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# Assessment of the risk to Fraser River Sockeye Salmon due to *Yersinia ruckeri* 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)

**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

**Sublethal:** insufficient to cause death

**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.

This document is the assessment of the risk to Fraser River Sockeye Salmon due to *Yersinia ruckeri* on Atlantic Salmon farms in the Discovery Islands area of British Columbia (BC) under current farm practices. The risk assessment was conducted in three main steps: first, a likelihood assessment that includes four consecutive assessment steps (farm infection, pathogen release, exposure of Fraser River Sockeye Salmon, and infection of Fraser River Sockeye Salmon); second, a consequence assessment; and third, a risk estimation.

*Yersinia ruckeri* is the causative agent of enteric redmouth (ERM) and is endemic to British Columbia, Canada where it has been detected both in wild and farmed salmon. Based on the evidence of infection and disease that has been reported on Atlantic Salmon farms between 2002 and 2017, it is very unlikely, with reasonable certainty, that farmed Atlantic Salmon in the Discovery Islands area will become infected with *Y. ruckeri* in any given year under the current farm practices. Although the shedding rates from *Y. ruckeri*-infected Atlantic Salmon have not been quantified, it is extremely likely, with high certainty, that the bacterium would be released from infected Atlantic Salmon into the marine environment given rearing practices in net pens. Given the limited temporal overlap of *Y. ruckeri* infections on farms and juvenile Fraser River Sockeye Salmon migration through the Discovery Islands area, it is very unlikely, with reasonable certainty, that at least one juvenile will be exposed in a given year. Exposure for adults is extremely unlikely given the lack of temporal overlap between their migration window and infections on farms. Assuming exposure, the likelihood for Fraser River Sockeye Salmon to become infected with *Y. ruckeri* attributable to Atlantic Salmon farms is extremely unlikely, with reasonable certainty, given that Atlantic Salmon farms are considered to represent a negligible infection pressure. Overall, it was concluded that it is extremely unlikely that Fraser River Sockeye Salmon would become infected with *Y. ruckeri* released from Atlantic Salmon farms in the Discovery Islands area under current farm practices.

The potential magnitude of consequences to the abundance and diversity of Fraser River Sockeye Salmon was determined to be negligible, with high certainty. This conclusion was made with high certainty given that ERM is primarily a freshwater trout disease.

Overall, the assessment concluded that *Y. ruckeri* 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. Conclusions have been reached based on a series of rankings estimated with a range of uncertainties. 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, 2012).

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 *Yersinia ruckeri*, the causative agent of enteric redmouth (ERM), from Atlantic Salmon farms in the Discovery Islands area in BC. This pathogen was selected to undergo a formal pathogen transfer risk assessment because ERM has been diagnosed at the farm level on Atlantic Salmon farms in the Discovery Islands area through the Fish Health Audit and Surveillance Program.

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, 2012), 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 *Y. ruckeri* attributable to Atlantic Salmon farms in the Discovery Islands area.

### 2.2.2 Hazard characterization

Wade (2019) synthesized the relevant characteristics of *Y. ruckeri* and ERM (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. While *Y. ruckeri* is primarily a freshwater pathogen it has been isolated from some salmonid species in saltwater (as summarized in Wade (2019)). The review includes a summary of the occurrence of *Y. ruckeri* and ERM 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 *Y. ruckeri* 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.

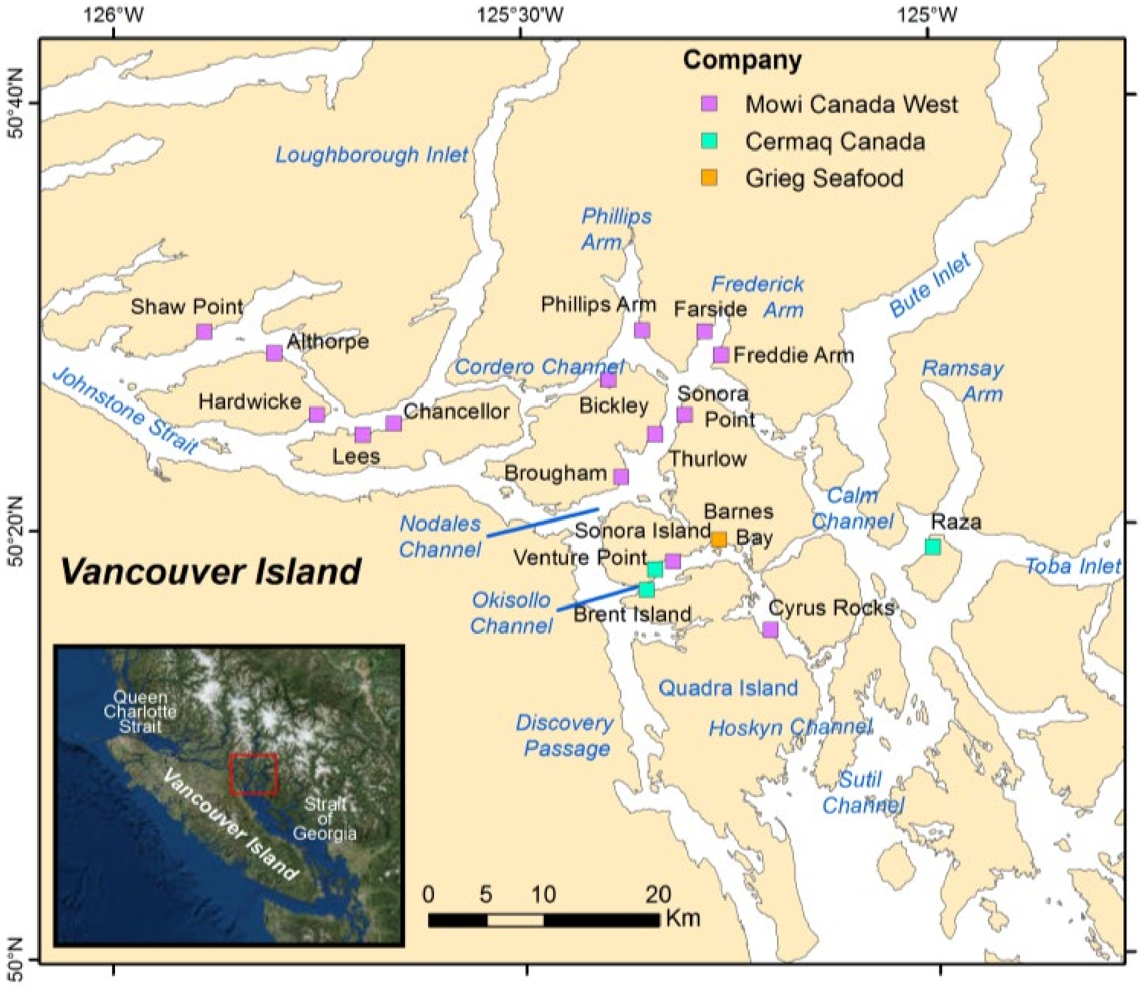


*Figure 1. Locations of Atlantic Salmon farms in the Discovery Islands area (Fish Health Surveillance Zone 3-2 and three farms in Fish Health Surveillance Zone 3-3) included in this risk assessment. Symbol size for fish farms is not to scale. The insert illustrates the location of the Discovery Islands 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 *Y. ruckeri* 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 risk matrix to estimate the risk. The likelihood assessment is done 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 *Y. ruckeri* infection attributable to Atlantic Salmon farms in the Discovery Islands area on the abundance and diversity of Fraser River Sockeye Salmon.

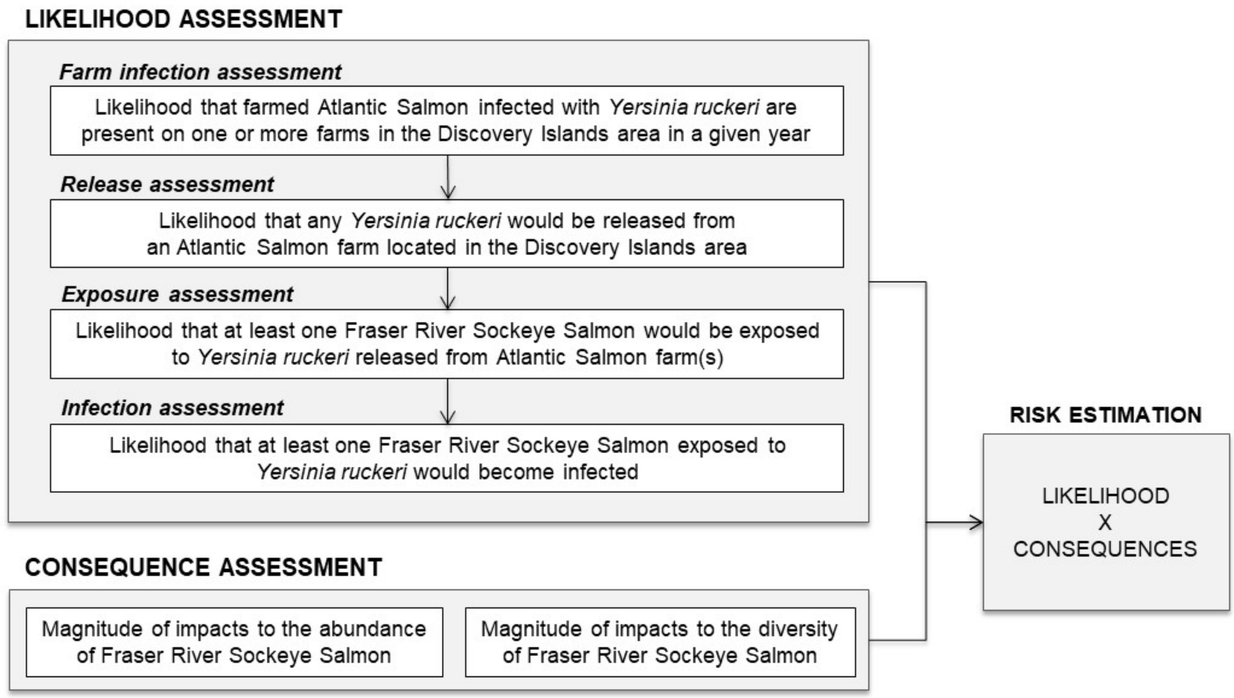


*Figure 2. Conceptual model to assess the risks to Fraser River Sockeye Salmon resulting from* Yersinia ruckeri *attributable to Atlantic Salmon farms located in the Discovery Islands area, British Columbia. Adapted from Mimeault et al. (2017).*

#### 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 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.

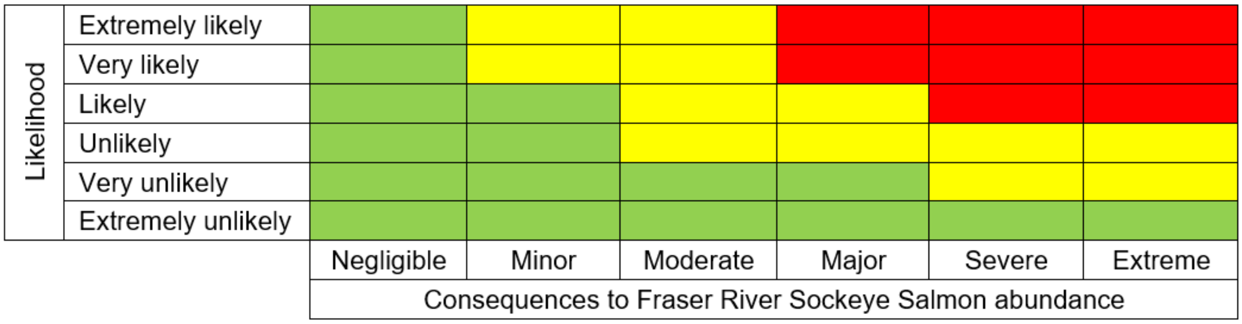


*Figure 3. Risk matrix for combining the results of the assessment of the likelihood and consequence to Fraser River Sockeye Salmon abundance. Green, yellow and red represent minimal, moderate and high risk, respectively.*

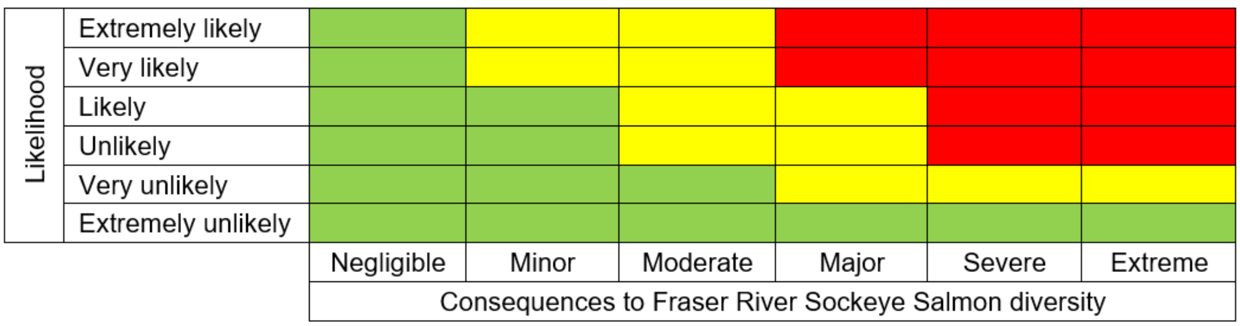


*Figure 4. Risk matrix for combining the outputs of the assessment of likelihood and consequence to Fraser River Sockeye Salmon diversity. Green, yellow and red represent minimal, moderate and high risk, respectively.*

# 3 LIKELIHOOD ASSESSMENT

The likelihood assessment consists of determining the likelihood that Fraser River Sockeye Salmon would become infected with *Y. ruckeri* 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 Questions

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

### 3.1.2 Considerations

Factors contributing to the detection of *Y. ruckeri* 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, ERM is diagnosed in an Atlantic Salmon population when there is elevated mortality in the population, gross and microscopic lesions consistent with the disease and isolation of *Y. ruckeri* in sampled fish (I. Keith, DFO, pers. comm., 2018).

Wade (2019) summarized audit-based detections of *Y. ruckeri* and farm-level ERM 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 *Y. ruckeri* in 2002-2005, 2008-2010, 2012, 2013, 2015 and 2016;
- *Yersinia ruckeri* was isolated by culture in a small number of fish (n=1 to 4) in four years (2006, 2007, 2011 and 2014) on a total of four farms;
- Histological diagnoses for ERM were reported in a very small number of fish (n=2) in one year (2006) on one farm; and
- ERM was diagnosed at the farm level in one year (2011) on one farm.

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.

#### 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 FHE attributed to ERM 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 ERM, or to any other infectious diseases, 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 the prevention of the introduction of pathogens on marine farm sites and are hence relevant to determine the likelihood of *Y. ruckeri* infection on Atlantic Salmon farms.

CFIA grants permits for Aquatic Animal Domestic Movements to contain certain aquatic animal reportable diseases. As ERM is not a reportable finfish disease 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 ERM. 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 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) are 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 polymerase chain reaction (PCR) testing (for infectious hematopoietic necrosis virus (IHNV), viral hemorrhagic septicaemia virus (VHSV), and *Piscirickettsia 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).

##### *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 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 testing (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 *Piscirickettsia 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). Ermogen® is the only vaccine licenced for use in Canada to prevent ERM. Ermogen® is a serotype O1 bacterin vaccine delivered via immersion to fish 2 g or larger. It was not possible to obtain efficacy data for Ermogen® as it is proprietary.

Cermaq Canada and Mowi Canada West vaccinate all Atlantic Salmon raised in hatcheries supplied with surface water with Ermogen®, which represents approximately a third of the production (B. Milligan, Cermaq Canada, pers. comm., 2018; D. Morrison, Mowi Canada West, pers. comm., 2018). Grieg Seafood has always and continues to vaccinate 100% of their Atlantic Salmon against ERM and considers the vaccine efficacious in production fish (P. Whittaker and T. Hewison, Grieg Seafood, pers. comm., 2018).

##### *3.1.2.2.4 Treatment*

Treatment for ERM in hatcheries can vary between aquaculture companies. Cermaq Canada and Grieg Seafood may treat fish for 10 days with in-feed oxytetracycline (OTC) or florfenicol if signs of ERM are present in Atlantic Salmon in a hatchery in BC (B. Milligan, Cermaq Canada, pers. comm., 2018; P. Whittaker and T. Hewison, Grieg Seafood, 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. Alternatively, infected stocks may be culled. Treatment or culling is determined case-by-case based on the likelihood of spread and recovery (B. Milligan, Cermaq Canada, pers. comm., 2018). Antibiotic treatment is efficacious at reducing ERM-related mortalities.

As ERM is primarily a freshwater disease, antibiotic treatment is not always administered on Atlantic Salmon marine production sites in BC when signs of ERM are present. Cermaq Canada and Grieg Seafood may not administer treatment on marine production sites as ERM infections are usually short lived and resorbed in two to four weeks (B. Milligan, Cermaq Canada, pers. comm., 2018; P. Whittaker and T. Hewison, Grieg Seafood, pers. comm., 2018). Mowi Canada West may administer treatment when fish are showing signs of ERM on marine facilities (D. Morrison, Mowi Canada West, pers. comm., 2018).

##### *3.1.2.2.5 Egg disinfection in hatcheries*

Egg disinfection following fertilization and water hardening is a requirement of the SHMP (DFO, 2015). Egg disinfection can be conducted either at the broodstock facility and/or at the hatchery (DFO, 2015). Company-specific egg disinfection protocols are described in their proprietary SOPs accompanying the SHMP. Cermaq Canada conducts double egg disinfection (at source and at the hatchery) (B. Milligan, Cermaq Canada, 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, *Y. ruckeri* was reported in at least one fish in 0.5% of site visits with testing for the bacterium. *Yersinia ruckeri* was detected in at least one sample on one farm in one year (2014). Refer to Appendix B for details.

#### 3.1.2.4 Summary of *Yersinia ruckeri* and enteric redmouth on Atlantic Salmon farms in the Discovery Islands area

In this risk assessment, evidence of *Y. ruckeri* infections and/or ERM refers to fish sampled during routine screenings by the industry, regulatory programs, fish health events, or any other diagnostic workups on the farms with positive bacterial cultures.

Table 7 summarizes data related to Atlantic Salmon farms in the Discovery Islands area with evidence of *Y. ruckeri* infections and/or ERM signs and diagnoses by year between 2002 and 2017. Data were collated separately from regulatory reporting through the FHASP, FHEs and mortality events, and industry 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.

Between 2002 and 2017, only one farm-level diagnosis was reported (in 2011), no FHEs or mortality events attributed to ERM have been reported. Available data demonstrate that *Y. ruckeri* infections on Atlantic Salmon farms are rare in the Discovery Islands area and do not cause increased mortalities (no FHEs nor mortality events) under the current farm management practices.

*Table 7. Number of Atlantic Salmon farms in the Discovery Islands area with evidence of* Yersinia ruckeri *infection and/or enteric redmouth (ERM) summarized by year. Data include results from industry (2011-2017), audit-based 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, the star (*) indicates a mixed etiology case in which ERM was diagnosed at the farm level and mouthrot was also reported but not at the farm-level. Three weeks after the audit, a FHE attributed to mouthrot was reported on the same farm and pens were treated with florfenicol (DFO, 2018a). Months with evidence of* Y. ruckeri *and/or ERM are shaded and bolded.*

| Year | Number of active farms | Industry data | FHASP data | | | Reported to DFO by industry | |
|---|---|---|---|---|---|---|---|
| | | Number of farms with positive samples (culture) / total number of farms tested | Number of farms with *Y. ruckeri* identified through bacteriology / total number of farms audited | Number of farms with histologic diagnosis for ERM / total number of farms audited | Number of farms with farm-level ERM diagnoses / total number of farms audited | Number of farms with FHEs attributed to ERM | Number of farms with mortality events attributed to ERM |
| 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 | **1/12** | **1/12** | 0/12 | 0 | NA |
| 2007 | 16 | NA | **1/13** | 0/13 | 0/13 | 0 | NA |
| 2008 | 17 | NA | 0/15 | 0/15 | 0/15 | 0 | NA |
| 2009 | 18 | NA | 0/14 | 0/14 | 0/14 | 0 | NA |
| 2010 | 16 | NA | 0/4 | 0/4 | 0/4 | 0 | NA |
| 2011 | 17 | 0/10 | **1/8** | 0/8 | **1*/8** | 0 | 0 |
| 2012 | 13 | 0/6 | 0/12 | 0/12 | 0/12 | 0 | 0 |
| 2013 | 8 | 0/5 | 0/7 | 0/7 | 0/7 | 0 | 0 |
| 2014 | 10 | **1/7** | **1/8** | 0/8 | 0/8 | 0 | 0 |
| 2015 | 10 | 0/6 | 0/9 | 0/9 | 0/9 | 0 | 0 |
| 2016 | 11 | 0/11 | 0/11 | 0/11 | 0/11 | 0 | 0 |
| 2017 | 12 | 0/10 | 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 *Y. ruckeri* 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* Yersinia ruckeri *are present on one or more Atlantic Salmon farms in the Discovery Islands area under the current fish health management practices. ERM: enteric redmouth disease.*

<table>
<tr><th>Contributing factors</th><th>Limiting factors</th></tr>
<tr><td><ul>
<li>Atlantic Salmon are susceptible to Y. ruckeri infections;</li>
<li>Between 2011 and 2017, Y. ruckeri was detected by the industry on one farm in one year (2014);</li>
<li>During fish health audits:<ul>
<li>Yersinia ruckeri was detected by bacteriological culture on one farm in each of 2006, 2007, 2011 and 2014;</li>
<li>ERM was diagnosed through histology on one farm in 2006; and</li>
<li>ERM was diagnosed at the farm level on one farm in 2011;</li></ul></li>
<li>Overall, 2002 to 2017, there is evidence of Y. ruckeri and/or ERM:<ul>
<li>on a total of four Atlantic Salmon farms in the Discovery Islands area;</li>
<li>on one farm in four different years (2006, 2007, 2011 and 2014); and</li></ul></li>
<li>Vaccination to protect against ERM is voluntary, not 100% efficacious and, not all fish are vaccinated.</li>
</ul></td><td><ul>
<li>Yersinia ruckeri is primarily a freshwater pathogen;</li>
<li>Testing for Y. ruckeri is done prior to any live transfer to Atlantic Salmon farms in the Discovery Islands area;</li>
<li>Atlantic Salmon from hatcheries supplied with surface water are vaccinated against ERM and there has been no report of ERM in hatcheries supplied with groundwater;</li>
<li>Fish are stocked into the Discovery Islands area from other marine sites, with the exception of Raza, and are therefore larger in size and less susceptible to post-transfer stress; and</li>
<li>SHMP include requirements for minimizing stress during transfer, handling and harvesting (DFO, 2015).</li>
</ul></td></tr>
</table>

It was concluded that, in a given year, the likelihood that farmed Atlantic Salmon infected with *Y. ruckeri* are present on one or more Atlantic Salmon farms in the Discovery Islands area is **very unlikely** under the current farm practices given evidence of *Y. ruckeri* and/or ERM on farms in four of 16 years (2002 to 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 *Y. ruckeri* are present, what is the likelihood that any *Y. ruckeri* 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 *Y. ruckeri* 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 *Yersinia ruckeri* from infected fish

The main source of infection is considered to be the shedding of a large number (unspecified) of bacteria from carrier fish or infected fish in the feces (Rodgers, 1992; Barnes, 2011) that is transmitted via water to uninfected fish (Wade, 2019). However, under experimental conditions, carrier fish (steelhead trout (*O. mykiss*)) did not shed enough bacteria to cause infection unless they were stressed (Hunter et al., 1980). No studies could be found which estimated bacterial shedding rates from *Y. ruckeri* infected fish (Wade, 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 was reported to be effective against ERM (Fraser et al., 2006).

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 Assumptions

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

### 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* Yersinia ruckeri *will be released from infected and/or diseased Atlantic Salmon farms in the Discovery Islands area under current farm practices.*

| **Contributing factors** | **Limiting factors** |
|---|---|
| • *Yersinia ruckeri* can be transmitted from infected fish via water;<br>• Stress (i.e., transfer to seawater, increased temperatures) contributes to pathogen release (Hunter et al., 1980); and<br>• Atlantic Salmon in the Discovery Islands area are reared in net pens allowing pathogens, including *Y. ruckeri*, to be released from farms to the surrounding environment. | • *Yersinia ruckeri* is primarily a freshwater pathogen;<br>• Carrier fish do not shed enough bacteria to cause infection unless they are stressed (Hunter et al., 1980);<br>• Fish are not directly stocked into the Discovery Islands area in order to minimize exposure to *Kudoa* spp.; as ERM may be more common in Atlantic Salmon recently transferred to seawater (Carson and Wilson, 2009), the more sensitive life history stage may have passed before the fish are transferred to the Discovery Islands area;<br>• 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 *Y. ruckeri* 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 as Atlantic Salmon are reared in net pens and can shed the bacterium. This conclusion was made with **reasonable certainty** as there are abundant data demonstrating horizontal transmission and shedding in trout species, but few studies conducted in sea water or in Atlantic Salmon.

#### 3.2.4.2 Release through vectors and fomites

It was concluded that the likelihood that *Y. ruckeri* 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 *Y. ruckeri* would be released from an infected Atlantic Salmon farm should it become infected.

## 3.3 EXPOSURE ASSESSMENT

### 3.3.1 Question

Assuming that *Y. ruckeri* 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 *Y. ruckeri* 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 *Y. ruckeri* in the marine environment; and timing of *Y. ruckeri* infections on Atlantic Salmon farms in the Discovery Islands area.

#### 3.3.2.1 Susceptible species

*Yersinia ruckeri* hosts include both salmonid and non-salmonid species (Kumar et al., 2015); however, the most susceptible species is Rainbow Trout (*O. mykiss*) (Ross et al., 1966; Tobback et al., 2007; Meyers et al., 2008). All salmonid life history stages are susceptible, but the disease is most acute in Rainbow Trout fry and fingerlings (freshwater) and presents as chronic in older larger fish (i.e., >12.5 cm) (Austin and Austin, 2012; Kumar et al., 2015).

The only report that could be found of *Y. ruckeri* in Pacific salmon species not in complete freshwater was Arkoosh et al. (2004), however, salinity was not reported. *Yersinia ruckeri* was isolated from juvenile Coho Salmon (*O. kisutch)* and sub-yearling Chinook Salmon (*O. tshawytscha*) from estuaries in Washington and Oregon, clinical signs of disease were not found (Arkoosh et al., 2004).

Although isolates of *Y. ruckeri* from Sockeye Salmon have been used in experiments (Busch, 1973; Bullock et al., 1978), whether they were from fish in the saltwater or freshwater phase was not indicated. Similarly, ERM in Sockeye Salmon could also not be confirmed (Wade, 2019). Sablefish is the only actual marine species in which *Y. ruckeri* has been detected (disease could not be confirmed). However, it is not possible to confirm that the detection occurred from a fish in saltwater as it was a report to the CFIA from BC where two hatcheries produce juveniles, one of which does not grow fish in full saltwater.

#### 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 a 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 those 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 four years with evidence of *Y. ruckeri* and/or ERM on Atlantic Salmon farms since 2002, one year reported evidence during the months of May to July (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 (Grant et al., 2018).

Out of the four years with evidence of *Y. ruckeri* and/or ERM on Atlantic Salmon farms since 2002, no evidence of infection was reported during the months of June to October (see Table 10 and Table 11).

#### 3.3.2.4 *Yersinia ruckeri* survival in the marine environment

Wade (2019) reviewed the state of knowledge about the survival of *Y. ruckeri* in the environment. Studies most relevant to survival in the marine environment are reported here.

*Yersinia ruckeri* can survive and remain infective in an aquatic environment (Tobback et al., 2007). In studies to determine the role of biofilms in freshwater Rainbow Trout farms, it has been shown that *Y. ruckeri* exhibits an overexpression of flagellar proteins, making it easy to adhere to hard surfaces and readily form biofilms (Coquet et al., 2002; Tobback et al., 2007). This has been suggested as a source of recurrent infection in Rainbow Trout farms (Tobback et al., 2007).

*Yersinia ruckeri* survival in water appears to be dependent on salinity. In a laboratory study, *Y. ruckeri* cultures survived starvation in water for at least four months (Thorsen et al., 1992). At low salinities (0-20 ppt), there were no detectable changes in colony forming unit (CFU) during the first three days of starvation and only a small decrease over the next four months. At higher salinity (35 ppt), survival decreased below detection limit (3 CFU/mL) after 32 days (Thorsen et al., 1992). Similarly, optimal growth for *Y. ruckeri* strains was reported to occur at 5 and 15 ppt (Diler and Ekici (2003) in Karatas et al. (2004)).

A study examining the survival of *Y. ruckeri* in different environments found that it could survive for more than three months in a river, lake and estuary (Romalde et al., 1994; Austin and Austin, 2012). The persistence of culturable cells in sediment was greater than that in water and was also greater at 6$^{o}$C than at 18$^{o}$C (Romalde et al., 1994; Austin and Austin, 2012).

#### 3.3.2.5 Timing of *Yersinia ruckeri* and enteric redmouth on Atlantic Salmon farms in Discovery Islands area

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

- based on industry surveillance and screening results, *Y. ruckeri* was detected once on one farm, which was reported in the month of November;
- based on audit results, *Y. ruckeri* was reported on farms in the months of March, May, November and December; the one occurrence at the farm level was reported in May;
- no FHEs were attributed to ERM; and
- no mortality events (2011-2017) were attributed to ERM.

Overall, from 2002 to 2017, based on all sources of data, *Y. ruckeri* and/or ERM has been detected on Atlantic Salmon farms in the Discovery Islands area in the months of March, May, November and December. No seasonal patterns of infection or disease could be found. Table 11 summarizes all evidence of *Y. ruckeri* and/or ERM 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* Yersinia ruckeri *and/or enteric redmouth (ERM) summarized by month. The "X" indicates evidence of the presence of Sockeye Salmon in a given month. Data include industry bacteriology testing (2011-2017), audits results (2002-2016), fish health events (FHEs) and mortality events (2002-2017) 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. The star (*) indicates a mixed etiology case in which ERM was diagnosed at the farm level and mouthrot was also reported but not at the population level. Three weeks after the audit, a FHE attributed to mouth rot was reported on the same farm and pens were treated with florfenicol. Months with Fraser River Sockeye Salmon in the Discovery Islands area and months with evidence of Y. ruckeri and/or ERM 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 *Y. ruckeri* and/or ERM** | **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) | 0/9 | 0/7 | 0/9 | 0/7 | 0/3 | 0/8 | 0/7 | 0/9 | 0/8 | 0/10 | **1/10** | 0/12 |
| Number of farms with *Y. ruckeri* identified through bacteriology / total number of farms audited (audit data) | 0/14 | 0/11 | **1/5** | 0/14 | **1/10** | 0/10 | 0/12 | 0/14 | 0/11 | 0/16 | **1/13** | **1/10** |
| Number of farms with ERM identified through histology / total number of farms audited (audit data) | 0/14 | 0/11 | 0/5 | 0/14 | 0/10 | 0/10 | 0/12 | 0/14 | 0/11 | 0/16 | **1/13** | 0/10 |
| Number of farms with farm-level ERM diagnoses / total number of farms audited (audit data) | 0/14 | 0/11 | 0/5 | 0/14 | **1*/10** | 0/10 | 0/12 | 0/14 | 0/11 | 0/16 | 0/13 | 0/10 |
| Number of farms with FHEs attributed to ERM (reported by industry) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Number of farms with mortality events attributed to ERM (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* Yersinia ruckeri *and/or enteric redmouth (ERM) 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* Y. ruckeri *and/or ERM 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 | **1** | 0 |
| **2007** | 0 | 0 | **1** | 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 | 0 | 0 |
| **2010** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2011** | 0 | 0 | 0 | 0 | **1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2012** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 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 | **1** | **1** |
| **2015** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2016** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2017** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### 3.3.3 Assumptions

- Sockeye Salmon are susceptible to *Y. ruckeri* infections;
- Positive detection of *Y. ruckeri* is evidence that the pathogen is present in sampled fish;
- *Yersinia ruckeri* has been released from at least one Atlantic Salmon farm operating in the Discovery Islands area;
- *Yersinia ruckeri*-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 *Y. ruckeri* 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* Yersinia ruckeri *released from infected and/or 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)); and<br>• There is temporal overlap between juvenile Fraser River Sockeye Salmon migration and evidence of *Y. ruckeri* on Atlantic Salmon farms in the Discovery Islands area. | • Atlantic Salmon farms are not found in all channels of the Discovery Islands area;<br>• Atlantic Salmon farms occupy a relatively small surface area and volume of the Discovery Islands area region (Mimeault et al., 2017);<br>• There is no temporal overlap between adult Fraser River Sockeye Salmon migration and evidence of *Y. ruckeri* on Atlantic Salmon farms in the Discovery Islands area; and<br>• Survival of *Y. ruckeri* in water is affected by salinity. The bacterium can survive in fresh or brackish water for at least four months, but survival is greatly reduced in 35 ppt water (Barnes, 2011). |

Two exposure groups were assessed: (1) juvenile Fraser River Sockeye Salmon and (2) adult Fraser River Sockeye Salmon.

The likelihood that at least one Fraser River Sockeye Salmon susceptible fish could be exposed to *Y. ruckeri* attributable to Atlantic Salmon farms was informed by the number of years with evidence of *Y. ruckeri* and/or ERM during periods of time when Fraser River Sockeye Salmon are present in the area, divided by the number of years with evidence of *Y. ruckeri* and/or ERM (four 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 could be exposed to *Y. ruckeri* attributable to Atlantic Salmon farms in the Discovery Islands area through waterborne exposure is **very unlikely** under the current fish health management practices given the limited temporal overlap with reports of *Y. ruckeri* on farms. Out of the four years with evidence of *Y. ruckeri* and/or ERM on farms since 2002, one year 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 *Y. ruckeri* and ERM 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 *Y. ruckeri* attributable to an Atlantic Salmon farm in the Discovery Islands area through waterborne exposure is **extremely unlikely** under the current fish health management practices given the lack of temporal overlap with reports of *Y. ruckeri* on farms. Out of the four years with evidence of *Y. ruckeri* and/or ERM on farms since 2002, no evidence of infection was reported 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 occurrence (or absence) of *Y. ruckeri* and ERM on Atlantic Salmon farms in the Discovery Islands area.

## 3.4 INFECTION ASSESSMENT

### 3.4.1 Question

Assuming that at least one Fraser River Sockeye Salmon has been exposed to *Y. ruckeri* released from Atlantic Salmon farm(s) 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; and estimated infection pressure from farms.

#### 3.4.2.1 Oceanographic and environmental conditions

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). *Yersinia ruckeri* is primarily a freshwater pathogen with survival greatly reduced in the marine environment (see section 3.3.2.4 or Wade (2019) for details).

#### 3.4.2.2 Minimum infectious and lethal doses

To date, no studies could be found which estimated the minimum (infectious or lethal) concentrations of *Y. ruckeri* necessary to cause signs of ERM or mortality in fish through exposure routes that mimic natural transmission pathways (Wade, 2019). However, given that *Y. ruckeri* has been detected on Atlantic Salmon farms in the Discovery Islands area but no FHEs or mortality events were attributed to ERM, it is reasonable to assume that the waterborne *Y. ruckeri* concentration remained lower than that required to spread disease on those farms.

#### 3.4.2.3 Estimated duration of exposure

The potential duration that a susceptible fish species would be exposed to *Y. ruckeri* 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 *Y. ruckeri* infection and ERM 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 distance. 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 time to fallowed farms (Rechisky et al., 2018).

##### *3.4.2.3.2 Duration of* Yersinia ruckeri *infection and enteric redmouth on Atlantic Salmon farms in the Discovery Islands area*

The absence of FHEs and mortality events attributed to ERM on Atlantic Salmon farms in the Discovery Islands area combined with the single audit-based farm-level diagnosis and the fact that *Y. ruckeri* is primarily a freshwater pathogen suggest that shedding from infected fish is of short duration.

#### 3.4.2.4 Estimated *Yersinia ruckeri* infection pressure from Atlantic Salmon farms

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

There is evidence of infection on some Atlantic Salmon farms (Table 7 and Table 10) but it is not possible to determine the prevalence of *Y. ruckeri* infection on these farms. *Yersinia ruckeri*-infected fish have been reported on some Atlantic Salmon farms in the Discovery Islands area but in all cases, including during the audit with a farm-level ERM diagnosis, detections were limited to a small number of fish carcasses (≤ four fish) (Wade, 2019).

Considering the scarcity of detections, combined with the absence of mortality events or fish health events, it is reasonable to conclude that shedding from infected fish on those farms, and the potential *Y. ruckeri* waterborne concentration, would be negligible.

### 3.4.3 Assumptions

- Fraser River Sockeye Salmon entering the Discovery Islands area naïve to *Y. ruckeri*; and
- Fraser River Sockeye Salmon have been exposed to *Y. ruckeri* 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 *Y. ruckeri* 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 to and limiting the likelihood that Fraser River Sockeye Salmon would become infected with* Yersinia ruckeri *released from Atlantic Salmon farms in the Discovery Islands area under current fish health management practices. ERM: enteric redmouth; FHE: fish health events.*

| Contributing factors | Limiting factors |
|---|---|
| • Sockeye Salmon are susceptible to *Y. ruckeri* as isolates from the species have been used in experiments. It is not known if the fish originated in fresh or saltwater; and<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 (Mimeault et al., 2017). | • *Yersinia ruckeri* is primarily a freshwater trout pathogen;<br>• Could not confirm ERM in Sockeye Salmon in either freshwater or saltwater;<br>• Sockeye Salmon is not listed as one of the major fish species infected with *Y. ruckeri* (Barnes, 2011);<br>• Based on telemetry study, juvenile Sockeye Salmon spend limited time (minutes) in the vicinity of fallowed farms (Rechisky et al., 2018);<br>• No FHEs or mortality events were attributed to *Y. ruckeri* on Atlantic Salmon farms in the Discovery Islands area (2002-2017);<br>• A vaccine against ERM is available and all fish raised in hatcheries supplied with surface water are vaccinated; and<br>• Shedding from infected fish and consequently the potential *Y. ruckeri* waterborne concentration attributable to Atlantic Salmon farms in the Discovery Islands area are negligible. |

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 at least one juvenile or adult Fraser River Sockeye Salmon to become infected with *Y. ruckeri* released from an Atlantic Salmon farm located in the Discovery Islands area under current fish health management practices is **extremely unlikely** given that Atlantic Salmon farms are considered to represent a negligible infection pressure and that no evidence of disease in Sockeye Salmon could be confirmed in the literature. This conclusion was made with **reasonable certainty** given abundant data and information in the literature to support that *Y. ruckeri* is a freshwater trout disease.

## 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 *Y. ruckeri* released from Atlantic Salmon farms in the Discovery Islands area is **extremely unlikely** for both juveniles and adults.

*Table 14. Summary of the likelihood and uncertainty rankings for the likelihood assessment of the* Yersinia ruckeri *risk assessment. Results are reported in white cells and likelihood combination results are reported in shadowed cells under the "Rankings" column.*

<table>
<tr><th colspan="2">Steps</th><th colspan="2">Rankings</th></tr>
<tr><td>Farm infection assessment</td><td>Likelihood</td><td colspan="2">Very unlikely<br>(reasonable certainty)</td></tr>
<tr><td rowspan="3">Release assessment</td><td>Release pathways</td><td>Farmed Atlantic Salmon</td><td>Vectors and fomites</td></tr>
<tr><td>Likelihoods</td><td>Extremely likely<br>(reasonable certainty)</td><td>Unlikely<br>(reasonable certainty)</td></tr>
<tr><td>Combined likelihoods of release</td><td colspan="2">Extremely likely</td></tr>
<tr><td rowspan="3">Exposure and infection assessments</td><td>Exposure groups</td><td>Juvenile Fraser River Sockeye Salmon</td><td>Adult Fraser River Sockeye Salmon</td></tr>
<tr><td>Likelihood of exposure</td><td>Very unlikely<br>(reasonable certainty)</td><td>Extremely unlikely<br>(reasonable certainty)</td></tr>
<tr><td>Likelihood of infection</td><td>Extremely unlikely<br>(reasonable certainty)</td><td>Extremely unlikely<br>(reasonable certainty)</td></tr>
<tr><td colspan="2">Combined exposure and infection likelihoods for each exposure group</td><td>Extremely unlikely</td><td>Extremely unlikely</td></tr>
<tr><td colspan="2">Combined likelihoods (farm infection, release, exposure and infection) for each exposure group</td><td>Extremely unlikely</td><td>Extremely unlikely</td></tr>
</table>

# 4 CONSEQUENCE ASSESSMENT

The consequence assessment aims to determine the potential magnitude of impact of *Y. ruckeri* 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 very unlikely that Atlantic Salmon infected with *Y. ruckeri* would be present on at least one farm in the Discovery Islands area. In years with no *Y. ruckeri* 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 *Y. ruckeri* infection on farms, the exposure assessment determined that infected fish have been present on a maximum of one farm in any given month (see Table 11). The overall likelihood assessment concluded that it is extremely unlikely for Fraser River Sockeye Salmon to become infected with *Y. ruckeri* attributable to Atlantic Salmon farms in the Discovery Islands area under current management practices.

Notwithstanding this conclusion and assuming that at least one Fraser River Sockeye Salmon would have been infected with *Y. ruckeri* 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 susceptible Fraser River Sockeye Salmon has been infected with *Y. ruckeri* released from infected Atlantic Salmon, what is 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, proportion of Fraser River Sockeye Salmon potentially exposed to infected farms; and exposure over two generations.

### 4.2.1 *Yersinia ruckeri* infection dynamics

ERM is principally a freshwater trout disease (reviewed in Wade (2019)). Sockeye Salmon was not listed as one of the major fish species infected with *Y. ruckeri* infection (Barnes, 2011). No evidence of ERM at the individual or population level, in freshwater or in seawater, could be found in Sockeye Salmon (Wade, 2019).

As *Y. ruckeri* is primarily a freshwater pathogen and no FHEs or mortality events were attributed to ERM on Atlantic Salmon farms (i.e., little spread within the farm population), it is unreasonable to expect that a minimum infectious dose for Sockeye Salmon, a species expected to be less susceptible to *Y. ruckeri* infections than Atlantic Salmon, could be achieved.

### 4.2.2 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 *Y. ruckeri* infections and/or ERM have been reported on Atlantic Salmon farms.

Noting that there are migration pathways through the Discovery Islands areas 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 *Y. ruckeri* infections and/or ERM 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 *Y. ruckeri* attributable to an infected Atlantic Salmon farm 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.

#### 4.2.2.1 Juveniles

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 *Y. ruckeri* 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 (one year), 30% of juveniles would have had the opportunity to be exposed to *Y. ruckeri* attributable to Atlantic Salmon farm(s) in the Discovery Islands area during their out-migration migration in a year with infection (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).

#### 4.2.2.2 Adults

Between 2002 and 2017, no returning adults had the opportunity to be exposed to *Y. ruckeri* attributable to Atlantic Salmon farm(s) in the Discovery Islands area during their returning migration given their lack of temporal overlap with infections on farms.

### 4.2.3 Estimates of exposure over two generations

The potential exposure of Fraser River Sockeye Salmon populations to Atlantic Salmon farms infected with *Y. ruckeri* 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 Fraser River Sockeye Salmon could encounter *Y. ruckeri*-infected Atlantic Salmon farms in the Discovery Islands area in one of the eight years. 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 (eight years) is 0.006% (see Appendix D). Adults are not expected to be exposed (see section 4.2.2.2).

Despite the potential exposure over two generations, the likelihood assessment concluded that it was extremely unlikely for Fraser River Sockeye Salmon to become infected with *Y. ruckeri* attributable to Atlantic Salmon farms in the Discovery Islands area under current management practices.

## 4.3 ASSUMPTIONS

- There is no correlation between ERM 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 *Y. ruckeri* released from an Atlantic Salmon farm located in the Discovery Islands area.

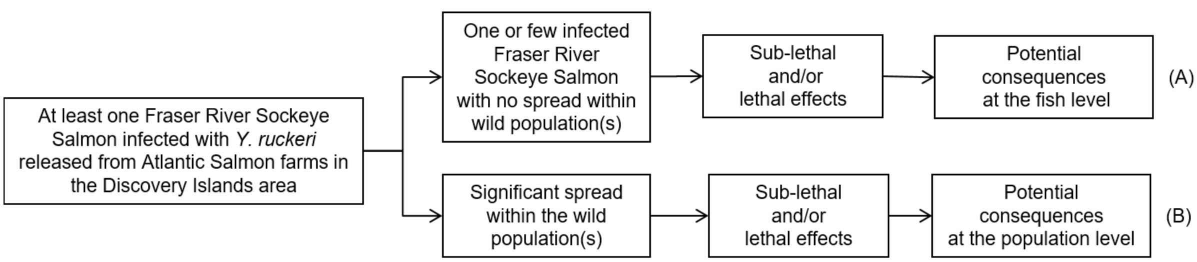


*Figure 5. Potential outcomes resulting from at least one Fraser River Sockeye Salmon infected with* Yersinia ruckeri *released from Atlantic Salmon farms located in the Discovery Islands area.*

Based on the information above it is concluded that it would be unreasonable to expect that a minimum infectious dose for Sockeye Salmon attributable to the farms in the Discovery Islands area would be achieved. Therefore, no or, at most, very few Fraser River Sockeye Salmon will be infected during their migration through the Discovery Islands area, which will lead to negligible consequences at the population level. Outcome B is therefore not considered. Should one or a few fish become infected, with no spread within the population sublethal and or lethal effects may result in consequences to the fish level (Outcome A).

The potential magnitude of consequence on both the abundance and diversity of Fraser River Sockeye Salmon resulting from the exposure to *Y. ruckeri* infected Atlantic Salmon was assessed for juvenile and adult Fraser River Sockeye Salmon. Rankings were determined referring to consequence to abundance (Table 3), consequences to diversity (Table 4) and uncertainty (Table 5) definitions.

It was concluded that the potential magnitude of consequences to the abundance and diversity of returning Fraser River Sockeye Salmon resulting from a *Y. ruckeri* infection of either juvenile or adult Fraser River Sockeye Salmon attributable to an Atlantic Salmon farm in the Discovery Islands area under the current fish health management practices would be **negligible** given that ERM is mainly a freshwater trout disease and infections in Atlantic Salmon in the Discovery Islands do not spread within the farms (i.e., no FHEs or mortality events have been reported), and that Fraser River Sockeye Salmon are transient in the Discovery Islands area. This conclusion was made with **high certainty** given that ERM is primarily a freshwater trout disease and the abundance of data about the occurrence of *Y. ruckeri* on Atlantic Salmon farms.

# 5 RISK ESTIMATION

## 5.1 ABUNDANCE

The risk to the abundance of Fraser River Sockeye Salmon due to infections with *Y. ruckeri* 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* Yersinia ruckeri *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 | Extremely unlikely | Negligible | Minimal |
| Adult Fraser River Sockeye Salmon | Extremely unlikely | | |

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 *Y. ruckeri* 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 *Y. ruckeri* 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* Yersinia ruckeri *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 | Extremely unlikely | Negligible | Minimal |
| Adult Fraser River Sockeye Salmon | Extremely unlikely | | |

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 *Y. ruckeri* 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).

Acknowledging that *Y. ruckeri* is primarily a freshwater pathogen, the main uncertainties in this risk assessment are related to the likelihood assessment:

- there are few studies on the persistence, infectivity and virulence of *Y. ruckeri* in seawater or in salmonids in the marine phase;
- the lack of shedding rates in *Y. ruckeri* carriers, heavily infected fish and diseased Atlantic Salmon in seawater;
- the lack of evidence that Sockeye Salmon can develop ERM; and
- the lack of studies estimating infectious or lethal doses of *Y. ruckeri* in Sockeye Salmon in either freshwater or saltwater.

## 7 CONCLUSIONS

The assessment concluded that *Y. ruckeri* 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 extremely unlikely that Fraser River Sockeye Salmon would become infected with *Y. ruckeri* released from an Atlantic Salmon farm located in the Discovery Islands area. Second, even in the extremely unlikely event that Fraser River Sockeye Salmon would become infected with *Y. ruckeri* due to Atlantic Salmon farms in the Discovery Islands area, the infection would not be expected to spread within wild populations, hence the magnitude of consequences to both Fraser River Sockeye Salmon abundance and diversity would be negligible.

*Y. ruckeri* is considered to be mainly a freshwater trout pathogen and consequently, the main sources of uncertainty in this risk assessment are related to its behaviour in saltwater. Those uncertainties include the lack of knowledge of the shedding rates of *Y. ruckeri* in healthy and infected Atlantic Salmon in seawater, Sockeye Salmon susceptibility and infectious or lethal doses of *Y. ruckeri* in Sockeye Salmon in either freshwater or saltwater.

## 8 REFERENCES CITED


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# 9 APPENDICES

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

This section summarizes the audit-based farm-level ERM 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, one audit-based farm-level diagnosis for ERM was reported on Atlantic Salmon farms in the Discovery Islands area.

*Table 17. Summary of active Atlantic Salmon farms, number of audits conducted and audit-based farm-level enteric redmouth 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 ERM diagnoses | Number of farms with farm-level ERM 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 | 1 | 1 |
| 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 | 0 | 0 |
| **Total** | **---** | **245** | **---** | **---** | **1** | **1** |

Detection of *Y. ruckeri* in the absence of other evidence of disease is not sufficient to trigger a farm-level diagnosis of ERM. Consequently, in addition to farm-level diagnoses, low levels of *Y. ruckeri* may be present in farmed populations and these are only detectable using sensitive diagnostic methods.

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 *Y. ruckeri* infection are summarized in Table 18. Since 2002, one farm-level diagnosis of ERM was made in 2011 on Venture farm during their only audit that year (in May). There was audit confirmation of *Y. ruckeri* infection on Hardwicke in 2006 (November audit; in three of 14 samples), Sonora/Okisollo in 2007 (March audit; in one of 12 samples) and Phillips Arms in 2014 (December audit; in the only sample collected). The bacterium was not detected by audit between 2001 and 2005, 2008 and 2010, nor in 2012, 2013, 2015 and 2016.

*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* Yersinia ruckeri *and/or enteric redmouth disease (ERM) have been detected. Testing for* Y. ruckeri *through bacteriology and histopathology were conducted on all carcasses collected through the DFO audit program (2011-2016). Sources: DFO (2018c), data provided by DFO Aquaculture Management and the BC Salmon Farmers Association.*

| Year | Farm name | Number of audits | Number of carcasses assessed | Number of fish in which *Y. ruckeri* was isolated by culture | Number of fish diagnosed through histology | Farm-level diagnosis |
|---|---|---|---|---|---|---|
| 2006 | Hardwicke | 1 | 14 | 3 | 2 | Open |
| 2007 | Sonora/ Okisollo | 3 | 29 | 1 | 0 | 1st and 2nd audit: Mouthrot3rd audit: Open |
| 2011 | Venture | 1 | 10 | 4 | 0 | Acute ERM (mouthrot also present but not significant at population level) |
| 2014 | Phillips Arm | 2 | 4 | 1 | 0 | 1st and 2nd audit: No disease that is significant at the population level |

## 9.2 APPENDIX B: INDUSTRY SURVEILLANCE AND SCREENING

The three companies raising Atlantic Salmon in marine net pens in the Discovery Islands area conduct bacteriological screening and testing as part of their fish health management procedures. All companies use tryptic soy agar (TSA) plates to culture and isolate non fastidious bacterial pathogens (including *Y. ruckeri*) from kidney and from additional tissues sampled from moribund fish and fresh mortalities. Blood agar plates are also used. Additional in-house procedures (bacterial subcultures, Gram staining, and biochemical tests) can be done as needed for presumptive identification. Definitive identification is provided by a reference laboratory using additional biochemical or molecular tests (PCR).

Table 19 summarizes screening and detections of *Y. ruckeri* in samples taken by industry during routine health checks, screening of broodstock kept in marine net pens, investigation of elevated mortality and as a part of fish health assessments for research and development (R&D) projects. Only one farm was found positive for *Y. ruckeri* between 2011 and 2017 in the Discovery Islands area. Presumptive diagnosis of *Y. ruckeri* is based on bacteriological cultures of kidneys (with or without additional tissues) on TSA plates, followed by bacterial isolation and testing (Gram staining (-), cytochrome oxidase (-)). Definitive pathogen identification is done by a reference laboratory.

*Table 19. Summary of industry results of* Yersinia ruckeri *screening through bacteriological culture between 2011 and 2017 on Atlantic Salmon farms in the Discovery Islands area.*

| Year | Number of site visits with | | Number of farms with | |
|---|---|---|---|---|
| | **positive *Y. ruckeri* tests** | **testing for *Y. ruckeri*** | **positive *Y. ruckeri* tests** | **testing for *Y. ruckeri*** |
| 2011 | 0 | 16 | 0 | 10 |
| 2012 | 0 | 14 | 0 | 6 |
| 2013 | 0 | 6 | 0 | 5 |
| 2014 | 1 | 29 | 1 | 7 |
| 2015 | 0 | 9 | 0 | 6 |
| 2016 | 0 | 64 | 0 | 11 |
| 2017 | 0 | 44 | 0 | 10 |

## 9.3 APPENDIX C: PROPORTION OF POPULATION POTENTIALLY EXPOSED

This appendix details the estimation of the proportion of juvenile Fraser River Sockeye Salmon population that could be in the Discovery Islands area at the same time as *Y. ruckeri* infections 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 during periods when *Y. ruckeri* infections and/or ERM have been detected on one or more farms.

### 9.3.1 Juveniles

The proportion of juvenile Sockeye Salmon that could be exposed to *Y. ruckeri*-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 *Y. ruckeri* 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 20). For instance, in 2011, May had infected farms and received its respective weight of 30% but June 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 exposed in this year to be 30%.

*Table 20. Estimated proportion of juvenile lake-type Fraser River Sockeye Salmon that could potentially have been exposed to a* Yersinia ruckeri-*infected Atlantic Salmon farms 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 | 1 | 0 | 0 | 0.30 | 0.00 | 0.00 | 0.30 |
| 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 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2017 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |

With the evidence of *Y. ruckeri* 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 *Y. ruckeri* was released from Atlantic Salmon farms between 2002 and 2017 in the Discovery Islands area ranged between 0 and 30% (median=0% and mean=2%) (Table 20).

However, in the consequence assessment, the years without evidence of infection (total of 15 years) have to be disregarded given the assumption that "at least one migratory fish has been infected with the *Y. ruckeri* released from an infected farm(s)." There is only one year with evidence of *Y. ruckeri* infection while juveniles were migrating through the area between 2002 and 2017, during which the proportion of juvenile Fraser River Sockeye Salmon that could have been in the Discovery Islands area when *Y. ruckeri* was released from Atlantic Salmon farms was 30%. This estimate is based on the evidence of *Y. ruckeri* occurrences summarized in Table 11.

### 9.3.2 Adults

Given the lack of historical temporal overlap of returning adults and evidence of *Y. ruckeri* occurrences on Atlantic Salmon farms in the Discovery Islands area, the proportion of the returning adults expected to be exposed is zero.

## 9.4 APPENDIX D: EXPOSURE OVER TWO GENERATIONS

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

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, one and no year reported evidence of *Y. ruckeri* and/or ERM 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 are at the same time as a farm is infected with *Y. ruckeri* is, on average, 6.25% (1/16). 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 *Y. ruckeri* is zero (0/16).

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) = 0.0625 for juveniles, and
- number of trials (n) = eight years, representing two generations for Fraser River Sockeye Salmon.

### 9.4.1 Juveniles

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

- On average, 0.5 year out of the eight years (mean = n × P = 8 × (1/16) = 0.5, with SD = $\sqrt{n \times p \times (1-p)}$ = 0.68).
- 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 8%, while the probability that juveniles become exposed in at least five out of eight years is nearly zero, and so on.
- Over one generation (four years), the probability of exposure in four consecutive years is 0.0015% ($P^4 = 0.0625^4 = 0.000015$).
- 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 *Y. ruckeri* released from infected Atlantic Salmon farms in the Discovery Islands area in at least four consecutive years over two generations is 0.006% (see Table 21).

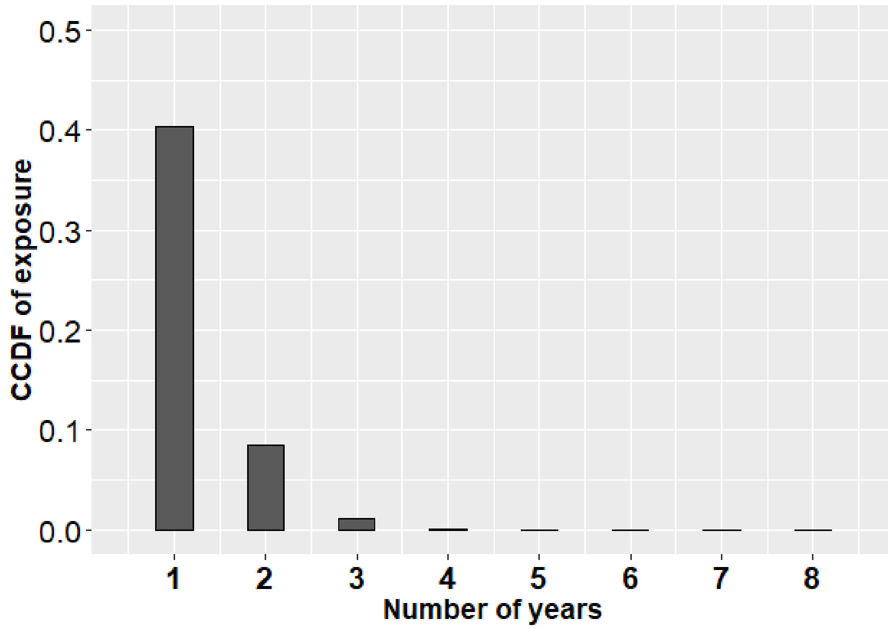


*Figure 6. Complementary cumulative probability distribution (CCDF) of potential exposure of juvenile Fraser River Sockeye Salmon to* Yersinia ruckeri*-infected Atlantic Salmon farms in the Discovery Islands area over eight years.*

*Table 21. Probability of exposure of juvenile Fraser River Sockeye Salmon to* Yersinia ruckeri *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 0.0625 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 ($c \times d / e$) |
|---|---|---|---|---|---|
| 4 | 8 | $8.3 \times 10^{-4}$ | 5 | 70 | $5.9 \times 10^{-5}$ |
| 5 | 8 | $4.4 \times 10^{-5}$ | 4 | 56 | $3.1 \times 10^{-6}$ |
| 6 | 8 | $1.5 \times 10^{-6}$ | 3 | 28 | $1.6 \times 10^{-7}$ |
| 7 | 8 | $2.8 \times 10^{-8}$ | 2 | 8 | $7.0 \times 10^{-9}$ |
| 8 | 8 | $2.3 \times 10^{-10}$ | 1 | 1 | $2.3 \times 10^{-10}$ |
| **Probability of at least four consecutive years in two generations (eight years)** | | | | | **$6.2 \times 10^{-5}$** |

* *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 Adults

As demonstrated above, the probability that adults are in the Discovery Islands area at the same time as an infection with *Y. ruckeri* on an Atlantic Salmon farm, and hence could potentially be exposed to a *Y. ruckeri*–infected farm is zero (0/16).