2, Table 5 and Table 6.

*Table 13. Factors contributing and limiting the likelihood that Fraser River Sockeye Salmon would become infected with* Piscirickettsia salmonis *released from infected Atlantic Salmon farms in the Discovery Islands area under current fish health management practices. FHE: fish health events; SRS: salmonid rickettsial septicaemia.*

| **Contributing factors** | **Limiting factors** |
|---|---|
| • BC strains of *P. salmonis* have caused disease in farmed Atlantic and Chinook salmon (Brocklebank et al., 1993) and there are anecdotal reports of rickettsial septicaemia in farmed Pink, Coho and Chinook salmon (Brocklebank et al., 1992);<br>• Sockeye Salmon susceptibility to *P. salmonis* infection and SRS remains to be determined; however, the wide host range of *P. salmonis* indicates a high likelihood that Sockeye Salmon would be susceptible, despite the absence of direct evidence of infection in this species (Jones, 2019);<br>• Juvenile Sockeye Salmon could encounter Atlantic Salmon farms over three to eight days and returning adults over two days during their migration through the Discovery Islands area; and<br>• There is no commercial vaccine against SRS. | • No FHEs or mortality events were attributed to SRS on Atlantic Salmon farms in the Discovery Islands area (2002-2017);<br>• Based on telemetry tracking results, juveniles Sockeye Salmon spend limited time (minutes) in the vicinity of fallowed farms (Rechisky et al., 2018); and<br>• Mortalities during a SRS outbreak on an Atlantic Salmon and Chinook Salmon farm in BC in 1991, were limited to two of the eight net pens containing Atlantic Salmon and remained negligible in the four pens of Chinook Salmon in the same system (Brocklebank et al., 1993), suggesting limited spread of disease between net pens. |

The likelihood of infection was considered separately for the two exposure groups and resulted in the same conclusion.

It was concluded that the likelihood of both juvenile and adult Fraser River Sockeye Salmon to become infected with *P. salmonis* attributable to Atlantic Salmon farms located in the Discovery Islands area under the current fish health management practices is **very unlikely** given low reported mortalities during a SRS outbreak suggesting limited spread of infection. This conclusion was made with **high uncertainty** given absence of data to estimate the infection pressure from an infected Atlantic Salmon farm and other significant knowledge gaps such as survival of *P. salmonis* in the marine environment, relative salmonid susceptibility to *P. salmonis*, and minimum infectious and lethal dose.

## 3.5 OVERALL LIKELIHOOD ASSESSMENT

The estimated likelihoods were combined as per the combination rules described in the methodology section. The combined likelihood for the release assessment was determined by adopting the highest likelihood ranking among the release pathways. The combined likelihood for each exposure group was determined by adopting the lowest ranking among the farm infection, release, exposure and infection assessments. Uncertainties were not combined.

Table 14 summarizes the likelihood assessment. It was concluded that the likelihood that Fraser River Sockeye Salmon would become infected with *P. salmonis* released from Atlantic Salmon farms in the Discovery Islands area is **very unlikely** for both juveniles and adults.

*Table 14. Summary of the likelihood and uncertainty rankings for the likelihood assessment of the* Piscirickettsia salmonis *risk assessment. Results 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 |

# 4 CONSEQUENCE ASSESSMENT

The consequence assessment aims to determine the potential magnitude of impact of *P. salmonis* attributed to Atlantic Salmon farms in the Discovery Islands area on the abundance and diversity of the Fraser River Sockeye Salmon.

Based on the farm infection assessment, it was determined that it is unlikely that Atlantic Salmon infected with *P. salmonis* would be present on at least one farm in the Discovery Islands area. In years with no *P. salmonis* infections on farms, no consequence to the abundance and diversity of Fraser River Sockeye Salmon would be attributable to the bacterium on Atlantic Salmon farms in the Discovery Islands area. In years with evidence of *P. salmonis* infection on farms, the exposure assessment determined that infected fish have been present on a maximum of five farms in any given month and a maximum of three farms between the months of May and October (see Table 11). The overall likelihood assessment concluded that it is very unlikely for Fraser River Sockeye Salmon to become infected with *P. salmonis* attributable to Atlantic Salmon farms in the Discovery Islands area under the current fish health management practices.

Notwithstanding this conclusion and assuming that at least one Fraser River Sockeye Salmon would have been infected with *P. salmonis* attributable to those farms, the consequence assessment explores the potential magnitude of impacts to the number of returning adults and diversity of Fraser River Sockeye Salmon.

## 4.1 QUESTION

Assuming that at least one Fraser River Sockeye Salmon has been infected with *P. salmonis* released from infected Atlantic Salmon, what is the potential magnitude of impact on the number of returning adults and diversity of Fraser River Sockeye Salmon?

## 4.2 CONSIDERATIONS

Considerations include infection dynamics; prevalence and impacts in wild fish populations; subclinical infections; mortalities in infected farmed populations; and estimates of Fraser River Sockeye Salmon densities; proportion of Fraser River Sockeye Salmon potentially exposed to infected farms; and exposure over two generations.

### 4.2.1 *Piscirickettsia salmonis* infection dynamics

For a disease outbreak to occur, a combination of conditions that are unfavourable to the host (i.e., environmental and physiological) and favourable to the pathogen (i.e., presence of susceptible hosts, pathogen survival) are required. In Chile, the probability of SRS on a salmonid farm was positively associated with temperature, time farmed fish spent in salt water, and the number of SRS-infected neighbours (Rees et al., 2014).

*Piscirickettsia salmonis* is transmitted both horizontally and vertically (summarized in Jones (2019)). Following transmission of the bacterium, the incubation period, while dependent on environmental conditions, dose and strain of *P. salmonis* and the condition of the susceptible host species, ranges from 10 to 20 days, with incubation periods in Atlantic Salmon ranging from 15 to 20 days (Rozas and Enriquez, 2014; Rozas-Serri et al., 2017).

### 4.2.2 Prevalence and impact in wild fish populations

A recent study using molecular techniques reported evidence of *P. salmonis* genomic DNA in less than 1% of Fraser River Sockeye Salmon returning to spawn (Miller et al., 2014). Two other studies used similar techniques to detect infectious agents and reported positive results when detected at more than 1% prevalence in a species (Miller et al., 2017; Tucker et al., 2018). *Piscirickettsia salmonis* was not reported in marine-caught Chinook Salmon of Fraser River origin (Tucker et al., 2018) nor in marine-caught Chinook or Sockeye salmon from several origins (Miller et al., 2017). To date, there are no morbidity or mortality data associated with *P. salmonis* infection in wild fish (Jones, 2019).

### 4.2.3 Subclinical infections with *Piscirickettsia salmonis*

It is recognized that there can be both sublethal and cumulative effects of exposure to pathogens and there is no reason to believe that this is different for exposure to *P. salmonis*. However, the current state of knowledge is not sufficient to quantify sublethal effects due to *P. salmonis* infection. Furthermore, it is unknown whether sublethal exposure of marine phase Sockeye Salmon to *P. salmonis* could result in elevated resistance to further infection with *P. salmonis* and/or other bacteria or elevated susceptibility to other pathogens. Consequently, the impact at the population level resulting from an exposure to a concentration lower than the minimum lethal dose is unknown.

### 4.2.4 Mortality in *Piscirickettsia salmonis*-infected salmon farms in BC

Given the lack of information about the impacts of a *P. salmonis* infection and SRS in wild salmon populations (Jones, 2019) on-farm mortality rates in BC Atlantic Salmon were used as proxy data in this risk assessment. Acknowledging that wild Fraser River Sockeye Salmon have to migrate, avoid predators, and compete for resources but also considering that wild susceptible species would be exposed to *P. salmonis* attributable to farms for shorter durations and at lower concentrations than farmed salmon, it is assumed that susceptible wild populations could at most become diseased and die at similar rates to farmed salmon.

The 1991 SRS outbreak on an Atlantic and Chinook salmon farm (Brocklebank et al., 1992; Brocklebank et al., 1993) is the only SRS outbreak in BC for which daily mortality is documented. During this outbreak, daily mortality rate remained negligible in Chinook Salmon, but in Atlantic Salmon, mortality increased from 0.01% in October to a maximum of 0.66% prior to treatment in January. The cumulative mortality in Atlantic Salmon for this outbreak was 8% (Brocklebank et al., 1992; Brocklebank et al., 1993). Based on data submitted by the industry to inform this risk assessment, percent daily mortalities attributed to SRS on farms with audit-based SRS diagnoses remained lower that the ones reported in Brocklebank et al. (1993).

### 4.2.5 Estimates of Fraser River Sockeye Salmon densities

Following infection with a pathogen, the spread of infection within a population depends, amongst other parameters, on the density of the population. As this risk assessment considers the potential spread of infection acquired from Atlantic Salmon farm(s) in the Discovery Islands area, in-river juvenile density estimates are not relevant. Of most relevance to this assessment are the densities in the Discovery Islands area and in the open ocean.

#### 4.2.5.1 During juvenile outmigration

Approximate densities of juvenile Sockeye Salmon in the Strait of Georgia were estimated from purse seine data collected in May and June of 2010-2012 (Neville et al., 2013; Freshwater et al., 2017). These studies used a 280 m long and 9 m deep purse seine (approximate cylindrical volume of 56,000 $m^3$). The highest reported average CPUE for Fraser River Sockeye Salmon was 1,534 and occurred in the Discovery Islands area in June of 2012 (Neville et al., 2013). Average CPUEs in the Strait of Georgia in May and June were at least an order of magnitude lower (Neville et al., 2013). Using the same dataset, Freshwater et al. (2017) reported May and June combined CPUEs of 49 ± 239 and 323 ± 780 (average ± SD) for 2011 and 2012, respectively.

Based on the highest average CPUE (1,534) and assuming that the water sampled in each set was 56,000 $m^3$, the highest estimated average density of juvenile Sockeye Salmon in this area would be approximately 0.03 fish/$m^3$. Note that these estimates assume that fish are uniformly distributed within the area sampled by the net, and that all fish present in the sampled area are caught (i.e., there is no net avoidance behaviour or fish escaping from the net). These estimates should be revised as results from on-going studies become available.

#### 4.2.5.2 In the open ocean

There are no data on Sockeye Salmon abundance or density in the open ocean, hence proxy data were used in this risk assessment.

Using hydro acoustic methods, Nero and Huster (1996) estimated the mean density of salmon (spp.) to 114 salmon/$km^2$ in the Gulf of Alaska (which they mention is comparable with historical estimates of 160 salmon/$km^2$). As salmon were at most 40 m from the sea surface during the day (Nero and Huster, 1996), their average density is therefore estimated to be approximately $2.9 \times 10^{-6}$ fish/$m^3$. Assuming that salmon mainly stay in the top 10 meters, this is where the greatest concentration would occur (Ware and McFarlane (1989); Groot and Margolis (1991); cited in Nero and Huster (1996)), their density would be approximately $1.1 \times 10^{-5}$ fish/$m^3$. Note that Nero and Huster (1996) did not specify salmon species or sizes.

As the spatial arrangement of salmon suggests that at small spatial scales (2–200 m), salmon are uniformly distributed, whereas at larger spatial scales (400–2,000 m), they are aggregated (Nero and Huster, 1996), the density at small scales could be higher than the average estimates above. However, although data are limited, it is reasonable to anticipate that the density of Fraser River Sockeye Salmon would be lower at sea than during their migration through the channels of the Discovery Islands area.

### 4.2.6 Estimates of the proportion potentially exposed to infected farms

This section explores the proportion of Fraser River Sockeye Salmon population in the Discovery Islands area at the same time as *P. salmonis* infections and/or SRS have been reported on Atlantic Salmon farms.

Noting that there are routes through the Discovery Islands area where there are no Atlantic Salmon farms, and that location and number of simultaneously infected farms will be critical aspects in assessing actual exposure to infected farm(s), the following analysis provides an overestimate of the proportion of the population exposed to infected farms in the Discovery Islands area during periods when *P. salmonis* infections and/or SRS were detected on one or more farms.

This is the first step in determining the proportion of the population that could potentially be exposed to *P. salmonis* attributable to infected Atlantic Salmon farms in the Discovery Islands area acknowledging that concurrent overlap does not necessarily result in exposure and that exposure does not necessarily result in infection. The estimates are based on the timing of Fraser River Sockeye Salmon migration and evidence of infections on farms in the area.

#### 4.2.6.1 Juvenile

Millions of juvenile Fraser River Sockeye Salmon migrate through the Discovery Islands area every year (reviewed in Grant et al. (2018)). Knowledge of juvenile marine out-migration routes through the Discovery Islands area and interactions with Atlantic Salmon farms is limited. Consequently, it is not possible to estimate the proportion of the population that could swim by an infected Atlantic Salmon farm based on their migration routes. It was therefore assumed that all out-migrating juvenile Fraser River Sockeye Salmon could potentially be exposed to *P. salmonis* attributable to infected farm(s) during their migration through the Discovery Islands area. This assumption should be reviewed as our knowledge of Fraser River Sockeye Salmon migratory routes expands.

However, as Atlantic Salmon farms are not located in every channel and do not occupy a large volume of the Discovery Islands area (see Figure 1 and section 3.3.2.2), it is reasonable to assume that not all fish would encounter an infected farm or be exposed to pathogens dispersed from the farm(s). Additionally, these estimates need to consider the presence of Fraser River Sockeye Salmon in the area in relation to the timing of the infections. Juvenile lake-type Fraser River Sockeye Salmon migrate through the Discovery Islands area from mid-May to mid-July (Grant et al., 2018). The outmigration is, however, not uniformly distributed over the three months (Neville et al., 2016; Freshwater et al., 2019). Based on capture data from Freshwater et al. (2019), 30%, 62% and 8% of juveniles were captured in May, June and July, respectively.

Taking into consideration the temporal distribution of Fraser River Sockeye Salmon through the Discovery Islands area and only considering years with infection, between 8 and 62% (median=35% and mean=35%) of juveniles would have had the opportunity to be exposed to *P. salmonis* attributable to Atlantic Salmon farm(s) in the Discovery Islands area during their out-migration migration (see Appendix C). These estimates also assume that migrating fish would encounter the infected farm(s), i.e., fish would use the route(s) which have the infected farm(s).

#### 4.2.6.2 Adults

Sockeye Salmon return to the Fraser River either through the northern route (Johnstone Strait) or the southern route (Strait of Juan de Fuca) (reviewed in Grant et al. (2018)). Northern diversion rates are highly variable with rates ranging from 10 to 96% annually between 1980 and 2017 (Grant et al. (2018) and Pacific Salmon Commission (2017, 2018)). Assuming that all returning Sockeye Salmon using the northern route would migrate through the Discovery Islands area, between 10 and 96% of returning adult Fraser River Sockeye Salmon could be exposed to an Atlantic Salmon farm during their migration.

Returning adult Fraser River Sockeye Salmon migrate through the Discovery Islands area from late-June to early-October (reviewed in Grant et al. (2018)). The returning migration is, however, not uniformly distributed over the five months. Based on capture data below Mission provided by the Pacific Salmon Commission (see Appendix C), 0.3%, 12.2%, 79.7%, 7.7% and 0.1% of adults returning through the northern route are expected in the Discovery Islands area in the months of June, July, August, September and October, respectively.

Taking into consideration the temporal distribution and the northern diversion of returning adults and only considering years with infections, between 5 and 44% (median=14% and mean=19%) of adults would have had the opportunity to be exposed *P. salmonis* attributable to Atlantic Salmon farm(s) in the Discovery Islands area during their returning migration (see Appendix C). These estimates also assume that migrating fish would encounter the infected farm(s), i.e., fish would use the route(s) which have the infected farm(s).

### 4.2.7 Estimates of exposure over two generations

The potential exposure of Fraser River Sockeye Salmon populations to Atlantic Salmon farms infected with *P. salmonis* over two generations (eight years for Fraser River Sockeye Salmon) was estimated to explore potential impacts on diversity.

Given the two possible exposure outcomes in any given year for migrating Fraser River Sockeye Salmon, i.e., migrating salmon can be exposed given evidence of infection on farms in the area (success outcome) or migrating salmon cannot be exposed given lack of evidence of infection on farms in the area (failure outcome), the number of successes (s) over a given number of trials (n) can be estimated using the binomial process (Appendix D).

On average, over two generations, juvenile and adult Fraser River Sockeye Salmon could encounter *P. salmonis*-infected Atlantic Salmon farms in the Discovery Islands area in one and two of the eight years, respectively. This assumes that when a farm(s) is infected, the Sockeye Salmon choose the route(s) that takes them by the infected farm(s). The probability of exposure, but not necessarily infection, to occur in at least four consecutive years over two generations is 0.08% and 1.6% for juvenile and adult Fraser River Sockeye Salmon, respectively (see Appendix D).

Despite potential exposure in consecutive years, the likelihood assessment concluded that it was very unlikely for Fraser River Sockeye Salmon to become infected with *P. salmonis* attributable to Atlantic Salmon farms in the Discovery Islands area under current management practices.

## 4.3 ASSUMPTIONS

- There is no correlation between SRS mortality and marine mortality from other sources in Sockeye Salmon; i.e., the marine mortality rate is the same in infected and non-infected fish; and
- When a farm(s) is infected, the Sockeye Salmon use the route(s) that takes them by the infected farm(s).

## 4.4 MAGNITUDE OF CONSEQUENCES

Figure 5 illustrates potential outcomes of spread and establishment resulting from at least one Fraser River Sockeye Salmon infected with *P. salmonis* released from infected Atlantic Salmon on farms located in the Discovery Islands area.

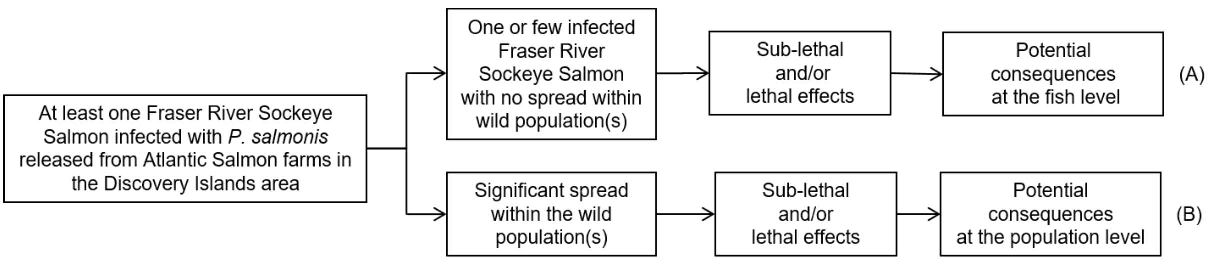


*Figure 5. Potential outcomes resulting from at least one Fraser River Sockeye Salmon infected with* Piscirickettsia salmonis *released from Atlantic Salmon farms located in the Discovery Islands area.*

The infection assessment concluded that it is very unlikely that Fraser River Sockeye Salmon exposed to concentrations of *P. salmonis* released from infected Atlantic Salmon from a farm located in the Discovery Islands area will become infected.

The potential magnitude of consequences on both the abundance and diversity of Fraser River Sockeye Salmon resulting from the exposure and infection of juvenile Fraser River Sockeye Salmon and adult Fraser River Sockeye Salmon were determined separately. Rankings were determined referring to consequence to abundance (Table 3), consequences to diversity (Table 4) and uncertainty (Table 5) definitions.

### 4.4.1 Juvenile Fraser River Sockeye Salmon

Juvenile Fraser River Sockeye Salmon are expected to encounter *P. salmonis*-infected Atlantic Salmon farms in the Discovery Islands area during their out-migration in one of eight years; and have almost a zero probability of exposure to occur over four consecutive years (section 4.2.7). In years with infections, based on 2002-2017 data (Table 11), juveniles could have been exposed to one *P. salmonis*-infected farm during their migration through the Discovery Islands area.

Following exposure to a *P. salmonis*-infected Atlantic Salmon farm in the Discovery Islands area, juvenile Fraser River Sockeye Salmon will continue their migration through Johnstone Strait, Queen Charlotte Strait, and into the open ocean. It is worth noting that despite potential exposure, the likelihood assessment concluded that it was very unlikely for juvenile Fraser River Sockeye Salmon to become infected with *P. salmonis* attributable to Atlantic Salmon farms in the Discovery Islands area under current management practices. Nevertheless, the potential for an infection theoretically acquired in the Discovery Islands area to spread to other juvenile Fraser River Sockeye Salmon during migration at sea was considered (Figure 5, Outcome A).

The estimated migration period from the Discovery Islands area through Queen Charlotte Strait is approximately 5 to 15 days based on juvenile migration swimming speed (10 to 30 km/day) summarized in Grant et al. (2018). The incubation period of *P. salmonis* ranges from 10 to 20 days depending on environmental conditions, dose, strain of the bacterium and host species (Rozas and Enriquez, 2014; Rozas-Serri et al., 2017). Therefore, any juvenile Fraser River Sockeye Salmon infected with *P. salmonis* attributable to infected farm(s) in the Discovery Islands area would be expected to show signs of infection during their migration through the Queen Charlotte Strait and into the open ocean.

Whether or not infection will spread in the population, as well as the rate and extent of the spread, depends on the probability of susceptible individuals making successful contact (i.e., contact leading to transmission of the infection) with an infectious individual in the same population. This probability depends, amongst other parameters, on the density of the population.

To date, there are no references documenting the prevalence and mortality attributable to SRS in wild salmonid populations. The SRS outbreak on an Atlantic and Chinook salmon farm described by (Brocklebank et al., 1992; Brocklebank et al., 1993) provides information related to the development and spread of SRS at farm densities. This information can be used as proxy information in this risk assessment as there is no vaccine for SRS in Canada. The 1991 outbreak lasted four months prior to treatment and had a cumulative mortality of 8%. The density of farmed fish during the 1991 outbreak was 1.9 salmon/$m^3$, which is several fold magnitude higher than the estimated densities of salmon in the open ocean (see section 4.2.5). It is therefore concluded that the critical density of the host population required for effective transmission of *P. salmonis* and progression to the disease would not be met for juvenile Fraser River Sockeye Salmon.

Consequently, it is concluded that it is not plausible for juvenile Fraser River Sockeye Salmon exposed to *P. salmonis* released from infected Atlantic Salmon farm(s) to result in an infection that would spread and establish within the population. Therefore, it is concluded that the potential magnitude and consequences to the population abundance or diversity of Fraser River Sockeye Salmon would be **negligible**. This conclusion was made with **reasonable uncertainty** as it is based primarily on surrogate data from a farm outbreak and estimates of densities of Fraser River Sockeye Salmon in the open ocean.

### 4.4.2 Adult Fraser River Sockeye Salmon

Adult Fraser River Sockeye Salmon could be exposed to infected Atlantic Salmon on up to three farms during their return migration through the Discovery Islands area to the Fraser River. There is an approximate 2% probability that exposure to infected farms could occur over at least four consecutive years over two generations (see section 9.4.1.2). The potential for an infection theoretically acquired in the Discovery Islands area to spread to other adult Fraser River Sockeye Salmon during freshwater migration on the spawning grounds (prior to successful spawning) is considered.

Grant et al. (2018) estimated that returning Fraser River Sockeye Salmon can travel the distance between the southeastern limit of the Discovery Islands area and Mission in approximately three to four days. The distance between Fraser River Sockeye Salmon spawning grounds and the ocean ranges widely, from 40 km for the Widgeon Slough population to 1,200 km for the Early Stuart population (Cohen, 2012b). In a fish health study, the Early Stuart River Sockeye took up to about a month to reach spawning grounds (Stoddard, 1993).

Given an incubation period as short as 10 days, it is plausible for returning Fraser River Sockeye Salmon, exposed to *P. salmonis* from infected Atlantic Salmon farms in the Discovery Islands area to become infected and to develop SRS during the freshwater migration phase.

There remain significant knowledge gaps regarding the infection dynamics of *P. salmonis*, particularly the strain found in BC. However, given that adult Fraser River Sockeye Salmon, exposed to Atlantic Salmon farms with *P. salmonis* attributable to farms in the Discovery Islands area, will have up to approximately a month between exposure and spawning, an unrealistically high basic reproductive ratio ($R_0$) would be required, similar to what was modelled for *A. salmonicida* (Mimeault et al., 2020), for there to be spread to 1% of the returning population within this timeframe. It is therefore concluded that this is not a plausible outcome, and therefore, the potential magnitude of consequences to the population abundance or diversity of adult Fraser River Sockeye Salmon would be **negligible**. This conclusion was made with **high uncertainty** given the lack of data on the infection dynamics of *P. salmonis*, and the reliance on proxy data from farms and expert opinion.

# 5 RISK ESTIMATION

## 5.1 ABUNDANCE

The risk to the abundance of Fraser River Sockeye Salmon due to infections with *P. salmonis* attributable to Atlantic Salmon farms in the Discovery Islands area (Table 15) was estimated based on the matrix combining the results of the likelihood assessment and the results of the consequence to the abundance assessment (Figure 3).

*Table 15. Risk estimation to the abundance of Fraser River Sockeye Salmon resulting from* Piscirickettsia salmonis *attributable to Atlantic Salmon farms located in the Discovery Islands area under current farm management practices.*

| Exposure group | Likelihood assessment | Consequence assessment | Risk to Fraser River Sockeye Salmon abundance |
|---|---|---|---|
| Juvenile Fraser River Sockeye Salmon | Very unlikely | Negligible | Minimal |
| Adult Fraser River Sockeye Salmon | Very unlikely | Negligible | Minimal |

It was concluded that, under the current fish health management practices, the risk to the abundance 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**.

## 5.2 DIVERSITY

The risk to the diversity of Fraser River Sockeye Salmon due to infections with *P. salmonis* attributable to Atlantic Salmon farms in the Discovery Islands area (Table 16) was estimated based on the risk matrix combining the results of the likelihood assessment and the results of the consequence to the diversity assessment (Figure 4).

*Table 16. Risk estimation to the diversity of Fraser River Sockeye Salmon resulting from* Piscirickettsia salmonis *attributable to Atlantic Salmon farms located in the Discovery Islands area under current farm management practices.*

| Exposure group | Likelihood assessment | Consequence assessment | Risk to Fraser River Sockeye Salmon diversity |
|---|---|---|---|
| Juvenile Fraser River Sockeye Salmon | Very unlikely | Negligible | Minimal |
| Adult Fraser River Sockeye Salmon | Very unlikely | Negligible | Minimal |

It was concluded that, 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**.

# 6 SOURCES OF UNCERTAINTIES

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

## 6.1 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;
- the lack of information about the survival of *P. salmonis* in the marine environment in BC;
- the lack of information about the minimum infectious and lethal doses of *P. salmonis* in susceptible species;
- the variability and knowledge gaps about precise migration routes of juvenile Fraser River Sockeye Salmon through the Discovery islands area; and
- the lack of data to precisely 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.

## 6.2 CONSEQUENCE ASSESSMENT

The main uncertainties in the consequence assessments for both abundance and diversity resulted from:

- the absence of data on SRS mortality in wild Sockeye Salmon, and other wild susceptible fish, and the consequent 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 subclinical infection with *P. salmonis*.

# 7 CONCLUSIONS

The 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 Fraser River 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 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 the population, hence the magnitude of consequences to both Fraser River Sockeye Salmon abundance and diversity would be negligible.

There are considerable sources of uncertainties associated with 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 (1) likelihood of infection of wild fish for which there is a lack of information about shedding rates in *P. salmonis*-infected healthy and diseased salmon; 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 susceptible species; and (2) 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 subclinical infection with *P. salmonis*. Conclusions of this risk assessment should be reviewed as new research findings fill knowledge gaps.

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# 9 APPENDICES

## 9.1 APPENDIX A: FISH HEALTH AUDIT AND SURVEILLANCE PROGRAM

### 9.1.1 Audit-based *Piscirickettsia salmonis* detections and salmonid rickettsial septicaemia diagnoses

This section summarizes the audit-based farm-level SRS diagnoses on Atlantic Salmon farms located in the Discovery Islands area which includes all farms in Fish Health Surveillance Zone 3-2 and three farms in Fish Health Surveillance Zone 3-3 (Hardwicke, Althorpe, Shaw Point).

Between 2004 and 2016, there was on average 14 farms stocked per year, ranging from eight in 2013 to 18 in 2009 (Table 17). Between 2002 and 2016, 245 audits were conducted. From 2004 to 2011 between 25 and 88% of farms were audited annually. From 2012 to 2016, most active farms have been audited annually (80 to 100%).

Between 2002 and 2016, a total of three audit-based farm-level diagnoses of SRS were reported on two Atlantic Salmon farms in the Discovery Islands area, all in 2016.

*Table 17. Summary of active Atlantic Salmon farms, number of audits conducted and audit-based farm-level salmonid rickettsial septicaemia diagnoses on Atlantic Salmon farms located in the Discovery Islands area (Fish Health Surveillance Zone 3-2 and three farms in proximity in Fish Health Surveillance Zone 3-3) between 2002-2016. Number of farms is the total number of Atlantic Salmon farms with fish on site at any point in the year. Sources: DFO (2018c), data provided by DFO Aquaculture Management and the BC Salmon Farmers Association. NA: not available.*

| Year | Number of farms | Number of audits | Number of farms audited | Percentage of farms audited | Number of audits with farm-level SRS diagnoses | Number of audited farms with farm-level SRS diagnoses |
|---|---|---|---|---|---|---|
| 2002 | NA | 3 | 3 | NA | 0 | 0 |
| 2003 | NA | 10 | 4 | NA | 0 | 0 |
| 2004 | 14 | 13 | 9 | 64 | 0 | 0 |
| 2005 | 15 | 18 | 11 | 73 | 0 | 0 |
| 2006 | 16 | 19 | 12 | 75 | 0 | 0 |
| 2007 | 16 | 24 | 13 | 81 | 0 | 0 |
| 2008 | 17 | 28 | 15 | 88 | 0 | 0 |
| 2009 | 18 | 23 | 14 | 78 | 0 | 0 |
| 2010 | 16 | 4 | 4 | 25 | 0 | 0 |
| 2011 | 17 | 13 | 8 | 47 | 0 | 0 |
| 2012 | 13 | 23 | 12 | 93 | 0 | 0 |
| 2013 | 8 | 12 | 7 | 88 | 0 | 0 |
| 2014 | 10 | 16 | 8 | 80 | 0 | 0 |
| 2015 | 10 | 18 | 9 | 90 | 0 | 0 |
| 2016 | 11 | 21 | 11 | 100 | 3 | 2 |
| **Total** | **---** | **245** | **---** | **---** | **3** | **2** |

Detection of *P. salmonis* or rickettsia-like organisms in the absence of other evidence of disease, is not sufficient to trigger a farm-level diagnosis of SRS. Consequently, in addition to farm-level diagnoses, low levels of *P. salmonis* may be present in farmed populations and these are only detectable using sensitive diagnostic methods. The factors that trigger clinical SRS are poorly understood but are believed to be related to environmental or production associated stressors.

Data from the BC provincial and DFO Fish Health Audit and Surveillance Program conducted on Atlantic Salmon farms in the Discovery Islands area between 2002 and 2016 which document findings indicative of *P. salmonis* infection are summarized in Table 18. Since 2002, two farms have had farm-level diagnoses of SRS, both in 2016. One was at Barnes Bay in two of three audits (August and November) and one at Sonora/Okisollo in one of three audits (November). In addition, there was audit confirmation of *P. salmonis* infection on one farm in each of 2009 (Cyrus Rocks in November) and 2012 (Cyrus Rocks in August and October) and on three farms in 2016 (Barnes Bay in April, Brent Island in November, Sonora/Okisollo in August). Audits resulted in three presumptive diagnoses of *P. salmonis*, both at Venture Point; one in 2015 (in September) and two in 2016 (in August and November). The bacterium was not detected by audit between 2002 and 2008, nor in 2010, 2011, 2013 and 2014. It is noteworthy that the farms with confirmed or presumptive diagnoses of *P. salmonis* through audits were all located in Okisollo Channel.

*Table 18. Results of provincial (2002-2010) and DFO (2011-2016) fish health audits conducted on Atlantic Salmon farms in the Discovery Islands area on which* Piscirickettsia salmonis *and/or salmonid rickettsial septicaemia (SRS) have been detected. Testing for* P. salmonis *through PCR (pools of up to five fish) and histopathology were conducted on all carcasses collected through the DFO audit program (2011-2016). Source: DFO Aquaculture Management for provincial fish health audits (2002-2010) and DFO (2018c) for DFO fish health audits (2011-2016). * provincial results only mentioned SRS and* P. salmonis *lesions as opposed to SRS and* Piscirickettsia*-like bacteria in histological findings.*

| Year | Facility Name | Number of fish health audits | Number of carcasses assessed | Number of *P. salmonis* positive results using PCR | Number of fish with histologic diagnosis for SRS with *Piscirickettsia*-like bacteria | Farm-level veterinary diagnosis |
|---|---|---|---|---|---|---|
| 2009 | Cyrus Rocks | 3 | 16 | 1 | Signs of SRS in 1* | 1st audit: Open – no known cause no significant lesions;<br>2nd audit: Other;<br>3rd audit: Open – no known cause no significant lesions |
| 2012 | Cyrus Rocks | 3 | 15 | 2 | 2 | No disease that is significant at the population level |
| 2015 | Venture Point | 2 | 11 | 1 | 0 | No disease that is significant at the population level |
| 2016 | Barnes Bay | 3 | 25 | 3 | 13 | 1st audit: No disease that is significant at the population level;<br>2nd audit: SRS<br>3rd audit: SRS |
| | Brent Island | 2 | 17 | 1 | 1 | 1st audit: No disease that is significant at the population level;<br>2nd audit: Low level mortality associated with environmental conditions |
| | Okisollo | 3 | 18 | 2 | 9 | 1st audit: No disease that is significant at the population level;<br>2nd audit: No mortality that is significant at the population level;<br>3rd audit: SRS |
| | Venture Point | 3 | 28 | 2 | 0 | 1st audit: No disease that is significant at the population level;<br>2nd audit: Open: low level mortality associated with environmental conditions;<br>3rd audit: Open: extent of infectious disease limited, no significant lesions |

### 9.1.2 Seasonality in audits on Atlantic Salmon farms in the Discovery Islands area

Between 2002 and 2016, a total of 245 audits were conducted on Atlantic Salmon farms located in the Discovery Islands area. Table 19 presents the total number of audits conducted by months over the 15-year period ranging from eight in March to 34 in January.

*Table 19. Total number and monthly average number of audits (BC provincial government (2002-2010) and DFO-AMD (2011-2016)) conducted on Atlantic Salmon farms located in the Discovery Islands area.*

| Month | Total number of audits | Mean number of audits (range) |
|---|---|---|
| January | 34 | 2 (0-6) |
| February | 16 | 1 (0-3) |
| March | 8 | 1 (0-2) |
| April | 33 | 2 (0-6) |
| May | 11 | 1 (0-4) |
| June | 13 | 1 (0-3) |
| July | 25 | 2 (0-5) |
| August | 21 | 1 (0-5) |
| September | 17 | 1 (0-4) |
| October | 31 | 2 (0-6) |
| November | 23 | 2 (0-6) |
| December | 13 | 1 (0-4) |
| **Total** | **245** | - |

To determine if the number of audits was equally distributed over all months of the year, the observed total number of audits for each month (Table 19) was compared to the expected counts (1/12 of 245 audits per month) using a Chi-Square goodness of fit test. Results showed that the number of audits was not equally distributed over all months ($p$-value $< 0.001$) and the number of audits was higher than expected in the months of January, April, July, August, October and November.

Efforts to understand seasonality in audit-based detections of pathogens or farm-level diagnoses of diseases, need to be interpreted in light of the significantly unequal distribution in the number of audits conducted per month in this region.

## 9.2 APPENDIX B: INDUSTRY SURVEILLANCE AND DETECTIONS

Table 20 summarizes screening and detections of *P. salmonis* by industry in samples obtained during routine health checks, screening of broodstock in marine net pens, investigations of elevated mortality and from research projects conducted on Atlantic Salmon farms in the Discovery Islands area.

Industry diagnostic tests for SRS involve a combination of histology, tissue imprints and PCR testing to confirm presence of *P. salmonis*. Fish sampling varied between years and companies. The exact number of fish sampled and the number of individual PCR tests are not available as PCR tests were conducted using either pooled samples or individual fish or both. All companies sampled freshly dead fish (with or without visible lesions) and moribund fish.

From 2011 to 2017, *P. salmonis* was detected by industry on a total of 22 of 110 farm visits (Table 20) on seven different farms. Of the 22 positive *P. salmonis* detections, 20 were made by PCR. Fifteen of these 22 positive results came from five farms in 2016. One of the five farms had positive cases in January, February, August, September and October. Another farm had three positive cases confirmed by PCR between September and November, one farm had two positive results confirmed in June and November and two farms had one detection each by PCR; one in November and one in December. In 2017, there were five detections by PCR among three farms; positive samples were found in July (one farm), September (one farm) and in October (twice at one farm, and one at another farm).

*Table 20. Summary of industry results of* Piscirickettsia salmonis *screening between 2011 and 2017 on Atlantic Salmon farms in the Discovery Islands area.*

| Year | Number of site visits with | | Number of farms with | |
|---|---|---|---|---|
| | **positive *P. salmonis* tests** | **testing *for P. salmonis*** | **positive *P. salmonis* tests** | **testing for *P. salmonis*** |
| 2011 | 0 | 2 | 0 | 1 |
| 2012 | No tests | No tests | No tests | No tests |
| 2013 | 0 | 4 | 0 | 3 |
| 2014 | 0 | 3 | 0 | 2 |
| 2015 | 2 | 5 | 2 | 3 |
| 2016 | 15 | 52 | 5 | 10 |
| 2017 | 5 | 44 | 3 | 10 |

## 9.3 APPENDIX C: PROPORTION OF POPULATION POTENTIALLY EXPOSED

This appendix details the estimation of the proportion of the Fraser River Sockeye Salmon population, juveniles and adults that could be in the Discovery Islands area at the same time as *P. salmonis* infections and/or SRS have been reported on Atlantic Salmon farms.

These estimates assume that migrating fish would encounter the infected farm(s), i.e., fish would use the route(s) which have the infected farm(s). However, noting that there are routes through the Discovery Islands area where there are no Atlantic Salmon farms, and that location and number of simultaneously infected farms will be critical aspects in assessing actual exposure to infected farm(s), the following analysis provides an overestimate of the proportion of the population exposed to infected farms in the Discovery Islands area during periods when *P. salmonis* infections and/or SRS were detected on one or more farms.

### 9.3.1 Juveniles

The proportion of juvenile Sockeye Salmon that could be exposed to *P. salmonis*-infected farms in the Discovery Islands area during their migration was estimated based on:

- the out-migration timing of juvenile Fraser River Sockeye Salmon; and
- the weighted number of months with evidence of *P. salmonis* infection during which juveniles could encounter infected farms each year between 2002 and 2017.

Juvenile lake-type Fraser River Sockeye Salmon tend to migrate through the Discovery Islands area from mid-May to mid-July, with peak catches in early-to-mid June (Grant et al., 2018). Raw data from a study conducted by Freshwater et al. (2019), from mid-May to mid-July over three years (2014-2016) of out-migration of Fraser River Sockeye Salmon were used to calculate the temporal distribution of captured juveniles around the Discovery Islands area. According to this dataset, 30%, 62% and 8% of juveniles were captured in May, June and July, respectively, which is in agreement with other studies indicating Fraser River Sockeye Salmon outmigration peak occurs in June around the Discovery Islands area (Neville et al., 2016; Grant et al., 2018).

These three percentages were then applied as frequency weights to (i.e., multiplied by) each corresponding monthly infection status within any given year, between 2002 and 2017 (Table 21). For instance, in 2016, June had infected farm(s) and received its respective weight of 62%, but May and July were uninfected (zero). Therefore, the sum of the three weighted-months resulted in an estimate of the proportion of juveniles that could potentially have been in the Discovery Islands area at the time of an infection in this year to be 62%.

*Table 21. Estimated proportion of juvenile lake-type Fraser River Sockeye Salmon that could potentially have been exposed to* Piscirickettsia salmonis*-infected Atlantic Salmon farm(s) during their migration through the Discovery Islands area between 2002 and 2017. Presence (1) or absence (0) of infection on farms are the binary representation of data from Table 11. Weighted presence/absence are the presence/absence multiplied by the estimate temporal distribution of juveniles through the Discovery Islands area (30% for May, 62% for June and 8% for July). The proportion of juvenile potentially exposed is the sum of the weighted presence/absence (May to July).*

| Year | Presence (1) / absence (0) | | | Weighted presence/absence | | | Proportion of juveniles potentially exposed |
|---|---|---|---|---|---|---|---|
| | May | June | July | May | June | July | |
| 2002 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2005 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2006 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2007 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2008 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2009 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2010 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2011 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2012 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2013 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2014 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2015 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2016 | 0 | 1 | 0 | 0.00 | 0.62 | 0.00 | 0.62 |
| 2017 | 0 | 0 | 1 | 0.00 | 0.00 | 0.08 | 0.08 |

With the evidence of *P. salmonis* on Atlantic Salmon farms in the Discovery Islands area and the weighted frequency distribution based on the timing of migration, the proportion of juvenile Fraser River Sockeye Salmon that could have been in the Discovery Islands area when *P. salmonis* was released from Atlantic Salmon farms between 2002 and 2017 (16 years) in the Discovery Islands area ranged between 0 and 62% (median=0% and mean=4%).

However, in the consequence assessment, the years without evidence of infection (total of 14 years) have to be disregarded given the assumption that “at least one migratory fish has been infected with the *P. salmonis* released from an infected farm(s).” When only considering years with evidence of infection while juveniles were migrating through the area between 2002 and 2017 (two years), the proportion of juvenile Fraser River Sockeye Salmon that could have been in the Discovery Islands area when *P. salmonis* was released from Atlantic Salmon farms ranged between 8 and 62% (median=35% and mean=35%). These estimates are based on the evidence of *P. salmonis* occurrences summarized in Table 11.

### 9.3.2 Adults

The proportion of adult Sockeye Salmon that could be exposed to *P. salmonis*-infected farms in the Discovery Islands area during their return migration to the Fraser River (Table 22) was estimated based on:

- Northern diversion rates (NDR) of returning adult Fraser River Sockeye Salmon ranging from 10 to 96% between 2002 and 2017 (Pacific Salmon Commission data presented in

Grant et al. (2018) and 2016 and 2017 reports of the Fraser River Panel to the Pacific Salmon Commission (Pacific Salmon Commission, 2017, 2018)); and

- the weighted number of months with evidence of *P. salmonis* infections from June to October (when adults are in the Discovery Islands area) between 2002 and 2017.

Returning adult Fraser River Sockeye Salmon tend to migrate through the Discovery Islands area from late-June to early-October (Grant et al., 2018). Estimates of the temporal distribution of returning adults in the Discovery Islands area were based on data provided by the Pacific Salmon Commission. Based on this dataset, 0.3%, 12.2%, 79.7%, 7.7% and 0.1% of returning adults are expected in the Discovery Islands area in the months of June, July, August, September and October, respectively. Refer to Mimeault et al. (2020) for details.

These five percentages were then applied as frequency weights to (i.e., multiplied by) each corresponding monthly infection within any given year, between 2002 and 2017 (Table 11). For instance, in 2016, June, August, September and August had infected farms and received their respective weights of 0.3%, 79.7%, 7.7% and 0.1% but July was not infected (zero). Therefore, the sum of the five weighted-months (87.8%) multiplied by the NDR for the year (50%) resulted in an estimate of the proportion of adults that could potentially have been exposed in this year to be 44% (Table 22).

*Table 22. Estimated proportion of adult Fraser River Sockeye Salmon that could potentially have been exposed to* Piscirickettsia salmonis*-infected Atlantic Salmon farm(s) during their migration through the Discovery Islands area between 2002 and 2017. Northern diversion rates (NDR) are from data summarized in Grant et al. (2018) and the Pacific Salmon Commission (2017, 2018). Presence (1) or absence (0) of infection on farms are the binary representations of data from Table 11. Weighted presence/absence are presence/absence multiplied by the temporal distribution of returning adults through the Discovery Islands area (0.3%, 12.2%, 79.7%, 7.7% and 0.1% in June through October based on all catches below Mission offset to account for the time-lag migration from the Discovery Islands area). The proportion of the adults potentially exposed is the sum of weighted presence/absence (June to October) multiplied by the NDR.*

| Year | Presence (1) / absence (0) | | | | | Weighted presence/absence | | | | | Sum weighted presence/ absence | NDR | Proportion of adults potentially exposed |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jun | Jul | Aug | Sep | Oct | Jun | Jul | Aug | Sep | Oct | | | |
| 2002 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.51 | 0 |
| 2003 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.69 | 0 |
| 2004 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.64 | 0 |
| 2005 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.74 | 0 |
| 2006 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.65 | 0 |
| 2007 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.44 | 0 |
| 2008 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.10 | 0 |
| 2009 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.47 | 0 |
| 2010 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.73 | 0 |
| 2011 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.62 | 0 |
| 2012 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0.797 | 0 | 0.001 | 0.798 | 0.18 | 0.14 |
| 2013 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.71 | 0 |
| 2014 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.96 | 0 |
| 2015 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0.077 | 0 | 0.077 | 0.69 | 0.05 |
| 2016 | 1 | 0 | 1 | 1 | 1 | 0.003 | 0 | 0.797 | 0.077 | 0.001 | 0.878 | 0.50 | 0.44 |
| 2017 | 0 | 1 | 0 | 1 | 1 | 0 | 0.122 | 0 | 0.077 | 0.001 | 0.2 | 0.71 | 0.14 |

The proportion of returning adult Fraser River Sockeye Salmon that could have been in the Discovery Islands area when *P. salmonis* was released from Atlantic Salmon farms between 2002 and 2017 (16 years) during their returning migration in the Discovery Islands area ranged between 0 and 44% (median=0% and mean= 5%).

When only considering the four years with evidence of infection on farm(s) while adults were migrating through the area between 2002 and 2017, the proportion of returning adult Fraser River Sockeye Salmon that could have been in the Discovery Islands area when *P. salmonis* was released from Atlantic Salmon farms between 2002 and 2017 during their returning migration in the Discovery Islands area ranged between 5 and 44% (median=14% and mean= 19%). These estimates are based on evidence of *P. salmonis* occurrences including detections at the fish level summarized in Table 11.

## 9.4 APPENDIX D: EXPOSURE OVER TWO GENERATIONS

The potential exposure of Fraser River Sockeye Salmon populations to Atlantic Salmon farms infected with *P. salmonis* over two generations (eight years for Fraser River Sockeye Salmon) was estimated to explore potential impacts on diversity.

### 9.4.1 Binomial process approach

There are two possible exposure outcomes in any given year for migrating Fraser River Sockeye Salmon, i.e., migrating salmon can be exposed (success outcome) or not (failure outcome). Given the two possible outcomes, the number of successes (s) over a given number of trials (n) can be estimated using the binomial process.

The exposure assessment determined that between 2002 and 2017, two and four years reported evidence of *P. salmonis* and/or SRS during the months when, respectively, juvenile and adult Fraser River Sockeye Salmon are expected in the Discovery Islands area (Table 11). In other words, in any given year, the probability that juveniles could be in the Discovery Islands area at the same time as a farm is infected with *P. salmonis* is, on average, 13% (2/16). Similarly, in any given year, the probability that adults could be in the Discovery Islands area at the same time as a farm is infected with *P. salmonis* is, on average, 25% (4/16).

Assuming that (i) the probability of exposure each year is independent of the previous one and (ii) there is a constant probability of exposure each year, a binomial distribution was conducted in R with the following input parameters:

- probability of success (P) = 0.125 for juveniles and 0.25 for adults, and
- number of trials (n) = eight years, representing two generations of Fraser River Sockeye Salmon.

#### 9.4.1.1 Juveniles

The potential that juveniles are in the Discovery Islands area at the same time as an infection with *P. salmonis* on an Atlantic Salmon farm, based on the binomial process explained above is:

- On average, one year out of the eight years (mean = n × P = 8 × (2/16) = 1; with SD = $\sqrt{n \times p \times (1-p)}$ = 0.93).
- Figure 6 provides the complementary cumulative binomial probability distribution (CCDF), from which the probability of exposure in at least a given number of years is illustrated. For example, the probability that juveniles become exposed in at least two out of eight years is

26%, while the probability that juveniles become exposed in at least five out of eight years is <1%, and so on.

- Over one generation (four years), the probability of exposure in four consecutive years is 0.02% ($P^4 = 0.125^4 = 0.0002$).
- Over two generations, the probability of exposure in at least four consecutive years over eight years is determined by the sum of the products of the probabilities of exposure over at least four years and the probabilities for those years to be consecutive. Consequently, the probability that juveniles could be exposed to *P. salmonis* released from infected Atlantic Salmon farms in the Discovery Islands area in at least four consecutive years over two generations is 0.08% (see Table 23).

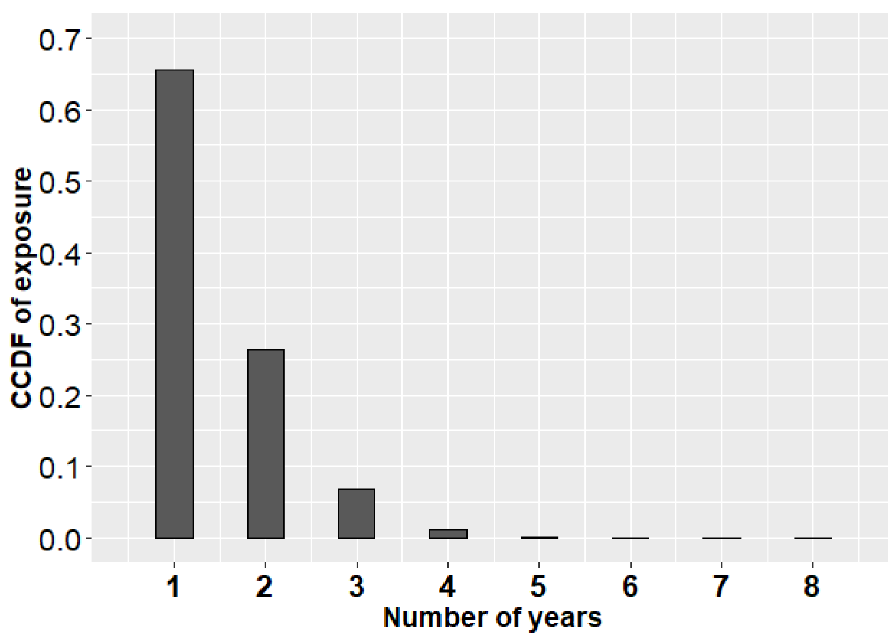


*Figure 6. Complementary cumulative probability distribution (CCDF) of potential exposure of juvenile Fraser River Sockeye Salmon to* Piscirickettsia salmonis-*infected Atlantic Salmon farms in the Discovery Islands area over eight years. The probability of exposure is based on a binomial process assuming a probability of success (p) of 0.125, and a number of trials (n) of eight years.*

*Table 23. Probability of exposure of juvenile Fraser River Sockeye Salmon to* Piscirickettsia salmonis *attributable to Atlantic Salmon farms in the Discovery Islands area in at least four consecutive years over a time period representing two generations (eight years). The probability of exposure is based on a binomial process assuming the probability of success (P) on an individual trial (year) is 0.125 and the number of trials (n) is eight.*

| (a) Number of success (x): number of years with exposure | (b) Number of trials (n): number of years for two generations | (c) Binomial probability: P(X = x) (exactly x successes in n trials) | (d) Number of consecutive combinations of x in n * | (e) Number of distinct combinations of x in n ** | (f) Probability of exactly x consecutive years in n years (c × d / e) |
|---|---|---|---|---|---|
| 4 | 8 | 0.0100 | 5 | 70 | 0.0007 |
| 5 | 8 | 0.0011 | 4 | 56 | $8.2 \times 10^{-5}$ |
| 6 | 8 | $8.2 \times 10^{-5}$ | 3 | 28 | $8.8 \times 10^{-6}$ |
| 7 | 8 | $3.3 \times 10^{-6}$ | 2 | 8 | $8.3 \times 10^{-7}$ |
| 8 | 8 | $6.0 \times 10^{-8}$ | 1 | 1 | $6.0 \times 10^{-8}$ |
| **Probability of at least four consecutive years in two generations (eight years)** | | | | | **0.0008** |

** For example, with x=4 and n=8: 1-2-3-4; 2-3-4-5; 3-4-5-6; 4-5-6-7; and 5-6-7-8.*
*** For example, with x=4 and n=8: 1-2-3-4; 1-2-3-5; 2-4-6-7; 4-5-7-8; ...; for a total of 70 combinations.*

### 9.4.1.2 Adults

The potential that adults are in the Discovery Islands area at the same time as an infection with *P. salmonis* on an Atlantic Salmon farm, based on the binomial process explained above is:

- On average, adults could be exposed to *P. salmonis*-infected adults in two years out of the eight years (mean = n × P = 8 × (4/16) = 2; with SD = $\sqrt{n \times p \times (1-p)}$ = 1.2).
- Figure 7 provides the complementary cumulative binomial probability distribution (CCDF), from which the probability of exposure in at least a given number of years is illustrated. For example, the probability that adults become exposed in at least two out of eight years is 64%, while the probability that adults become exposed in at least five out of eight years is 3%, and so on.
- Over one generation (four years), the probability of exposure in four consecutive years is 0.39% ($P^4$ = and $0.25^4$ = 0.0039).
- Over two generations, the probability of exposure in at least four consecutive years over eight years is determined as above for the juveniles. Consequently, the probability that adults could be exposed to *P. salmonis* released from infected Atlantic Salmon farms in the Discovery Islands area in at least four consecutive years over two generations is 1.6% (see Table 24).

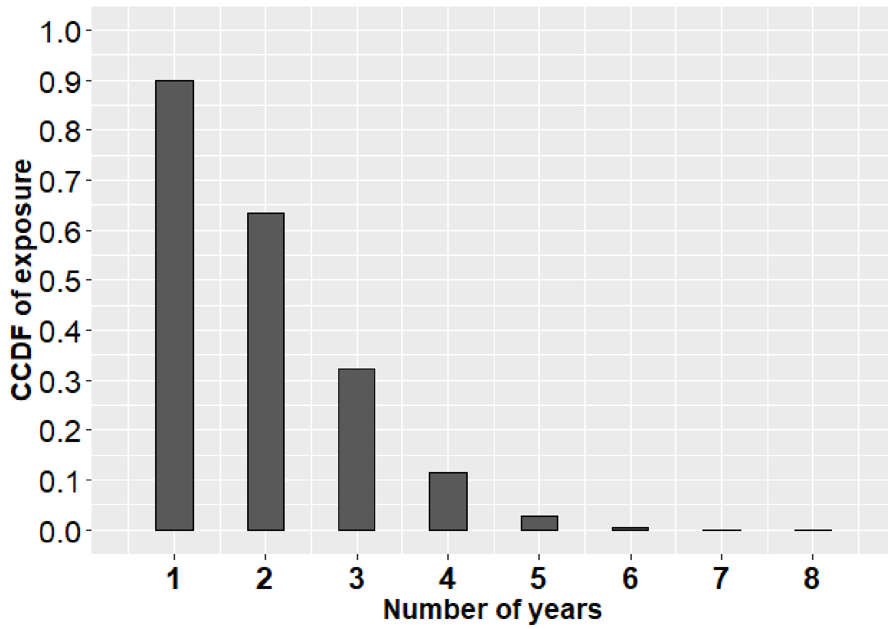


*Figure 7. Complementary cumulative probability distribution (CCDF) of potential exposure of adult Fraser River Sockeye Salmon to* Piscirickettsia salmonis*-infected Atlantic Salmon farms in the Discovery Islands area over eight years.The probability of exposure is based on a binomial process assuming a probability of success (p) of 0.25, and a number of trials (n) of eight years.*

*Table 24. Probability of exposure of adult Fraser River Sockeye Salmon to* Piscirickettsia salmonis *attributable to Atlantic Salmon farms in the Discovery Islands area in at least four consecutive years over a time period representing two generations (eight years). The probability of exposure is based on a binomial process assuming the probability of success (P) on an individual trial (year) is 0.3125 and the number of trials (n) is eight.*

| (a) Number of success (x): number of years with exposure | (b) Number of trials (n): number of years for two generations | (c) Binomial probability: P(X = x) (exactly x successes in n trials) | (d) Number of consecutive combinations of x in n * | (e) Number of distinct combinations of x in n ** | (f) Probability of exactly x consecutive years in n years (c × d / e) |
|---|---|---|---|---|---|
| 4 | 8 | 0.1491 | 5 | 70 | 0.0107 |
| 5 | 8 | 0.0542 | 4 | 56 | 0.0039 |
| 6 | 8 | 0.0123 | 3 | 28 | 0.0013 |
| 7 | 8 | 0.0016 | 2 | 8 | 0.0004 |
| 8 | 8 | $9.1 \times 10^{-5}$ | 1 | 1 | $9.1 \times 10^{-5}$ |
| **Probability of at least four consecutive years in two generations (eight years)** | | | | | **0.0163** |

** For example, with x=4 and n=8: 1-2-3-4; 2-3-4-5; 3-4-5-6; 4-5-6-7; and 5-6-7-8.*
*** For example, with x=4 and n=8: 1-2-3-4; 1-2-3-5; 2-4-6-7; 4-5-7-8; ...; for a total of 70 combinations.*

### 9.4.2 Simulation approach

To further evaluate the reliability of the exposure estimates from the binomial process, a simulation approach was undertaken. To do this, a bootstrap sampling strategy was used to randomly select eight years out of the 16 years of assessment (0: year without infection, 1: year with infection) with 1,000 and 10,000 iterations. The sum of infected years (per iteration) was calculated for each iteration to estimate the number of years during which juveniles and adults could be expected to migrate through the Discovery Islands area while there would be at least one Atlantic Salmon farm infected with *P. salmonis* and/or showing clinical signs of SRS.

The resulting frequency distributions of the sums were compared with the results of the binomial process (Table 25). The two approaches resulted in very close results, supporting the reliability of the approaches in estimating the potential exposure of Fraser River Sockeye Salmon over eight years. As the number of iterations increased (e.g., from 1,000 to 10,000), the bootstrap distribution resembled the binomial distribution (see Table 25 for examples).

*Table 25. Comparison of the exposure estimates from the binomial process and bootstrapping (1,000 and 10,000 iterations). Each percentage represents the probability of exposure of juvenile or adult Fraser River Sockeye Salmon in at least a given number of years (out of eight ).*

| Years of infection | Method | Juveniles (%) | Adults (%) |
|---|---|---|---|
| At least three | **Binomial process** | **~8** | **~46** |
| | Bootstrap (1,000) | ~7 | ~30 |
| | Bootstrap (10,000) | ~7 | ~32 |
| At least six | **Binomial process** | **~0** | **<1** |
| | Bootstrap (1,000) | ~0 | <1 |
| | Bootstrap (10,000) | ~0 | <1 |