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Assessment of the risk to Fraser River Sockeye Salmon due to *Moritella viscosa* 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

Clinical: outward appearance of a disease in a living organism

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 requires the involvement of a veterinarian and implementation of mitigation to reduce associated impact(s) or risk(s). Actions/mitigation could include: treatment(s), targeted sampling, site quarantine, enhanced biosecurity, or culling to control suspected or confirmed Disease

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

Horizontal transmission: fish to fish transfer of a pathogen

Incubation period: time between host infection by a pathogenic organism and appearance of the first signs of disease

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

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

Outbreak: unexpected occurrence of mortality or disease

Prevalence: 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 examined for that pathogen (or disease) in a population at a specific time

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: living organism that has the potential to transmit a disease, directly or indirectly, from one animal or its excreta to another animal (e.g., personnel, 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 *Moritella viscosa* on Atlantic Salmon farms in the Discovery Islands area of BC under current farm practices which was conducted in three main steps: first, a likelihood assessment which is the outcome of 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.

Moritella viscosa and winter ulcer have been reported on Atlantic Salmon farms in BC. Based on detections and/or winter ulcer diagnoses since 2012, it is very likely, with reasonable certainty, that farmed Atlantic Salmon infected with *M. viscosa* will be present on one or more Atlantic Salmon farm(s) in the Discovery Islands area in a given year. Shedding rates from Atlantic Salmon infected with *M. viscosa* have not yet been quantified; however, the bacterium has been isolated from skin lesions. It is therefore extremely likely, with reasonable certainty, that *M. viscosa* could be released from an infected Atlantic Salmon on a farm. *M. viscosa* detections and/or winter ulcer diagnoses have been reported on Atlantic Salmon farms during the months of December to February, while the migration timing of Fraser River Sockeye Salmon in the Discovery Islands area occurs from May to October. Given the lack of temporal overlap between *M. viscosa* occurrence and the Fraser River Sockeye Salmon migration, it is extremely unlikely, with reasonable certainty, that at least one juvenile or adult Fraser River Sockeye Salmon would be exposed to *M. viscosa* released from the Atlantic Salmon farms in the Discovery Islands area in any given year. The infection assessment was not performed given the outcome of the exposure assessment.

The likelihood assessment concluded that it is extremely unlikely that an infection with *M. viscosa* attributable to Atlantic Salmon farms in the Discovery Islands area will occur in Fraser River Sockeye Salmon. Given the lack of temporal overlap resulting in the likelihood assessment concluding that it is extremely unlikely that Fraser River Sockeye Salmon would become infected with *M. viscosa* released from Atlantic Salmon farms in the Discovery Islands area, the consequence assessment was not performed.

Overall, the assessment concluded that *M. viscosa* 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 of this risk assessment should be revised if winter ulcer on Atlantic Salmon farms in the Discovery Islands area were to occur between May and October.

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 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 *Moritella viscosa*, the causative agent of winter ulcer, on Atlantic Salmon farms in the Discovery Islands area in BC. This pathogen was selected to undergo a formal pathogen transfer risk assessment given that winter ulcer has been reported at the farm level on Atlantic Salmon farms in the Discovery Islands area. Risk posed to other wild fish populations and related to other fish farms, pathogens, and regions of BC will be determined through subsequent analyses and are consequently not included in this document.

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 has been validated through peer-reviewed processes (Mimeault et al., 2017; Mimeault et al., 2019). The Framework 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 *M. viscosa* attributable to Atlantic Salmon farms in the Discovery Islands area.

2.2.2 Hazard characterisation

Moritella viscosa, formerly *Vibrio viscosus* (Benediktsdóttir et al., 2000), is the main aetiological agent of winter ulcer (Løvoll et al., 2009; Tunsjø et al., 2009; Björnsson et al., 2011; Karlsen et al., 2017a; Karlsen et al., 2017b). Although *Moritella* species have been isolated from seawater, sediments or wood block samples (Urakawa et al., 1998; Urakawa et al., 1999; Kim et al., 2008), to date, no reference could be found reporting the isolation of *M. viscosa* from environmental sources other than from fish. However, studies conducted under experimental conditions demonstrated that *M. viscosa* can survive and proliferate in an oligotrophic and cold environment (Benediktsdóttir and Heidarsdóttir, 2007; Tunsjø et al., 2007) which is consistent with survival of the bacterium in seawater.

Winter ulcer manifests as superficial skin lesions that can develop into skin ulcers on the scaled parts of the body surface (Benediktsdóttir et al., 1998; Tunsjø et al., 2009; Tunsjø et al., 2011). Fin rot, gill pallor and severe internal pathology may also be present (Björnsdóttir et al., 2004; Grove et al., 2008; Tunsjø et al., 2009). Diffuse or petechial haemorrhages of internal tissue may occur (Jansson and Vennerström, 2014). Although mortalities may be low, the open ulcers facilitate the entry for other pathogens (Jansson and Vennerström, 2014).

Although *M. viscosa* is considered the causative agent of winter ulcer, in Norway the presence of other bacteria may contribute to winter ulcer outbreaks (Jansson and Vennerström, 2014; Karlsen et al., 2014).

Wade and Weber (2020) summarized the relevant characteristics of *M. viscosa* and winter ulcer and identified knowledge gaps relevant to this risk assessment. Wade and Weber (2020) also included a review of the occurrence of winter ulcer on Atlantic Salmon farms in BC. Additional details including evidence of *M. viscosa* specific to Atlantic Salmon farms located in the Discovery Islands area are included in this risk assessment.

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 Atlantic Salmon farms in the Discovery Islands area (Fish Health Surveillance Zone 3-2) and in close proximity (three farms in Zone 3-3 to the northwest of 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.

Although 18 farms are included, it is worth noting that from December 2010 to February 2016, the number of stocked Atlantic Salmon farms ranged between 3 and 18, with an average of eight farms in any given month (Mimeault et al., 2017).

This risk assessment focuses on the potential direct impacts of *M. viscosa* attributable to Atlantic Salmon farms in the Discovery Islands area on Fraser River Sockeye Salmon abundance and diversity.

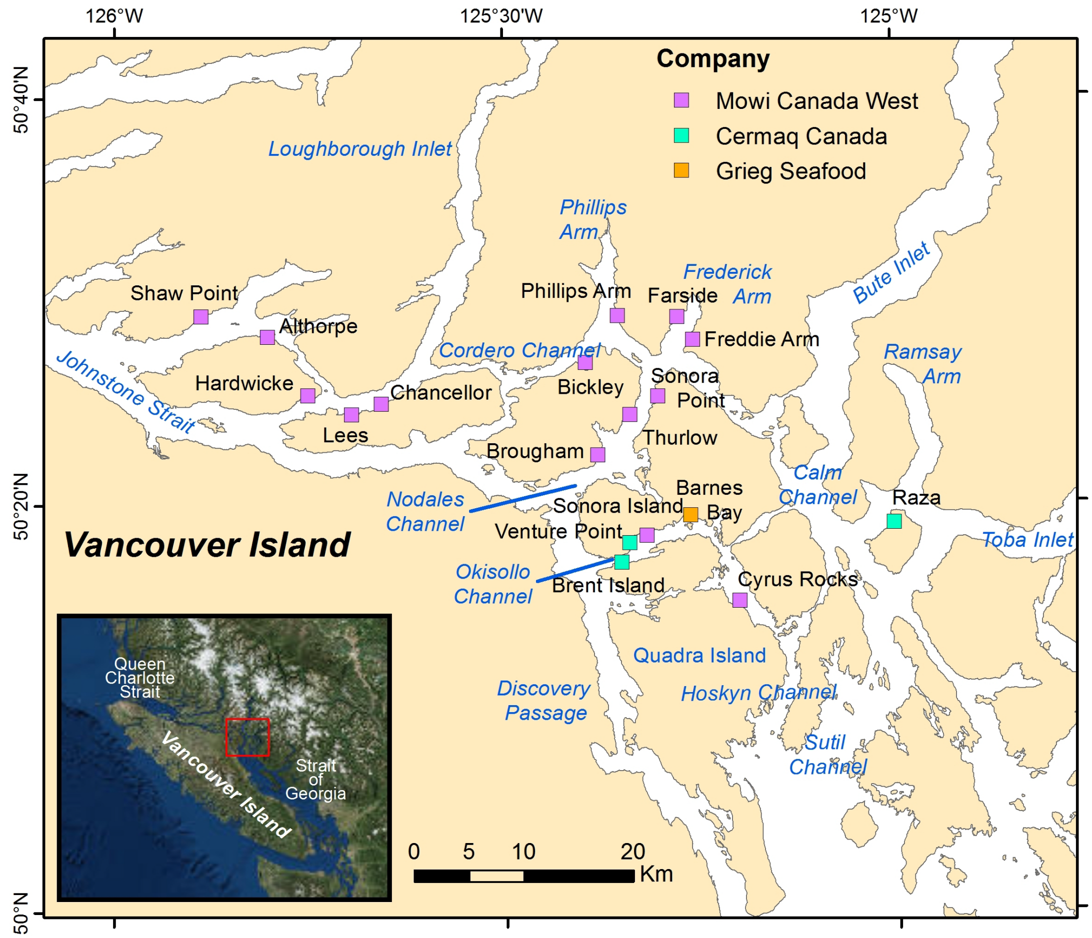

Figure 1. Locations of Atlantic Salmon farms in the Discovery Islands area, British Columbia (Zone 3-2 and three farms in Zone 3-3) included in this risk assessment. Symbol size for fish farms is not to scale. Different colours represent different companies operating the farms as identified in the legend. The insert illustrates the location of the Discovery Islands area. Adapted from Mimeault et al. (2017).

Table 1. List of the 18 Atlantic Salmon farms included in the risk assessment. Note that Althorpe, Hardwicke and Shaw Point are officially licensed in Fish Health Surveillance Zone 3.3 but are grouped with farms in Zone 3.2 for the purpose of this risk assessment and as per Aquaculture Management reporting practices.

Company	Farm	Licensed in 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 *M. viscosa* 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 Organisation 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 is assessed in four consecutive steps namely: a farm infection assessment; a release assessment; an exposure assessment; and an infection assessment. The consequence assessment determines the potential magnitude of impacts of *M. viscosa* infection attributable to

Atlantic Salmon farms in the Discovery Islands area on the abundance and diversity of Fraser River Sockeye Salmon.

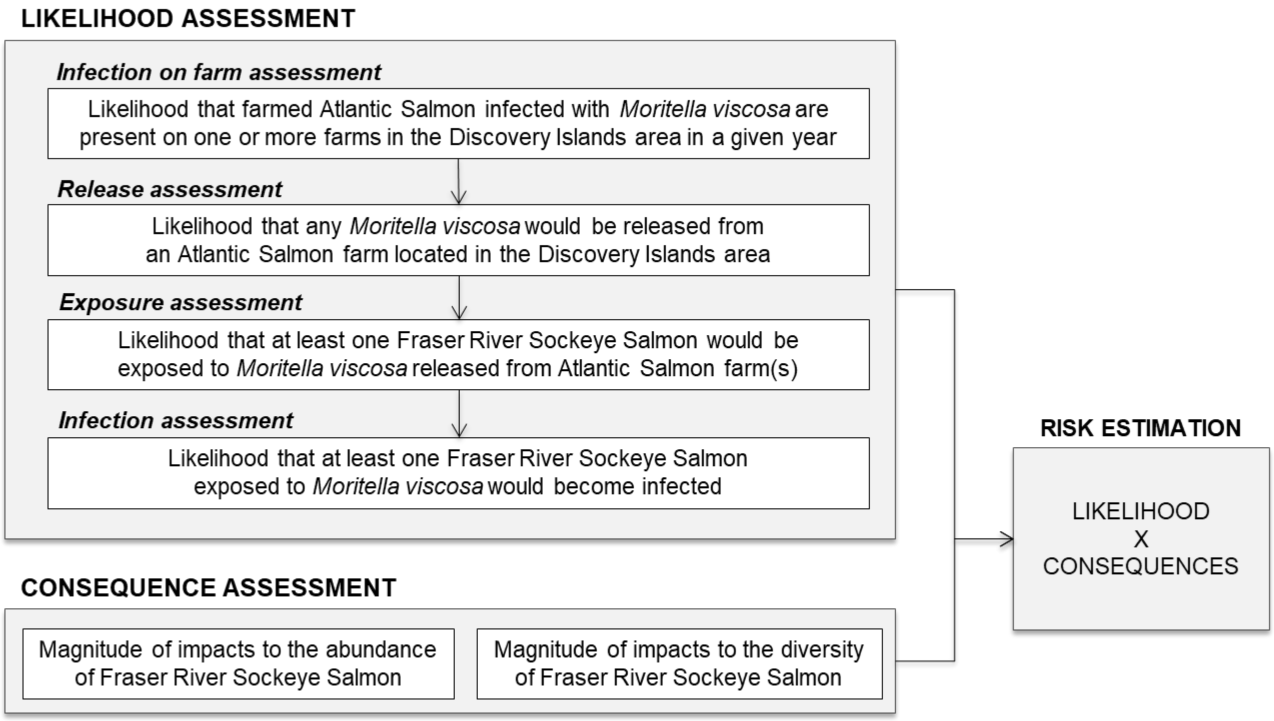

Figure 2. Conceptual model to assess the risks to Fraser River Sockeye Salmon due to Moritella viscosa *on Atlantic Salmon farms located in the Discovery Islands area, British Columbia. Adapted from Mimeault et al. (2017).*

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 taken or adapted from Mimeault et al. (2017) and Mimeault et al. (2019).

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. Taken from Mimeault et al. (2019).

Categories	Definitions
Extremely likely	Event will occur/is expected to occur
Very likely	Event will occur in most instances
Likely	Event will usually occur
Unlikely	Event could occur occasionally
Very unlikely	Event could occur rarely
Extremely unlikely	Event has little to no chance to occur

Table 3. Categories and definitions used to describe the potential consequences to the abundance of Fraser River Sockeye Salmon. Taken from Mimeault et al. (2019).

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. Taken from Mimeault et al. (2019).

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 conservation units that would not result in the loss of a Fraser River Sockeye Salmon CU over a generation; OR > 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. Adapted from Mimeault et al. (2019).

Categories	Definitions
High uncertainty	• No or insufficient data • Available data are of poor quality • Very high intrinsic variability • There is no consensus in the scientific literature
Reasonable uncertainty	• Limited, incomplete, or only surrogate data are available • Available data can only be reported with significant caveats • Significant intrinsic variability • Scientific literature and/or models come to different conclusions
Reasonable certainty	• Available data are abundant, but not comprehensive • Available data are robust • Low intrinsic variability • Scientific literature and/or models mostly agree
High certainty	• Available data are abundant and comprehensive • Available data are robust, peer-reviewed and published • Very low intrinsic variability • Scientific literature 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. Adapted from Mimeault et al. (2019).

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

2.2.5.3 Ranking attribution

Attribution of rankings was done in a multi-step and structured approach. First, drafts of the "Characterization of *Moritella viscosa* and winter ulcer to inform pathogen transfer risk assessments in British Columbia" (Wade and Weber, 2020); and this risk assessment (without ranking attribution) were distributed to the authors of the risk assessment. Each author individually ranked each step of the risk assessment and assigned an uncertainty level through a survey. Ranking results and rationales were discussed in a face-to-face meeting and subsequent calls to reach consensus included in this risk assessment.

2.2.5.4 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).

Uncertainties are reported at each step of the risk assessment. Several approaches have been used for combining qualitative uncertainty rankings in risk assessments. Some authors report uncertainty for every step without combination (Peeler and Thrush, 2009; Jones et al., 2015), others adopt the highest uncertainty (Mandrak et al., 2012) while finally others adopt the highest uncertainty associated with the lowest likelihood for dependent events (Cudmore et al., 2012). In this risk assessment, uncertainties are not combined in the overall likelihood and consequence assessments to keep the emphasis on the uncertainty associated with each step.

2.2.5.5 Risk estimation

As described in Mimeault et al. (2017), two risk matrices were developed in collaboration with DFO's Ecosystems and Oceans Sciences and 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 relevant scale of consequences for fisheries management and policy purposes, existing policy and current management risk tolerance relevant to the risk assessments.

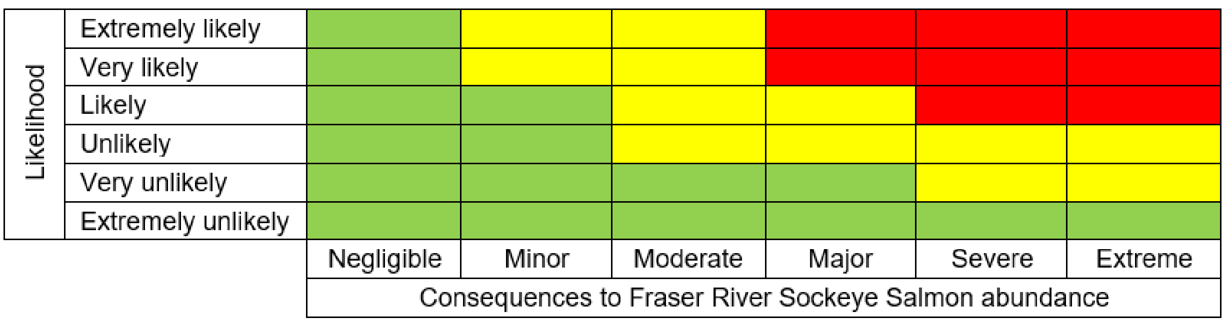

Figure 3. Risk matrix for combining the results of the assessment of the likelihood and consequences to Fraser River Sockeye Salmon abundance.Green, yellow and red represent minimal, moderate and high risk, respectively. Taken from Mimeault et al. (2017).

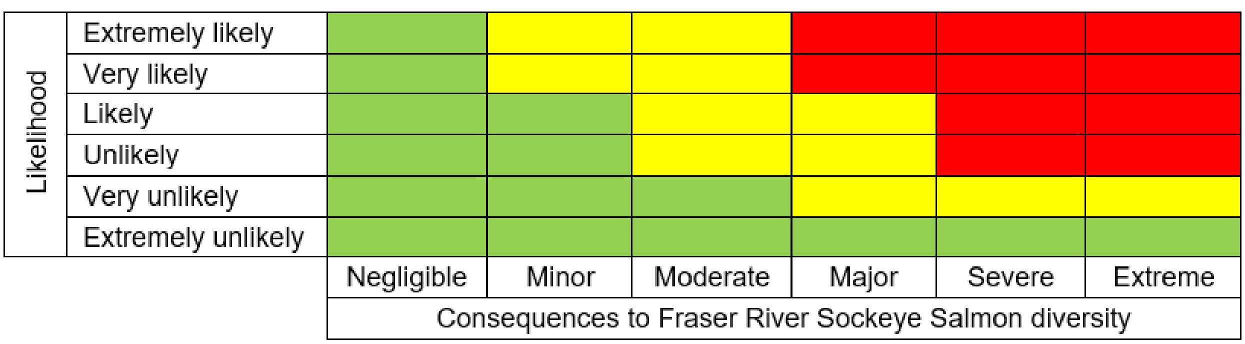

Figure 4. Risk matrix for combining the results of the assessment of the likelihood and consequences to Fraser River Sockeye Salmon diversity. Green, yellow and red represent minimal, moderate and high risk, respectively. Taken from Mimeault et al. (2017).

2.3 FISH HEALTH DATA SOURCES

This risk assessment relies on the current state of knowledge related to *M. viscosa* as summarised in Wade and Weber (2020). Fish health data on Atlantic Salmon farms in the

Discovery Islands area used to inform this assessment are from four different sources as summarized below. Refer to Section 3 for summaries of *M. viscosa* detections and winter ulcer diagnoses on Atlantic Salmon farms in the Discovery Islands area.

Herein, the "detection" of *M. viscosa* refers to the identification of the bacterium through visualization (e.g., in histopathology along with ulcerative dermatitis lesions), bacterial culture/isolation, and/or any positive results of screening or diagnostic tests (e.g., PCR) conducted on samples from an individual fish during routine screenings, regulatory and surveillance programs, fish health events, or any other diagnostic analyses on the farms.

2.3.1 Industry

The industry provided observations made by fish health staff during site visits for routine health checks, investigations of elevated mortality, fish health events and projects on Atlantic Salmon farms in the Discovery Islands area between 2011 and 2018 to inform this pathogen transfer risk assessment.

2.3.2 Fish Health Audit and Surveillance Program

Samples from recently dead fish are collected through the Fish Health Audit and Surveillance Program (FHASP) to audit the routine monitoring and reporting of diseases by the farms (Wade, 2017). 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, 2019c).

Audit data were compiled from the BC Ministry of Agriculture and Lands (2002-2010) and from DFO data available on the Open Canada website (2011-2018) (downloaded on May 29th, 2019) (DFO, 2019c).

2.3.3 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 submit a notification to the Department within seven days of initiating mitigation, take immediate action to manage the FHE, undertake follow up measures to evaluate the FHE and the efficacy of the mitigation measures, submit the therapeutic management measures to the Department (DFO, 2015).

Reporting of FHEs has been required since the autumn 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, companies voluntarily reported FHEs to the BC Salmon Farmers Association (BCSFA) even though there was no requirement to report this information to DFO. The BCSFA provided the FHEs that occurred on Atlantic Salmon farms in the Discovery Islands area during this period to inform this assessment.

FHE data from 2002-2010 are available on the BC Salmon Farmers Association (BCSFA) website; 2011-2012 data were provided by Aquaculture Management Division; 2013-2015 data for Atlantic Salmon farms in the Discovery Islands area were provided by the BCSFA as industry was not required to report those between 2013-2015Q1 (Wade, 2017); and 2016-2018 data are available on the Open Canada website (downloaded on June 6th, 2019) (DFO, 2019a).

2.3.4 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 as specified in the licence (DFO, 2015).

Mortality events reporting between 2002-2010 was required but details and reports are not available; 2011-2018 data are available on the Open Canada website (downloaded on May 29th, 2019) (DFO, 2019b).

2.4 REGULATORY REQUIREMENTS

2.4.1 Licensing and biosecurity

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 licenses 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, 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.

2.4.2 Introduction and Transfer Committee

DFO grants Introduction and Transfer licenses 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 into and within the Province. A Section 56 introductions and transfers licence is required for all movements of salmon between licensed aquaculture facilities (DFO, 2018).

For the aquaculture industry, the committee assesses the health of fish to be transferred which includes the diseases and causative agents of regional, national or international concern as listed in Appendix III[1] of the Marine Finfish Aquaculture Licence under the Fisheries Act, in

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[1] In 2018, diseases of regional, national or international concern listed in the Marine Finfish Aquaculture Licence under the *Fisheries Act* are Infectious Hematopoietic Necrosis (IHN) and infectious hematopoietic necrosis virus; Infectious Pancreatic Necrosis (IPN) and infectious pancreatic necrosis virus; Viral Hemorrhagic Septicemia (VHS) and viral hemorrhagic septicemia virus; Infectious Salmon Anemia (ISA) and infectious salmon anemia virus; *Oncorhynchus masou* Virus Disease (OMV) and *Oncorhynchus masou* virus; Whirling Disease and *Myxobolus cerebralis*; Cold Water Vibriosis and *Vibrio salmonicida*; and any other filterable replicating agent causing cytopathic effects in cell lines specified by the Minister or is causative of identifiable clinical disease in fish.

addition to any other disease or indication of poor health status as determined by fish health expert(s) sitting on the Introductions and Transfers Committee. This would include skin ulceration of various aetiologies, including winter ulcer.

For every marine finfish 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 committee may do any of: seek clarification, further diagnostics or additional information from the applicant; compel mitigation to address concerns; and/or recommend the transfer licence is not issued. In the case of winter ulcer, the ITC may recommend that the farm treat the disease at either the source or destination facility, undergo enhanced monitoring and reporting, and/or recommend that the transfer wait until the infection resolves.

2.5 INDUSTRY PRACTICES

As of late 2019, companies rearing Atlantic Salmon on marine sites in the Discovery Islands area are Cermaq Canada, Grieg Seafood and Mowi Canada West (formerly, Marine Harvest Canada).

2.5.1 Fish health management practices

Wade (2017) reviewed all common health management practices on Atlantic Salmon farms in BC. A brief description of the most relevant practices to our risk assessment is presented in this section.

As outlined under section 2.4.1, 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). 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 if a SOP is required, 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) and procedures can vary amongst the companies. 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 to control vessel movement (Wade, 2017).

Compliance with the above elements is determined through FHASP. On average, less than one deficiency has been reported per audit on Atlantic Salmon farms in BC between 2011 and 2017 (Wade, 2017; Mimeault et al., 2019). Most deficiencies reported in this period were related to sea lice protocols and sea lice records; carcass retrieval protocol or record keeping that requires improvement; mooring signage needing improvement; and transfer records not being complete.

2.5.2 Surveillance and testing

Every stocked 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 company's veterinarian if there are any concerns. 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.

Winter ulcer diagnoses on Atlantic Salmon farms in the Discovery Islands area is mainly based on clinical signs and testing for *M. viscosa* is not part of industry routine screening.

2.5.3 Stocking practices in the Discovery Islands area

In the Discovery Islands area, smolts are not transferred directly from freshwater hatcheries to marine sites due to the risk of infection from *Kudoa* sp., a parasite of marine fishes (Wade, 2017) with the exception of Raza where *Kudoa* sp. has not been an issue (D. New, Cermaq Canada, pers. comm., 2018).

3 LIKELIHOOD ASSESSMENT

The likelihood assessment determines the overall likelihood, in any given year, that at least one Fraser River Sockeye Salmon would become infected with *M. viscosa* attributable to Atlantic Salmon farms located in the Discovery Islands area. Each step of the likelihood assessment assumes that current management practices on Atlantic Salmon farms are followed and will be maintained.

3.1 FARM INFECTION ASSESSMENT

3.1.1 Question

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

3.1.2 Considerations

Considerations include the evidence of the occurrence of *M. viscosa* on Atlantic Salmon farms in the Discovery Islands area, and industry practices specific to the prevention and control of winter ulcer.

3.1.2.1 *Moritella viscosa* on Atlantic Salmon farms in the Discovery Islands area

M. viscosa detections and/or winter ulcer diagnoses on Atlantic Salmon farms in the Discovery Islands area were compiled from the sources listed in Section 2.3.

Although the detection of *M. viscosa* in an individual fish is not necessarily equivalent to clinical disease in that fish or at the population level, it can be indicative of the presence of infection with *M. viscosa* on the Atlantic Salmon farm.

3.1.2.1.1 Industry

Between 2011 and 2018, *M. viscosa* has been detected by PCR on two different farms (Table 7). Note that *M. viscosa* is not part of industry routine screening.

3.1.2.1.2 Fish Health Audit and Surveillance Program

Under FHASP, "winter ulcer is diagnosed in a farmed Atlantic Salmon population when the site is undergoing treatment for the disease or, if there is population-level mortality attributable to the disease with fish displaying lesions (ulcers) occurring in the characteristic season (winter) and location on the fish (triangle formed by the dorsal, anal and pelvic fins) and any of: (a) positive culture of *M. viscosa* from margin of skin ulcers and/or kidney; (b) positive PCR for *M. viscosa* from characteristic skin ulcers or systemically; and/or (c) intralesional rods visualized on histopathology from characteristic lesions" (refer to Wade and Weber (2020)).

Note that FHASP did not include screening for *M. viscosa* before 2012 (H. Manchester, Fisheries and Oceans Canada, pers. comm., 2019).

Between 2012 and 2018, in the Discovery Islands area (Table 7):

- *Moritella viscosa* or *Moritella* sp. were isolated by culture in a small number of fish (5 to 10) during five audits conducted on four different farms in four different years;
- Ulcerative dermatitis was diagnosed through histology during two audits when *M. viscosa* was isolated on one farm in two different years; and
- Winter ulcer was diagnosed at the farm level once on a single farm in a single year.

3.1.2.1.3 Fish Health Events

No FHE were attributed to winter ulcer on Atlantic Salmon farms in the Discovery Islands between 2002 and 2011. One FHE attributed to winter ulcer was reported on an Atlantic Salmon farm in the Discovery Islands area between 2012 and 2018 (Table 7).

3.1.2.1.4 Mortality Events

No mortality events attributed to winter ulcer, or to any other infectious diseases, were reported on Atlantic Salmon farms in the Discovery Islands area between 2011 and 2018 (DFO, 2019b).

3.1.2.1.5 Summary

Table 7 summarizes all evidence of *M. viscosa* and/or winter ulcer on Atlantic Salmon farms in the Discovery Islands area by year as of 2012, when the FHSAP started to screen for *M. viscosa*.

Between 2012 and 2018, *M. viscosa* was detected either by PCR, isolated by culture, identified by histology or diagnosed at the farm level in six of seven years.

Table 7. Number of Atlantic Salmon farms in the Discovery Islands area with evidence of Moritella viscosa *detection and/or winter ulcer diagnoses summarized by year. Data include results from industry observations by fish health staff and diagnostic testing (2012-2018), results from the Fish Health Audit and Surveillance Program (FHASP) (2012-2018), fish health events (2012-2018) and mortality events (2012-2018) reported by the industry to DFO. Histology results include diagnoses of ulcerative dermatitis when* M. viscosa *was isolated by culture. Months with evidence of* M. viscosa *and/or winter ulcer are shaded and bolded for clarity.*

Year	Active farms	Industry data	FHASP data			Reported to DFO by industry	
		Number of farms with *M. viscosa* identified through polymerase chain reaction	**Number of farms with *M. viscosa or Moritella* sp. isolated by culture / total number of farms audited**	**Number of farms with ulcerative dermatitis identified through histology / total number of farms audited**	**Number of farms with farm-level winter ulcer diagnoses**	**Number of farms with FHEs attributed to winter ulcer**	**Number of farms with mortality events attributed to winter ulcer**
2012	13	No test	0/12	0/12	0/12	1	0
2013	8	No test	0/7	0/7	0/7	0	0
2014	10	No test	**1/8**	**1/8**	**1/8**	0	0
2015	10	No test	**1/9**	**1/9**	0/9	0	0
2016	11	**2**	0/11	0/11	0/11	0	0
2017	12	**1**	**2/9**	0/9	0/9	0	0
2018	10	0	**1/3**	0/3	0/3	0	0

3.1.2.2 Preventive and control measures

In addition to industry practices described in Section 2.5, vaccination against *M. viscosa* and treatment of the clinical cases of winter ulcer on Atlantic Salmon farms in the Discovery Island area are implemented by the farming companies.

3.1.2.2.1 Vaccination

Although not mandatory for a licence, vaccination against *M. viscosa* has recently become a common practice by the industry in BC. Since October 2018, Mowi Canada West has been vaccinating all its fish (30-50 g) against *M. viscosa,* using “ALPHA JECT® 5-3”, before seawater entry in BC (B. Boyce, Mowi Canada West, pers. comm., 2019). Grieg Seafood also follows similar vaccination protocols against *M. viscosa* (T. Hewison and P. Whittaker, Grieg Seafood, pers. comm., 2019). Cermaq Canada also vaccinates Atlantic Salmon against *M. viscosa* when fish are expected to spend two winters in the marine net pens (K. Frisch, Cermaq Canada, pers. comm., 2019).

Thus far, there are no published data regarding the efficacy of vaccination in Atlantic Salmon against *M. viscosa* in BC.

3.1.2.2.2 Treatment

The industry treats clinical cases of winter ulcer with appropriate antibiotics. The treatment is typically applied at the farm level during an outbreak of winter ulcer and considered effective in reducing new cases of the disease and associated mortalities (B. Boyce, Mowi Canada West, pers. comm., 2019).

3.1.3 Assumptions

- Detection of *M. viscosa* is the evidence of true infection;
- Audit-based detections of *Moritella* sp. are equivalent to detection of *M. viscosa*; and
- All diagnoses of winter ulcer (and ulcerative dermatitis when *M. viscosa* was isolated by culture) are due to infection with *M. viscosa*.

3.1.4 Likelihood of farm infection

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

Table 8. Factors contributing to and limiting the likelihood that farmed Atlantic Salmon infected with Moritella viscosa *are present on one or more farms in Discovery Islands area under the current farm practices.*

Contributing factors	Limiting factors
• Between 2012 and 2018, *M. viscosa* or winter ulcer has been reported on at least one Atlantic Salmon farm in six of seven years.	• Salmonid Health Management Plan include requirements for minimizing stress during transfer, handling and harvesting (DFO, 2015). • Preventive measures (i.e., vaccination) specific to winter ulcer are in place.

It was concluded that, in a given year, the likelihood that farmed Atlantic Salmon infected with *M. viscosa* are present on one or more Atlantic Salmon farms in the Discovery Islands area is **very likely** under the current farm practices given the evidence of *M. viscosa* on at least one farm in six of seven years (2012-2018). This conclusion was made with **reasonable certainty** given that the evidence of infection is based on FHASP results and FHE reports (abundant and robust data) and low intrinsic variability in the data.

3.2 RELEASE ASSESSMENT

3.2.1 Question

Assuming that Atlantic Salmon infected with *M. viscosa* are present, what is the likelihood that any *M. viscosa* would be released from an Atlantic Salmon farm located in the Discovery Islands area into an environment accessible to Fraser River Sockeye Salmon?

3.2.2 Considerations

Two pathways were considered in the release assessment: (1) infected farmed Atlantic Salmon and (2) vectors and fomites. The latter pathway includes living organisms (e.g., salmon lice, jelly fish) and/or inanimate objects (e.g., contaminated net) that are capable of harbouring, transmitting, and releasing the bacterium from the farms into the surrounding water column.

Considerations include Atlantic Salmon rearing method in the Discovery Islands area; transmission and shedding of *M. viscosa* from infected fish; and fish health management practices (see Section 2.5.1).

3.2.2.1 Atlantic Salmon rearing method

Atlantic Salmon reared on marine sites in the Discovery Islands area are contained in net pens. 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 Transmission and shedding of *Moritella viscosa*

There are few studies on the transmission of *M. viscosa* (Lunder et al., 1995; MacKinnon et al., 2020). While horizontal transmission of the bacterium has not been demonstrated (Wade and Weber, 2020), the bacterium has been isolated from skin ulcers (Lunder et al., 1995; MacKinnon et al., 2020). There are no data on the timing and shedding rate of *M. viscosa* during infection.

3.2.3 Assumptions

- Atlantic Salmon infected with *M. viscosa* are present on at least one farm; and
- General biosecurity and biocontainment measures implemented by the industry are effective against *M. viscosa*.

3.2.4 Likelihood of release

Table 9 presents the main factors contributing to and limiting the likelihood that *M. viscosa* would be released from an infected Atlantic Salmon farm in the Discovery Islands area. These factors were used to determine the likelihood and uncertainty rankings based on definitions in Tables 2, 5 and 6.

Table 9. Factors contributing to and limiting the likelihood that any Moritella viscosa *would be released from an Atlantic Salmon on farm in the Discovery Islands area into an environment accessible to Fraser River Sockeye Salmon under the current farm practices.*

Contributing factors	Limiting factors
Infected farmed Atlantic Salmon	
• Atlantic Salmon in the Discovery Islands area are reared in net pens allowing pathogens, including *M. viscosa*, to be released from the farms to the surrounding environment.	• Removal of the moribund and dead fish from affected cages/farms; and • Control measures (e.g., treatment) specific to winter ulcer are in place.
Mechanical vectors and fomites	
• Adhesion mechanisms of Norwegians strains of *M. viscosa* have been shown in the laboratory; and • Wildlife, gear and equipment may act as mechanical vectors/fomites.	• Biosecurity and biocontainment protocols are in place to minimize pathogens on infected mechanical vectors and fomites; and • FHASP determined that the level of operational deficiencies (that may affect fish health) to be low on Atlantic Salmon farms in the Discovery Islands area.

3.2.4.1 Release through infected farmed Atlantic Salmon

Despite the limited evidence of shedding and horizontal transmission (i.e., spread from fish to fish) of *M. viscosa* under experimental conditions, it was concluded that the likelihood that *M. viscosa* would be released from an Atlantic Salmon farm located in the Discovery Islands area into an environment accessible to Fraser River Sockeye Salmon through infected farmed Atlantic Salmon is **extremely likely** under the current farm practices given general knowledge of infectious diseases and the isolation of the bacterium from skin lesions. This conclusion was made with **reasonable certainty** based on evidence from experimental studies.

3.2.4.2 Release through vectors and fomites

It was concluded that the likelihood that *M. viscosa* 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 farm practices given that effective biosecurity and biocontainment measures are in place and low levels of operational deficiencies that could affect fish health on Atlantic Salmon farms. This conclusion was made with **reasonable certainty** given that relevant biosecurity and biocontainment practices are part of SHMP and hence licence requirements.

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 *M. viscosa* would be released from an infected Atlantic Salmon farm.

3.3 EXPOSURE ASSESSMENT

3.3.1 Question

Assuming that *M. viscosa* 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 *M. viscosa* 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 timing of Fraser River Sockeye Salmon migration in the Discovery Islands area; timing of *M. viscosa* on Atlantic Salmon farms; temporal overlap between *M. viscosa* and Fraser River Sockeye Salmon in the Discovery Islands area; relative size and volume of Atlantic Salmon farms; survival of *M. viscosa* in the marine environment; and oceanographic and environmental conditions.

3.3.2.1 Timing of Fraser River Sockeye Salmon in Discovery Islands area

3.3.2.1.1 Out-migrating juveniles

Lake-type juvenile Fraser River Sockeye Salmon migrate through the Discovery Islands area every year from mid-May to mid-July, with a migration peak in June (Neville et al., 2016; Freshwater et al., 2019) (reviewed in Grant et al., 2018). The total number of juveniles out-migrating from the Fraser River is unknown (Grant et al., 2018). The only estimate of abundance is limited to stocks from Chilko Lake (Grant et al., 2018) based on smolts enumerated at a counting fence located at the outlet of the lake. Between 1953 and 2007, annual estimates ranged between 1.6 to 77 million (average: 20 million) (Grant et al., 2018).

To date, the exact distribution of Sockeye Salmon throughout the Discovery Islands area is not well understood.

3.3.2.1.2 Returning adults

Sockeye Salmon return to the Fraser River either through the northern route (Johnstone Strait) or the southern route (Strait of Juan de Fuca) (reviewed in Grant et al., 2018). Between 1980 and 2014, the total adult returns of Fraser River Sockeye Salmon ranged from 2 to 28 million, with an annual average of 9.6 million (Grant et al., 2018).

3.3.2.2 Timing of *Moritella viscosa* on Atlantic Salmon farms

Between 2012 and 2018, *M. viscosa* has been detected either by PCR or isolated by culture on at least one farm during the months of December, January and February; ulcerative dermatitis along with the isolation of *M. viscosa* was identified by histology in the month of January; winter ulcer was diagnosed at the farm level in the month of January; and winter ulcer has been attributed to a FHE once in January.

Overall, between 2012 and 2018, *M. viscosa* or winter ulcer has been reported on Atlantic Salmon farms in the Discovery Islands area during the months of December, January and February (Table 10).

3.3.2.3 Temporal overlap between Fraser River Sockeye Salmon and *Moritella viscosa*

Table 10 summarizes evidence of Fraser River Sockeye Salmon and of *M. viscosa* and winter ulcer on Atlantic Salmon farms in the Discovery Islands area by month. Fraser River Sockeye Salmon (juveniles and adults) are expected in the Discovery Islands area between May and October while *M. viscosa* on Atlantic Salmon farms in the Discovery Islands area has been reported in the months of December, January and February between 2012 and 2018. Consequently, based on seven years of data (2012 to 2018), there is no evidence of concurrence between Fraser River Sockeye Salmon and *M. viscosa* in the Discovery Islands area.

Table 10. Summary of temporal overlap between Fraser River Sockeye Salmon and evidence of Moritella viscosa *detection, ulcerative dermatitis and/or winter ulcer diagnoses on Atlantic Salmon farms in the Discovery Islands area. Data include results from industry observations by fish health staff and diagnostic testing (2012-2018), results from the Fish Health Audit and Surveillance Program (2012-2018), fish health events (2012-2018) and mortality events (2012-2018) reported by the industry to DFO. Histology results include diagnoses of ulcerative dermatitis when* M. viscosa *was isolated by culture. The "X" indicates evidence of presence of Fraser River Sockeye Salmon in a given month. Months with evidence of* M. viscosa *and/or winter ulcer are shaded and bolded for clarity.*

Fraser River Sockeye Salmon in the Discovery Islands area	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Lake-type juveniles					X	X	X					
Returning adults						X	X	X	X	X		
Evidence of *M. viscosa* on Atlantic Salmon farms in the Discovery Islands area	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Number of farms with positive detections of *M. viscosa* (industry)	**2**	0	0	0	0	0	0	0	0	0	0	**1**
Number of farms with *M. viscosa* isolated by culture	**3**	**1**	0	0	0	0	0	0	0	0	0	0
Number of farms with ulcerative dermatitis identified through histology	**1**	0	0	0	0	0	0	0	0	0	0	0
Evidence of winter ulcer on Atlantic Salmon farms in the Discovery Islands area	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Number of farms with farm-level winter ulcer diagnoses	**1**	0	0	0	0	0	0	0	0	0	0	0
Number of farms with fish health events attributed to winter ulcer	**1**	0	0	0	0	0	0	0	0	0	0	0
Number of farms with mortality events attributed to winter ulcer	0	0	0	0	0	0	0	0	0	0	0	0

3.3.2.4 Relative size and volume of Atlantic Salmon farms

The likelihood of Fraser River Sockeye Salmon to encounter Atlantic Salmon farms on their migration routes should take into account the relative size and volume of farms in the area and within channels.

Atlantic Salmon farms in the Discovery Islands area occupy an extremely small area (0.007%) and volume (0.0008%) of the overall region (Mimeault et al., 2017). However, considering that channel width in the Discovery Islands area varies between approximately 850 and 3,200 meters (Mimeault et al., 2017), a farm with dimension of 100 m by 100 m by 20 m depth would span over approximately three to 12% of the width of the channel (Figure 5) in the top 20 meters.

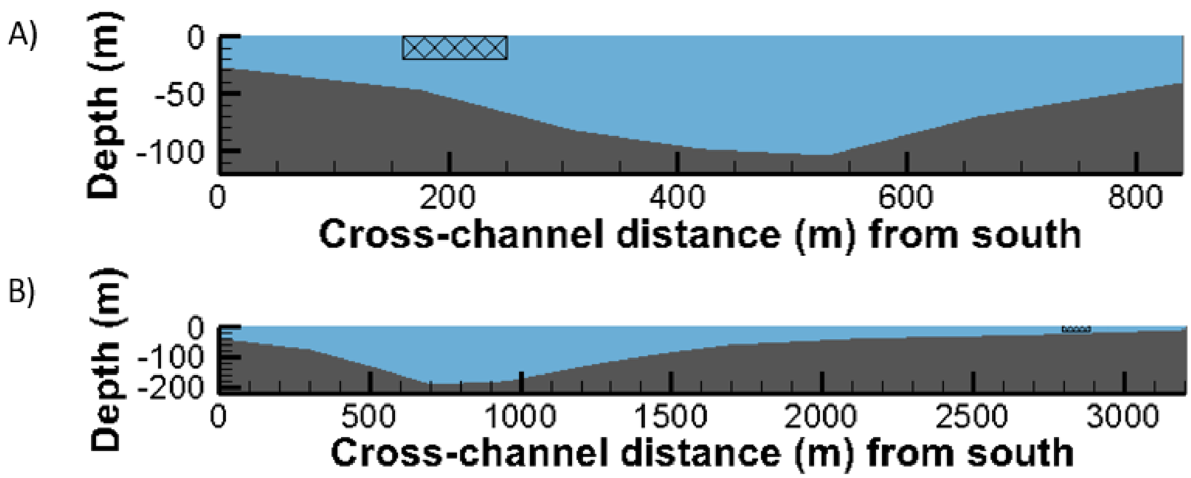

Figure 5. Cross sections of channels at (A) Brent and (B) Shaw farms located in respectively the narrowest and widest channel with Atlantic Salmon farms in the Discovery Islands area. Cross-hatched boxes show the cross-channel projection of the net-pens of the farms depicted at scale, i.e., what fish swimming along-channel would encounter in the top 20 meters. Note the difference in the ranges on the axes to maintain constant ratio (one:one) between the x and y axes in each cross section. Adapted from Mimeault et al. (2017).

3.3.2.5 *Moritella viscosa* survival in the marine environment

Wade and Weber (2020) reviewed the state of knowledge related to the survival of *M. viscosa* outside the host which is limited to two studies using artificial media supplemented with NaCl (Benediktsdóttir and Heidarsdóttir, 2007; Tunsjø et al., 2007). Both studies reached similar conclusions in which Norwegian strains of *M. viscosa* are favoured at low temperature (4°C compared to 10 or 15°C). Tunsjø et al. (2007) suggested that the poor stability of the *M. viscosa* at 15°C may explain why infections are not seen at higher temperatures. Benediktsdóttir and Heidarsdóttir (2007) concluded that the instability of the bacterium at temperatures above 10°C might contribute to its inability to infect fish at higher temperatures. Tunsjø et al. (2007) also showed that cell yield was highest when cultured at salinities similar to seawater (3-4%, which is equivalent to 30 to 40 ppt).

Based on information reviewed in Wade and Weber (2020), to this date, no studies have been conducted to determine the survival or decay rate of *M. viscosa* isolated from diseased fish in BC.

3.3.2.6 Oceanographic and environmental conditions

Water temperatures in the Discovery Islands area vary both seasonally and regionally with recorded temperatures ranging between three and 24°C (Chandler et al., 2017). Between 2005 and 2015, monthly water temperature in the top 15 m of Atlantic Salmon farms in the Discovery Islands area ranged from 7.6 ± 2.3°C to 11.5 ± 3.3°C (mean ± SD) (Chandler et al., 2017).

Monthly distributions of temperature (°C) recorded on Atlantic Salmon farms in the Discovery Islands area over a five-year period (2014-2018) are presented in Figure 6.

All occurrences of *M. viscosa* and winter ulcer on Atlantic Salmon farms in the Discovery Islands area were in the winter months (December to February), when the median water temperature on the farms varied approximately between 7.9 and 8.7°C (Figure 6).

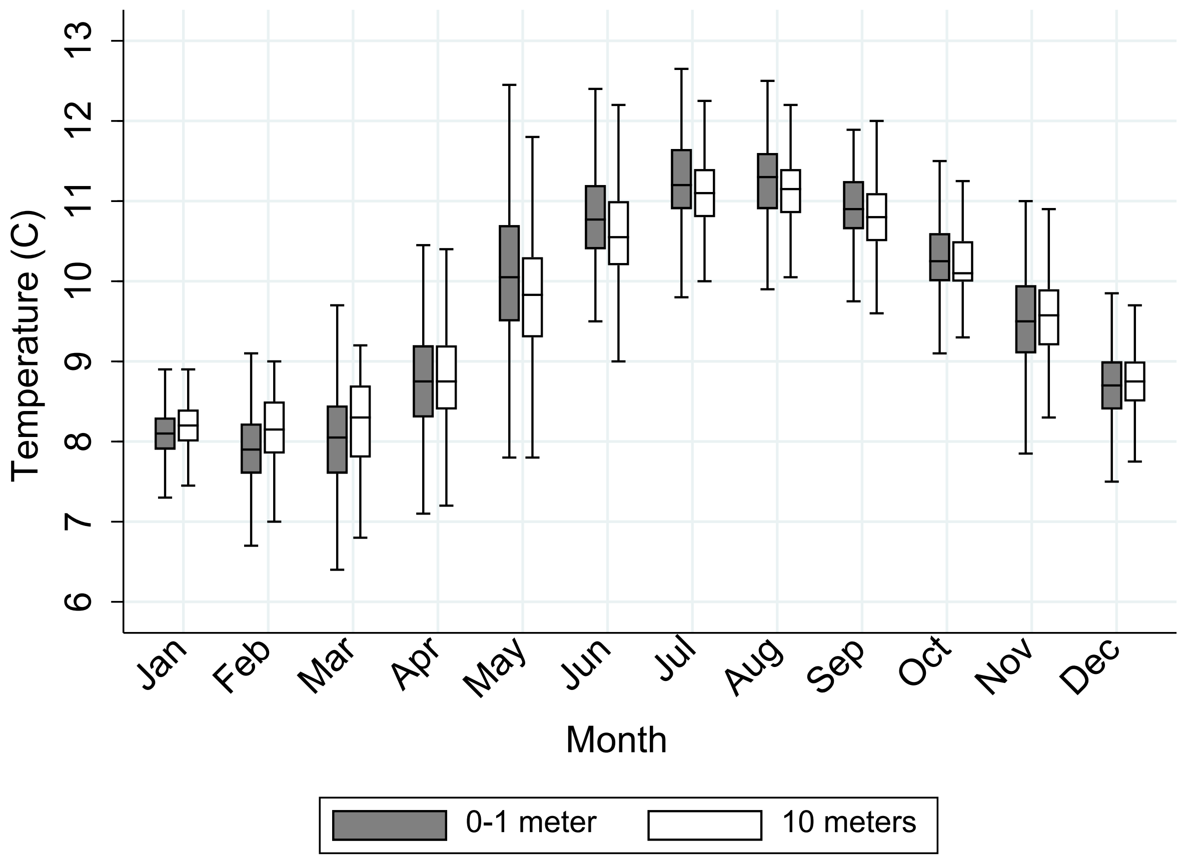

Figure 6. Distribution of temperatures (degree Celsius) recorded on Atlantic Salmon farms in the Discovery Islands area at <1 and 10 meters depth, between 2014 and 2018 (five years). Each box represents the interquartile range (IQR = Q3 – Q1), including the median line. Whiskers indicate the upper (Q3 + (1.5 × IQR)) and lower (Q1 – (1.5 × IQR)) adjacent values. Outliers, defined as values/observations outside the range between upper and lower adjacent values, are not shown for clarity in visualization. Data source: BC Salmon Farmers Association, 2019.

3.3.3 Assumptions

- *Moritella viscosa* has been released from at least one infected Atlantic Salmon farm in the Discovery Islands area;
- Shedding from infected farmed fish is limited to the month(s) with the evidence of infection or disease on farms;

- Sockeye Salmon are assumed to have a random distribution and movement through all channels of the Discovery Islands area in each month during their migration; and
- Wild and hatchery Sockeye Salmon are not differentiated for the purpose of this risk assessment.

3.3.4 Likelihood of exposure

Table 11 presents the main factors contributing to and limiting the likelihood that Fraser River Sockeye Salmon are exposed to *M. viscosa* attributable to Atlantic Salmon farm(s) in the Discovery Islands area. Those factors were used to determine the likelihood and uncertainty rankings based on definitions in Tables 2, 5 and 6.

Table 11. Factors contributing to and limiting the likelihood that at least one Fraser River Sockeye Salmon would be exposed to Moritella viscosa *released from infected Atlantic Salmon farm(s) in the Discovery Islands area under the current farm practices.*

Contributing factors	Limiting factors
• Fraser River Sockeye Salmon migrate through the Discovery Islands area every year; and • *Moritella viscosa* is capable of surviving in saltwater under laboratory conditions.	• There is no temporal overlap between Fraser River Sockeye Salmon migration time (May through October) and the evidence of *M. viscosa* on Atlantic Salmon farms in the Discovery Islands area, which is limited to winter months (December to February); • Atlantic Salmon farms are not found in all channels of the Discovery Islands area; and • Atlantic Salmon farms occupy an extremely small surface area and volume of the Discovery Islands area and occupy three to 12% of the width of channels which limits the probability that Fraser River Sockeye Salmon will encounter an Atlantic Salmon farm (infected or not) in the Discovery Islands area.

It was concluded that the likelihood of at least one Fraser River Sockeye Salmon (juvenile or adult) to be exposed to *M. viscosa* attributable to Atlantic Salmon farms located in the Discovery Islands area through waterborne exposure is **extremely unlikely** under the current farm practices given the absence of temporal overlap between Fraser River Sockeye Salmon and *M. viscosa* infection on Atlantic Salmon farms in the Discovery Islands area. This conclusion was made with **reasonable certainty** given the robust data available on the timing of Fraser River Sockeye Salmon migration through the Discovery Islands area and data on the occurrences of *M. viscosa* and winter ulcer on the farms.

3.4 INFECTION ASSESSMENT

3.4.1 Sockeye Salmon susceptibility

The World Organisation for Animal Health (OIE) considers a species of aquatic animals to be susceptible to infection with a pathogenic agent when the presence of a multiplying or developing pathogenic agent has been demonstrated by the occurrence of natural cases or by experimental exposure that mimics natural transmission pathways (OIE, 2019).

As of late 2019, winter ulcer had not been diagnosed in farmed Pacific salmon in BC (DFO, 2019b, a, c) and no reference could be found describing the bacterial isolation of *M. viscosa* or winter ulcer in Pacific salmon species (Wade and Weber, 2020). *M. viscosa* was detected in two of 2,006 juvenile Sockeye Salmon sampled along their out-migration route in the spring and summer of 2012 and 2013 using high-throughput microfluidics quantitative PCR (Nekouei et al., 2018). No disease was reported in those fish (O. Nekouei, Fisheries and Oceans Canada, pers. comm., 2019). As the presence of infectious agents was assessed using combined multi-tissue samples of DNA/cDNA, which included gill tissue (Nekouei et al., 2018), external contamination cannot be excluded.

Consequently, the susceptibility of Sockeye Salmon to *M. viscosa* infection is unknown.

3.4.2 Likelihood of infection

Given that infection is dependent on exposure, an infection assessment was not performed as it is extremely unlikely that Fraser River Sockeye Salmon will be exposed to *M. viscosa* attributable to Atlantic Salmon farms in the Discovery Islands area. Without exposure, there will be no chance for infection to occur (which corresponds to the definition of extremely unlikely likelihood, i.e., has little to no chance to occur, see Table 2).

Concluding the risk assessment given lack of exposure to the hazard is an accepted practice in risk assessment. For example, the OIE recommends that import risk analyses for animals and animal products are concluded if the likelihood of exposure is determined to be negligible (OIE, 2010).

3.5 OVERALL LIKELIHOOD ASSESSMENT

The estimated likelihoods were combined as per the combination rules described in the methodology section (2.2.5.4). 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 and exposure assessments as the infection assessment was not performed.

Table 12 summarizes the likelihood assessment. Overall, it was concluded that the likelihood that at least one Fraser River Sockeye Salmon would become infected with *M. viscosa* released from Atlantic Salmon farms in the Discovery Islands area is **extremely unlikely** for both juvenile and adult Fraser River Sockeye Salmon. This conclusion is driven by the likelihood of exposure which is extremely unlikely (with reasonable certainty) given the absence of temporal overlap between migrating Fraser River Sockeye Salmon and the evidence of infection with *M. viscosa* (or winter ulcer) on Atlantic Salmon farms in the Discovery Islands area.

Table 12. Summary of the likelihood and uncertainty rankings for the likelihood assessment part of the assessment of the risk to Fraser River Sockeye Salmon due to Moritella viscosa *transfer from Atlantic Salmon farms in the Discovery Island area. Uncertainties are not combined.*

Step		**Ranking**	
Farm infection assessment	**Likelihood** ***(uncertainty)***	Very likely *(reasonable certainty)*	
Release assessment	**Release pathways**	**Farmed Atlantic Salmon**	**Mechanical vectors and fomites**
	Likelihood ***(uncertainty)***	Extremely likely *(reasonable certainty)*	Unlikely *(reasonable certainty)*
	Combined likelihood	Extremely likely	
Exposure assessment	**Exposure groups**	**Fraser River Sockeye Salmon (juveniles and adults)**	
	Likelihood ***(uncertainty)***	Extremely unlikely *(reasonable certainty)*	
Infection assessment	**Likelihood** ***(uncertainty)***	Not performed	
Overall likelihood for each exposure group (combination of all four steps)		Extremely unlikely	

4 CONSEQUENCE ASSESSMENT

The consequence assessment aims to determine the potential magnitude of impacts of *M. viscosa* attributable to Atlantic Salmon farms in the Discovery Islands area on the abundance and diversity of the Fraser River Sockeye Salmon.

Based on the likelihood assessment, it was determined that it is extremely unlikely that at least one Fraser River Sockeye Salmon would become infected with *M. viscosa* released from Atlantic Salmon farms in the Discovery Islands area given the lack of temporal overlap between Fraser River Sockeye Salmon and *M. viscosa* infections on Atlantic Salmon farms in the Discovery Islands area. Therefore, there will be no consequence to the abundance (0% reduction in the number of returning Fraser River Sockeye Salmon which is captured in the definition of negligible consequences to abundance in Table 3) and diversity (no loss of Fraser River Sockeye Salmon which is captured in the definition of negligible consequences to diversity in Table 4) of Fraser River Sockeye Salmon attributable to Atlantic Salmon farms in the Discovery Islands area.

5 RISK ESTIMATION

In other pathogen transfer risk assessments in the Discovery Islands area (Mimeault et al., 2017; Mimeault et al., 2019), the risk to Fraser River Sockeye Salmon due to pathogens attributable to Atlantic Salmon farms in the Discovery Islands area was estimated using risk matrices combining the results of the likelihood assessment and the results of the consequence assessment for abundance (Figure 3) and diversity (Figure 4).

However, given the lack of temporal overlap between Fraser River Sockeye Salmon and evidence of *M. viscosa* on Atlantic Salmon farms in the Discovery Islands area, it was concluded that Fraser River Sockeye Salmon would not be exposed. Therefore, the infection assessment was not performed as it would be extremely unlikely that Fraser River Sockeye Salmon would be infected. Likewise, the consequence assessment was not performed as without infection there would be no consequence. Therefore, the risk estimate was classified at the pre-determined lowest level which is minimum in this case. This approach is in accordance with the risk estimation decision step of import risk assessments (OIE, 2010).

5.1 ABUNDANCE

Overall, it was concluded that, under the current farm practices, the risk to the abundance of Fraser River Sockeye Salmon as a result of a *M. viscosa* infection attributable to Atlantic Salmon farms in the Discovery Islands area is **minimal**.

5.2 DIVERSITY

Overall, it was concluded that, under the current farm practices, the risk to the diversity of Fraser River Sockeye Salmon as a result of a *M. viscosa* infection attributable to Atlantic Salmon farms in the Discovery Islands area is **minimal**.

6 SOURCES OF UNCERTAINTIES

Overall, 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).

There are few uncertainties related to this risk assessment and they are limited to: (i) the variability and knowledge gaps about the precise migration routes of lake-type Fraser River Sockeye Salmon through the Discovery Islands area; (ii) knowledge gaps about the horizontal transmission and shedding rates from *M. viscosa*-infected Atlantic Salmon; (iii) knowledge gaps about the susceptibility of Sockeye Salmon to *M. viscosa* infection; and (iv) the virulence of *M. viscosa* in Sockeye Salmon.

The risk estimates of this assessment are, however, not sensitive to the above uncertainties given the lack of temporal overlap of *M. viscosa* infection on Atlantic Salmon farms and the presence of Fraser River Sockeye Salmon in the Discovery Islands area.

7 CONCLUSIONS

The assessment concluded that *M. viscosa* 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.

The conclusion of minimal risk was mainly influenced by the extremely unlikely exposure of Fraser River Sockeye Salmon to *M. viscosa* attributable to Atlantic Salmon farms in the

Discovery Islands area given the lack of temporal overlap. However, if winter ulcer outbreaks were to be reported between May and October on Atlantic Salmon farms in the Discovery Islands area, this risk assessment would have to be redone.

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