Fisheries and Oceans Canada | Pêches et Océans Canada
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Canadian Science Advisory Secretariat (CSAS)

Research Document 2020/059

National Capital Region

Assessment of the risk to Fraser River Sockeye Salmon due to *Tenacibaculum maritimum* transfer from Atlantic Salmon farms in the Discovery Islands area, British Columbia

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November 2020

Canada

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.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Mimeault, C., Nekouei, O., Garver, K.A., Jones, S.R.M., Johnson, S., Holt, K., Aubry, P., Weber, L., Burgetz, I.J. and Parsons, G.J. 2020. Assessment of the risk to Fraser River Sockeye Salmon due to *Tenacibaculum maritimum* transfer from Atlantic Salmon farms in the Discovery Islands area, British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2020/059. viii + 49 p.

Aussi disponible en français :

Mimeault, C., Nekouei, O., Garver, K.A., Jones, S.R.M., Johnson, S., Holt, K., Aubry, P., Weber, L., Burgetz, I.J. et Parsons, G.J. 2020. Évaluation du risque pour le saumon rouge du fleuve Fraser attribuable au transfert de la bactérie Tenacibaculum maritimum *à partir des fermes d'élevage de saumon atlantique situées dans la région des îles Discovery (Colombie-Britannique). Secr. can. de consult. sci. du MPO. Doc. de rech. 2020/059. x + 55 p.*

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GLOSSARY

Chronic: a disease condition that is persistent or long lasting

Clinical: outward appearance of a disease in a living organism

Disease: An abnormality of structure or function which results in measurable compromise in physiological or behavioral performance and is not a direct result of physical injury

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

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 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

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: 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 potential risks to Fraser River Sockeye Salmon *(Oncorhynchus nerka)* due to pathogens on marine Atlantic Salmon *(Salmo salar)* farms located in the Discovery Islands area in British Columbia (BC).

This document is the assessment of the potential risk to Fraser River Sockeye Salmon due to *Tenacibaculum maritimum* on Atlantic Salmon farms in the Discovery Islands area of BC under current farm practices. The assessment was conducted in three main steps: first, a likelihood assessment which 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.

Mouthrot has commonly been reported on Atlantic Salmon farms in BC, it is therefore very likely, with reasonable certainty, that Atlantic Salmon infected with *T. maritimum* would be present on one or more Atlantic Salmon farm(s) in the Discovery Islands area in any given year. Despite knowledge gaps around the infection dynamics and shedding rates of *T. maritimum* in Atlantic Salmon in BC, the bacterium is extremely likely, with high certainty, to be released from infected farmed fish given the evidence of horizontal transmission of the bacterium in cohabitation trials. Given evidence of mouthrot on Atlantic Salmon farms while juvenile and adult Fraser River Sockeye Salmon are migrating through the Discovery Islands area, it is very likely, with reasonable certainty, that at least one juvenile or adult will be exposed to *T. maritimum* attributable to the farms in any given year. Taking a conservative approach in this risk assessment, Sockeye Salmon were assumed to be susceptible to infection with *T. maritimum*. Given the limited direct interaction of Fraser River Sockeye Salmon with farm sites, the lack of published reports of clinical signs associated to *T. maritimum* infection in Sockeye Salmon and the five positive detections of *T. maritimum* out of 2,006 juvenile Sockeye Salmon sampled around and north of the Discovery Islands area, it was concluded with high uncertainty that it is unlikely that juvenile Fraser River Sockeye Salmon will become infected with *T. maritimum* attributable to Atlantic Salmon farms in the Discovery Islands area under the current farm practices. Given that mouthrot is primarily a disease of concern for farmed Atlantic Salmon smolts, no report of mouthrot in the second year of production, very limited direct interactions of returning adults with the farms, quick migration of returning adults to freshwater, it was concluded with reasonable uncertainty that it is very unlikely that adult Fraser River Sockeye Salmon will become infected with *T. maritimum* attributable to Atlantic Salmon farms in the Discovery Islands area under the current farm practices.

The potential magnitude of impacts on the abundance and diversity of Fraser River Sockeye Salmon was determined to be negligible given that mortality attributable to *T. maritimum* infection from Atlantic Salmon farms was estimated to be less than one percent. This conclusion was made with reasonable uncertainty.

Overall, the assessment concluded that *T. maritimum* 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.

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.

It is recognized that there are interactions between aquaculture operations and the environment (Grant and Jones, 2010; Foreman et al., 2015b). 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 *Tenacibaculum maritimum*, the causative agent of mouthrot, 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 mouthrot 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 *T. maritimum* attributable to Atlantic Salmon farms in the Discovery Islands area.

2.2.2 Hazard characterisation

The genus *Tenacibaculum* includes several species pathogenic to marine fish. To date, three species (*Tenacibaculum dicentrarchi*, *Tenacibaculum finnmarkense*, and *T. maritimum*) have been associated with tenacibaculosis in Atlantic Salmon across the world. However, on the Pacific Coast of North America, the clinical presentation of *T. maritimum* infection in Atlantic Salmon differs from tenacibaculosis and is referred to as mouthrot or yellow mouth (summarised in Frisch et al. (2018a)).

Tenacibaculum maritimum, formerly *Flexibacter maritimum*, is the causative agent of mouthrot in BC (Frisch et al., 2018a; Frisch et al., 2018b). This bacterium has been detected in several fish species and it is considered an opportunistic pathogen (reviewed in Wade and Weber (2020)). The genus *Tenacibaculum*, a member of the family *Flavobacteriaceae*, is an abundant component of marine bacterial ecosystems (Habib et al., 2014).

Mouthrot has only been described in cultured salmonids in BC, Canada and Washington State, USA. In BC, mouthrot has commonly been reported as bacterial stomatitis, myxobacterial stomatitis or ulcerative stomatitis, which are all non-specific terms referring to a bacterial infection of the mouth (Wade and Weber, 2020). Mouthrot mainly affects smolts recently transferred into salt water (Frisch et al., 2018b).

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

Several challenge trials have been conducted to reproduce tenacibaculosis in various fish species; however, these studies cannot directly be applied to mouthrot (Wade and Weber, 2020) for the following reasons: (1) mouthrot and tenacibaculosis are clinically different; (2) there are significant antigenic differences among BC isolates, and between BC isolates and *T. maritimum* reference strains (Ostland et al., 1999); and (3) recent studies have demonstrated differences in the genetics, antibody response, and pathology of BC strains of *T. maritimum* compared to other strains causing tenacibaculosis (Frisch et al., 2017; Frisch et al., 2018a; Frisch et al., 2018b). Therefore, the present risk assessment, when available, relied on studies that involved BC isolates of *T. maritimum* (causing mouthrot). When not available, *T. maritimum* isolates from other locations were used as surrogate information.

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 three 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 *T. maritimum* attributable to Atlantic Salmon farms in the Discovery Islands area on Fraser River Sockeye Salmon abundance and diversity.

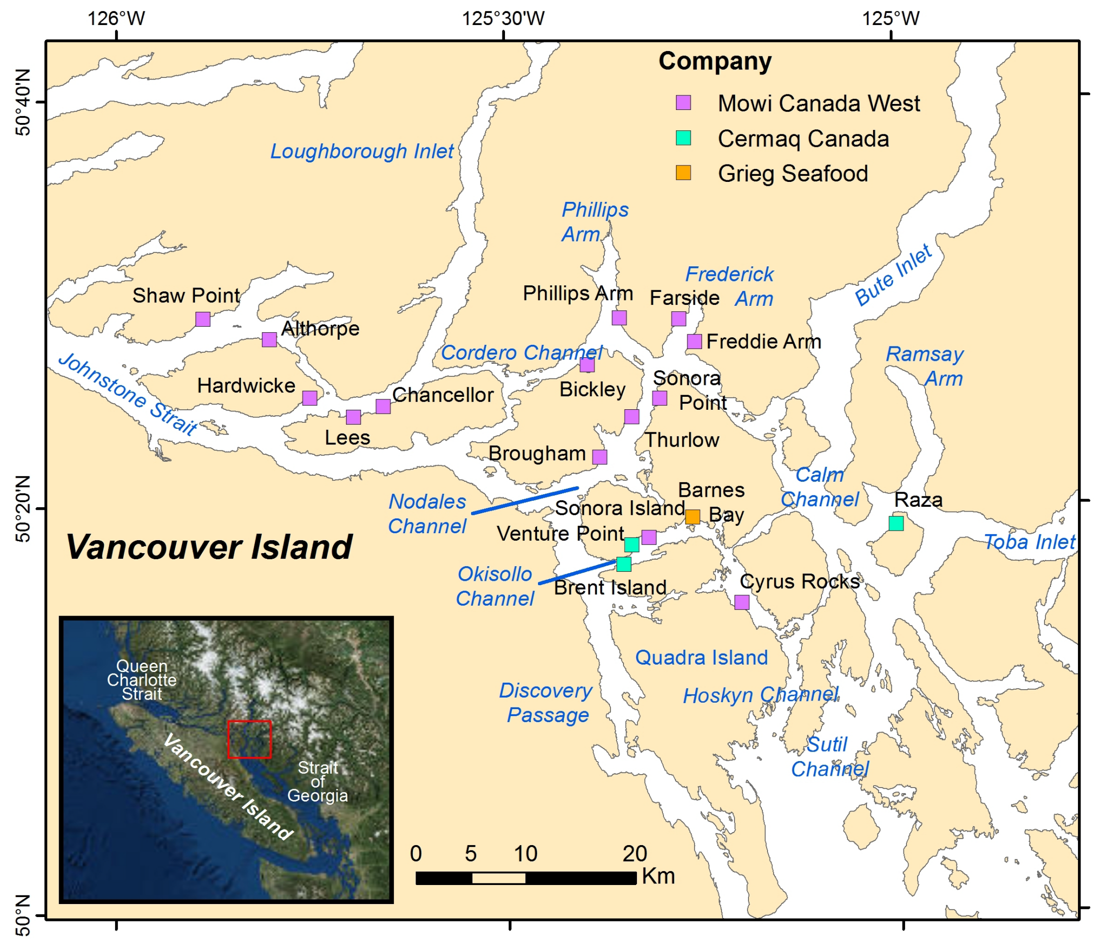

Figure 1. Locations of Atlantic Salmon farms in the Discovery Islands area, British Columbia (Zone 3-2 and three farms in Zone 3-3) included in this risk assessment. Symbol size for fish farms is not to scale. Different colours represent different companies operating the farms as identified in the legend. 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 *T. maritimum* 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 *T. maritimum* infection attributable to Atlantic Salmon farms in the Discovery Islands area on the abundance and diversity of Fraser River Sockeye Salmon.

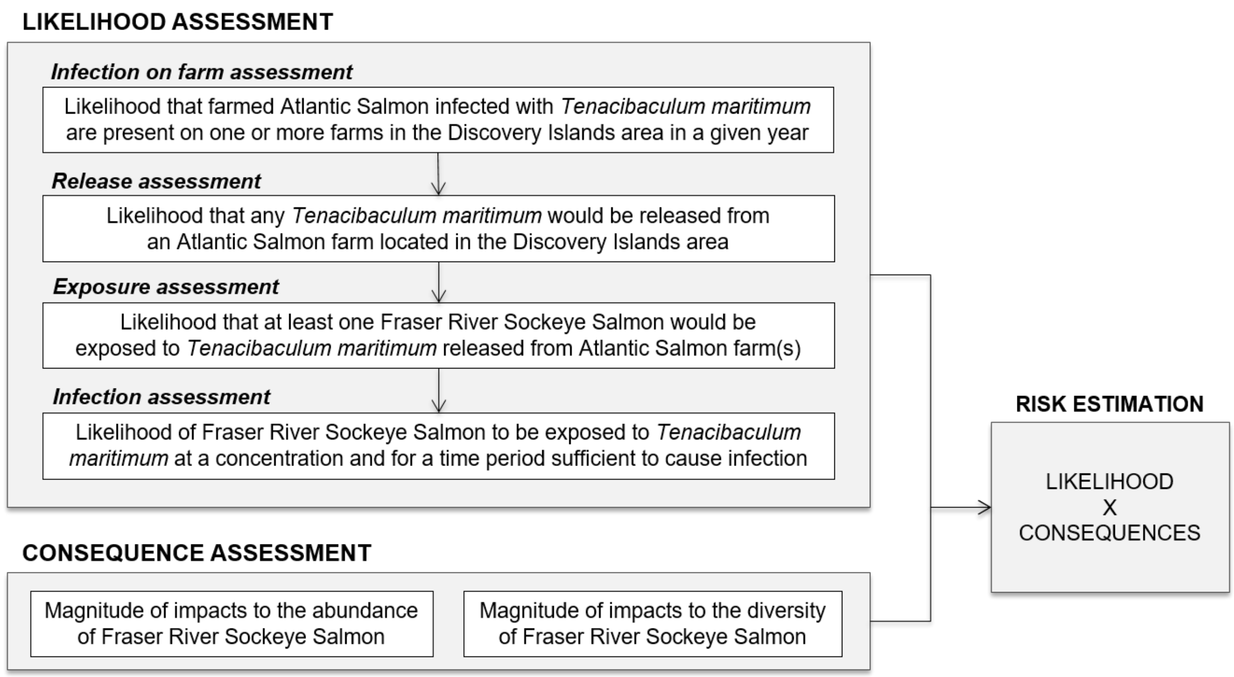

Figure 2. Conceptual model to assess the risks to Fraser River Sockeye Salmon due to Tenacibaculum maritimum *on Atlantic Salmon farms in the Discovery Islands area. Adapted from Mimeault et al. (2017).*

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 vary 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, structured approach. First, drafts of the (1) "Characterization of *Tenacibaculum maritimum* and mouthrot to inform pathogen transfer risk assessments in British Columbia" (Wade and Weber, 2020); and (2) this risk assessment (without ranking attribution) were distributed among 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.

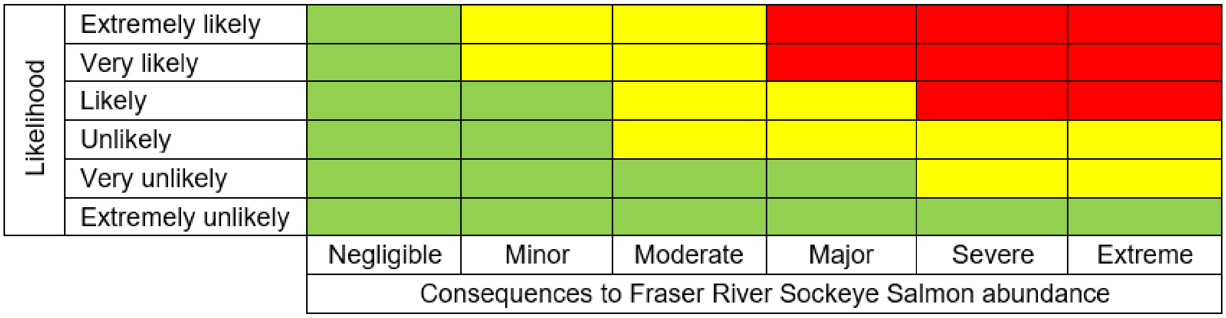

Figure 3. Risk matrix for combining the results of the assessment of the likelihood and consequences to Fraser River Sockeye Salmon abundance. Green, yellow and red represent minimal, moderate and high risk, respectively. Taken from Mimeault et al. (2017).

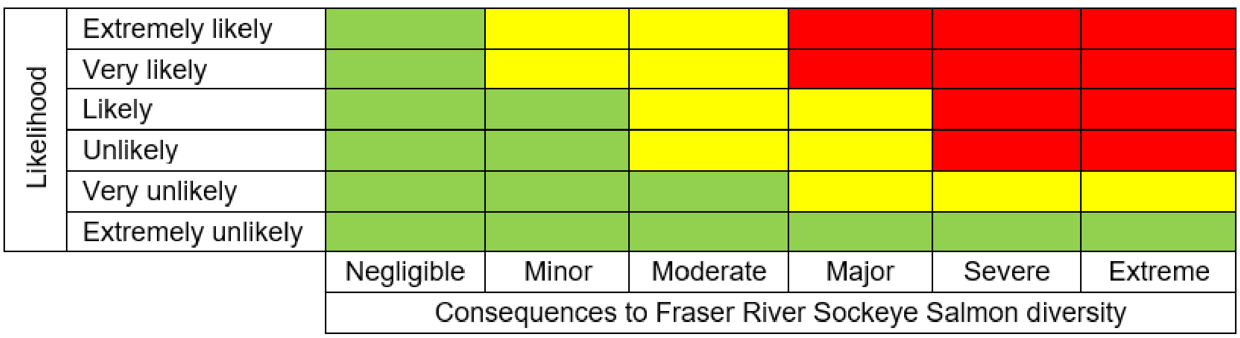

Figure 4. Risk matrix for combining the results of the assessment of the likelihood and consequences to Fraser River Sockeye Salmon diversity. Green, yellow and red represent minimal, moderate and high risk, respectively. Taken from Mimeault et al. (2017).

2.3 FISH HEALTH DATA SOURCES

This risk assessment relies on the current state of knowledge related to *T. maritimum* 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 summarized below. Refer to Section 3 for summaries of *T. maritimum* detections and mouthrot diagnoses on Atlantic Salmon farms in the Discovery Islands area.

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, 2019b).

Audit data were compiled from 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, 2019b).

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). All FHEs attributed to "bacterial stomatitis", "bacterial stomatitis/ulcers", "infectious stomatitis", "mouthrot", "*T. maritimum*", "myxobacterial infection", "Cytophaga-Flexibacter-Flavobacter-Myxobacteria", "Flexibacter sp." on Atlantic Salmon farms in the Discovery Islands area have been compiled as FHEs attributable to mouthrot in this document.

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 published on the Open Canada website (downloaded on May 28th, 2019) (DFO, 2019a).

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 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 clinical signs of mouthrot.

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 mouthrot, the ITC can 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 early 2020, 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).

[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.

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). 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 per audit has been reported 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 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 as needed based on syndromic surveillance, site history, environmental conditions and professional judgement of the veterinarian and fish health team.

Mouthrot diagnoses on Atlantic Salmon farms in the Discovery Islands area are mainly based on clinical signs and testing for *T. maritimum* 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, 203-919 Island Highway, Campbell River, BC, Canada V9W 2C2, pers. comm., 2018).

3 LIKELIHOOD ASSESSMENT

The likelihood assessment determines the overall likelihood, in any given year, that Fraser River Sockeye Salmon would become infected with *T. maritimum* 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 *T. maritimum* are present on one or more farms in the Discovery Islands area?

3.1.2 Considerations

Considerations include the evidence of the occurrence of *T. maritimum* on Atlantic Salmon farms in the Discovery Islands area, and industry practices specific to the prevention and control of mouthrot.

3.1.2.1 *Tenacibaculum maritimum* on Atlantic Salmon farms in the Discovery Islands area

Tenacibaculum maritimum and mouthrot diagnoses on Atlantic Salmon farms in the Discovery Islands area were compiled from the sources of data listed in Section 2.3.

Given that the industry and FHASP have not specifically been screening for *T. maritimum* mouthrot diagnoses data (based on clinical signs and visualization of filamentous bacteria in histopathology) rather than detection or isolation of *T. maritimum* are provided. All diagnoses of mouthrot on farms are assumed to be indicative of infection with *T. maritimum* for the purpose of this risk assessment.

3.1.2.1.1 Industry

Testing for *T. maritimum* is not part of routine screening, hence no detection was reported on Atlantic Salmon farms in the Discovery Islands area between 2011 and 2018.

3.1.2.1.2 Fish Health Audit and Surveillance Program

Under FHASP, “mouthrot 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 gross pathological and histopathological lesions consistent with the disease: characteristic gross pathology is yellow plaques in the mouth, gill rakers and/or palate; or characteristic histopathology is ulcerative stomatitis with the visualization of filamentous bacteria (consistent with *Tenacibaculum* sp.)” (Wade and Weber, 2020).

Mouthrot was diagnosed at the farm level on Atlantic Salmon farms in the Discovery Islands area in seven out of 17 years (Table 7).

3.1.2.1.3 *Fish Health Events*

In the Discovery Islands area, a total of 112 FHEs[2] attributed to mouthrot were reported on Atlantic Salmon farms between 2002 and 2018. FHEs attributed to mouthrot were reported in 12 out of 17 years (Table 7).

3.1.2.1.4 *Mortality Events*

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

3.1.2.1.5 *Summary*

Table 7 summarizes all evidence of clinical signs of mouthrot on Atlantic Salmon farms in the Discovery Islands area by year, between 2002 and 2018.

Overall, between 2002 and 2018, mouthrot was diagnosed on at least one Atlantic Salmon farm in the Discovery Islands area in 13 of 17 years.

[2] A total of 119 FHEs attributed to mouthrot have been reported on Atlantic Salmon farms in Fish Health Surveillance Zone 3.2 between 2002 and 2018 (Wade and Weber, 2020) of which only 100 occurred on farms included in this risk assessment (see Table 1 for list of farms). To complete this risk assessment, the industry and the BCSFA reported an additional 12 FHEs attributed to mouthrot in the Discovery Islands area between 2013 and 2015, when FHEs did not have to be reported to DFO, resulting in a total of 112 FHEs on Atlantic Salmon farms in the Discovery Islands area included in this risk assessment.

Table 7. Number of Atlantic Salmon farms in the Discovery Islands area with evidence of mouthrot summarized by year. Data include Fish Health Audit and Surveillance Program (FHASP) (2002-2018), fish health events (FHEs) (2002-2018) and mortality events (2011-2018) reported by the industry to DFO. NA: not applicable. Months with evidence of Tenacibaculum maritimum *and/or mouthrot are bolded and shaded for clarity.*

Year	Active farms	FHASP data	Reported by industry	
		Number of farms with farm-level mouthrot diagnoses / total number of farms audited	Number of farms with FHEs attributed to mouthrot	Number of farms with mortality events attributed to mouthrot
2002	NA	0/3	0	NA
2003	NA	0/4	0	NA
2004	14	0/9	**4**	NA
2005	15	**1/10**	**5**	NA
2006	16	0/11	**5**	NA
2007	16	**6/12**	**8**	NA
2008	17	**2/14**	**2**	NA
2009	18	**3/14**	**6**	NA
2010	16	0/4	**5**	NA
2011	17	0/7	**3**	0
2012	13	0/12	0	0
2013	8	0/7	**2**	0
2014	10	**1/8**	**2**	0
2015	10	**1/9**	0	0
2016	11	0/11	0	0
2017	12	0/9	**3**	0
2018	10	**1/9**	**1**	0

3.1.2.2 Preventive and control measures

In addition to industry practices described in Section 2.5, treatment of mouthrot on Atlantic Salmon farms in the Discovery Island area is implemented by the farming companies.

3.1.2.2.1 Vaccination

Currently, there is no commercially available vaccine for *T. maritimum* in Atlantic Salmon (Frisch et al., 2018b).

3.1.2.2.2 Treatment

For BC farmed Atlantic Salmon, antibiotics have traditionally been prescribed for the treatment of gram-negative bacteria causing furunculosis, vibriosis, enteric redmouth (ERM) and stomatitis (Morrison and Saksida, 2013). Active Atlantic Salmon producing companies in the Discovery Islands area apply antibiotic treatments once initial cases of mouthrot are diagnosed on their farms. The treatment is very efficacious and reduces associated mortalities (and the new cases of the disease) within two to three days (B. Boyce, Mowi, 124-1334 Island Highway, Campbell River, BC V9W 8C9, pers. comm., 2019; T. Hewison and P. Whittaker, Grieg Seafood, 1180 Ironwood St, Campbell River, BC V9W 5P7, pers. comm., 2019).

3.1.3 Assumption

- All diagnoses of mouthrot provide evidence of infection with *T. maritimum*.

3.1.4 Likelihood of farm infection

Table 8 presents the main factors contributing to and limiting the likelihood of a *T. maritimum* 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 Tables 2, 5 and 6.

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

Contributing factors	Limiting factors
• Between 2002 and 2018, mouthrot was reported on at least one Atlantic Salmon farm in 13 of 17 years; and • There is no commercially available vaccine for *T. maritimum* in Atlantic Salmon.	• Salmonid Health Management Plan include requirements for minimizing stress during transfer, handling and harvesting (DFO, 2015).

It was concluded that, in a given year, the likelihood that farmed Atlantic Salmon infected with *T. maritimum* 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 *T. maritimum* on at least one farm in 13 of 17 years (2002-2018). This conclusion was made with **reasonable certainty** given that the evidence is based on the clinical signs of mouthrot from FHASP 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 *T. maritimum* are present, what is the likelihood that any *T. maritimum* 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 are considered in the release assessment: (1) infected farmed Atlantic Salmon and (2) mechanical vectors and fomites. The latter pathway includes living organisms (e.g., salmon lice, jellyfish, etc.) 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 *T. maritimum* from infected fish; the adhesive nature of *T. maritimum;* 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 surrounding environment (Johansen et al., 2011).

3.2.2.2 Transmission and shedding of *Tenacibaculum maritimum*

Frisch et al. (2018a) demonstrated horizontal transmission of three Western Canadian *T. maritimum* isolates (TmarCan15-1, TmarCan16-1 and TmarCan16-5) among Norwegian Atlantic Salmon smolts in a cohabitation trial.

Although horizontal transmission in cohabitation trials can provide evidence of the shedding of the causative agent, to this date, neither the timing of shedding during infection nor the rate of shedding for *T. maritimum*-infected fish have not been described (Wade and Weber, 2020).

3.2.2.3 Adhesive nature of *Tenacibaculum maritimum*

T. maritimum is adhesive and can create biofilms on hard surfaces (Declercq et al., 2013; Frisch et al., 2017; Frisch et al., 2018a; Frisch et al., 2018b). The bacterium produces substantial amounts of “slime” allowing it to adhere to hydrophobic surfaces which may explain why it can adhere to external fish tissues (Avendaño-Herrera et al., 2006b). The kinetics of various *T. maritimum* strains tested, none from BC, suggest that the inert surfaces of aquaculture settings can harbour biofilms and serve as transient reservoirs for the bacteria (Levipan et al., 2019).

3.2.2.4 Fish health management practices

The legislative and regulatory requirements related to fish health management and additional practices implemented by the Atlantic Salmon farming industry in BC, including the Discovery Islands area have been reviewed (Wade, 2017) and summarised in sections 2.4 and 2.5.

Compliance with the above elements is determined through the audit program. 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.

3.2.3 Assumptions

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

3.2.4 Likelihood of release

Table 9 presents the main factors contributing to and limiting the likelihood that *T. maritimum* 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 Tenacibaculum maritimum *would be released from infected Atlantic Salmon farms 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	
• Horizontal transmission of *T. maritimum* has been shown in cohabitation trials; • Atlantic Salmon in the Discovery Islands area are reared in net pens allowing pathogens, including *T. maritimum*, to be released from the farms to the surrounding environment; and • There is no commercially available vaccine for *T. maritimum* in Atlantic Salmon.	• Removal of moribund and dead fish from affected cages/farms; and • Control measures and treatments for mouthrot are in place.
Mechanical vectors and fomites	
• *T. maritimum* produces substantial amounts of “slime” allowing it to adhere to hydrophobic surfaces; therefore, it can create biofilms on hard surfaces (e.g., on the farms); • *T. maritimum* has been detected from sea lice (*Lepeophtheirus salmonis*) and jellyfish; and • Wildlife, gears and equipment may act as mechanical vectors or fomites.	• Biosecurity and biocontainment protocols are in place to minimize pathogens spread on infected mechanical vectors and fomites (see Section 2.5.1); and • On average, less than one deficiency has been reported per audit on Atlantic Salmon farms in BC between 2011 and 2017.

3.2.4.1 Release through infected farmed Atlantic Salmon

It was concluded that the likelihood that *T. maritimum* would be released from an infected 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 the evidence of horizontal transmission under laboratory conditions. This conclusion was made with **high certainty** based on a number of cohabitation trials (one conducted on BC isolates), showing *T. maritimum* is transmitted from infected fish to naïve cohabitant fish through water.

3.2.4.2 Release through vectors and fomites

It was concluded that the likelihood that *T. maritimum* would be released from an infected Atlantic Salmon farm located in the Discovery Islands area into an environment accessible to wild fish populations through vectors or fomites is **likely** under the current farm practices given that although effective biosecurity and biocontainment measures are in place and low levels of operational deficiencies that could affect fish health on Atlantic Salmon farms, *T. maritimum* can form biofilms and adhere to structures. This conclusion was made with **reasonable uncertainty** given that relevant biosecurity practices are part of SHMP and hence licence requirements but the potential roles of vectors and fomites in releasing the bacterium are not well understood.

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 *T. maritimum* would be released from an infected Atlantic Salmon farm.

3.3 EXPOSURE ASSESSMENT

3.3.1 Question

Assuming that *T. maritimum* 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 *T. maritimum* 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., 2014).

Considerations include timing of Fraser River Sockeye Salmon in the Discovery Islands area; occurrence of mouthrot on Atlantic Salmon farms; temporal overlap between mouthrot and Fraser River Sockeye Salmon in the Discovery Islands area; relative size and volume of Atlantic Salmon farms; *T. maritimum* survival in the marine environment; and oceanographic and environmental conditions.

3.3.2.1 Timing of Fraser River Sockeye Salmon in the 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).

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); typically, between June and October (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 Occurrence of mouthrot on Atlantic Salmon farms

Table 10 summarizes mouthrot diagnoses on Atlantic Salmon farms in the Discovery Islands area by month.

Between 2002 and 2018, mouthrot was diagnosed at the farm level through FHASP on at least one farm in nine months, and mouthrot has been attributed to a FHE on at least one farm in every month of the year.

Overall, between 2002 and 2018, mouthrot was reported on Atlantic Salmon farms at least once in every month (Tables 10 and 11).

Table 10. Summary of the evidence of temporal overlap between Fraser River Sockeye Salmon and mouthrot occurrences on Atlantic Salmon farms in the Discovery Islands area.The "X" indicates the presence of Fraser River Sockeye Salmon in a given month. Data include monthly results (summed over all available years) from the Fish Health Audit and Surveillance Program (2002-2018), fish health events (2002-2018) and mortality events (2011-2018) reported by the industry to DFO. Months with evidence of Tenacibaculum maritimum *and/or mouthrot 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 mouthrot on farms	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Number of farms with farm-level mouthrot diagnoses	**1**	**2**	**2**	0	**1**	**2**	0	**5**	**1**	**1**	0	**2**
Number of farms with fish health events attributed to mouthrot	**4**	**6**	**5**	**6**	**9**	**12**	**9**	**5**	**4**	**2**	**6**	**5**
Number of farms with mortality events attributed to mouthrot	0	0	0	0	0	0	0	0	0	0	0	0

FHASP and FHE data were combined to determine the number of different farms with mouthrot diagnosis for a given month and year (Table 11). A single farm might have contributed to more than one month within each year. For example, in 2014, mouthrot was reported on one farm during May, June and July.

Table 11. Number of Atlantic Salmon farms in the Discovery Islands area with occurrences of mouthrot, between 2002 and 2018, summarized per year and month. Data include results from the Fish Health Audit and Surveillance Program (2002-2018) and Fish Health Events (2002-2018). No mortality events attributed to mouthrot were reported (2011-2017) on Atlantic Salmon farms in the Discovery Islands area. Months with evidence of Tenacibaculum maritimum *and/or mouthrot are shaded and bolded for clarity.*

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	**1**	**1**	0	0	**1**	0	0	0	0	0	**1**
2005	**1**	**2**	**1**	0	**1**	**3**	**3**	**3**	**1**	0	0	0
2006	0	0	0	**1**	**2**	**2**	0	0	0	**1**	**2**	**1**
2007	**2**	**1**	**1**	**2**	**2**	**4**	**2**	**3**	**2**	0	0	**1**
2008	0	0	**1**	0	0	0	0	0	0	0	**1**	**2**
2009	0	**2**	0	**1**	0	**3**	**3**	**4**	**1**	**1**	0	0
2010	0	0	**3**	**3**	**2**	**1**	0	0	**1**	**1**	**1**	0
2011	0	0	0	0	0	**2**	**1**	0	0	0	**1**	**1**
2012	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	0	0	**2**	**2**	**1**	0	0	0	0	0
2014	**1**	**1**	0	0	**1**	**1**	**1**	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0	0	0	**1**
2016	0	0	0	0	0	0	0	0	0	0	0	0
2017	0	0	0	0	0	**1**	**1**	0	0	0	**1**	0
2018	0	**1**	0	0	**1**	0	0	0	0	0	0	0

3.3.2.3 Temporal overlap between mouthrot and Fraser River Sockeye Salmon

Fraser River Sockeye Salmon (juveniles and adults) are expected in the Discovery Islands area between May and October. Between 2002 and 2018, mouthrot was reported in every month of the year through either audit-based farm-level diagnoses or FHE reporting from the industry (Tables 10 and 11), demonstrating a clear temporal concurrence between Fraser River Sockeye Salmon and *T. maritimum* attributable to Atlantic Salmon farms in the Discovery Islands area.

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). Additionally, 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 3 to 12% of the width of the channel (Figure 5).

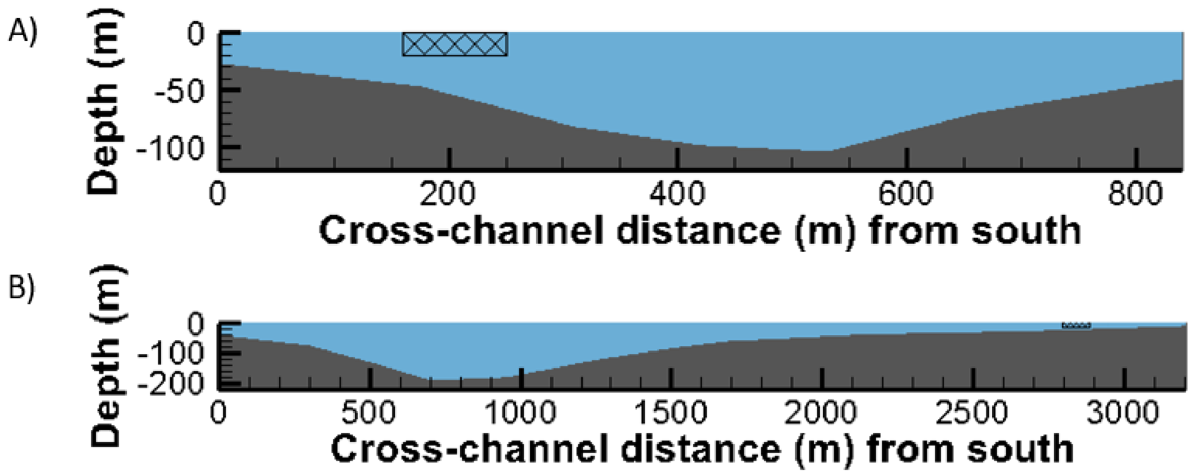

Figure 5. Cross sections of channels at (A) Brent and (B) Shaw farms located in respectively the narrowest and widest channel with Atlantic Salmon farms in the Discovery Islands area. Cross-hatched boxes show the cross-channel projection of the net-pens of the farms depicted at scale, i.e., what fish swimming along-channel would encounter. 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 *Tenacibaculum maritimum* survival in the marine environment

Wade and Weber (2020) reviewed the state of knowledge related to the survival of *T. maritimum* in the environment. To this date, there is no publications on the survival and decay rates of the strains of *T. maritimum* causing mouthrot in the marine environment. Little is known on the survival of *T. maritimum* and what is known is primarily correlation between diagnoses of mouthrot and environmental factors (Wade and Weber, 2020). Both salinity and temperature influence the survival of *T. maritimum* in the marine environment.

Outbreaks of mouthrot have been reported by Frelier et al. (1994) in Puget Sound with water temperatures ranging between eight and 12°C, and salinity between 29 and 32 ppt. Additionally, temperatures higher than 15°C (Wakabayashi et al., 1986; Sorum et al., 2000; Avendaño-Herrera et al., 2006b), rapid increases in water temperature (Devesa et al., 1989) and high salinity (30-35 ppt; Avendaño-Herrera et al. (2006b)) are among factors attributed to the *T. maritimum*-associated outbreaks. It is unclear whether these factors are only affecting the bacterial activity, host susceptibility, or both (and to what extent).

Avendaño-Herrera et al. (2006a) studied the survivability of the Spanish isolates of *T. maritimum* and showed that the bacterium can survive in sterile sea water in a culturable state for five months and in natural sea water for five days (Avendaño-Herrera et al., 2006a). The authors suggested the survivability difference between sterile and natural seawater was due to the natural aquatic microbiota. *Tenacibaculum maritimum* survives poorly in seawater alone and it may need to be protected in sediments, attached to a particle or an animal surface until environmental conditions are favourable for growth (Avendaño-Herrera et al., 2006a).

Tenacibaculum maritimum causing mouthrot in seawater has been demonstrated to transfer horizontally under laboratory conditions (Frisch et al., 2018a).

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). Water salinity in the Discovery Islands area varies considerably by season (river runoff of snowmelt), depth (the estuarine circulation), and location (some narrow channels are extremely well-mixed vertically) ranging from nearly zero to 32 (Chandler et al., 2017).

Monthly distributions of temperature (°C) and salinity (ppt) recorded on active Atlantic Salmon farms in the Discovery Islands area over the last five years (2014-2018) are presented in Figures 6 and 7, respectively. Between 2002 and 2018, although mouthrot occurrences were reported all year around, the majority of FHEs attributed to mouthrot were reported in spring and summer months (Table 10) when temperature was the highest (Figure 6) and salinity was the most variable (Figure 7).

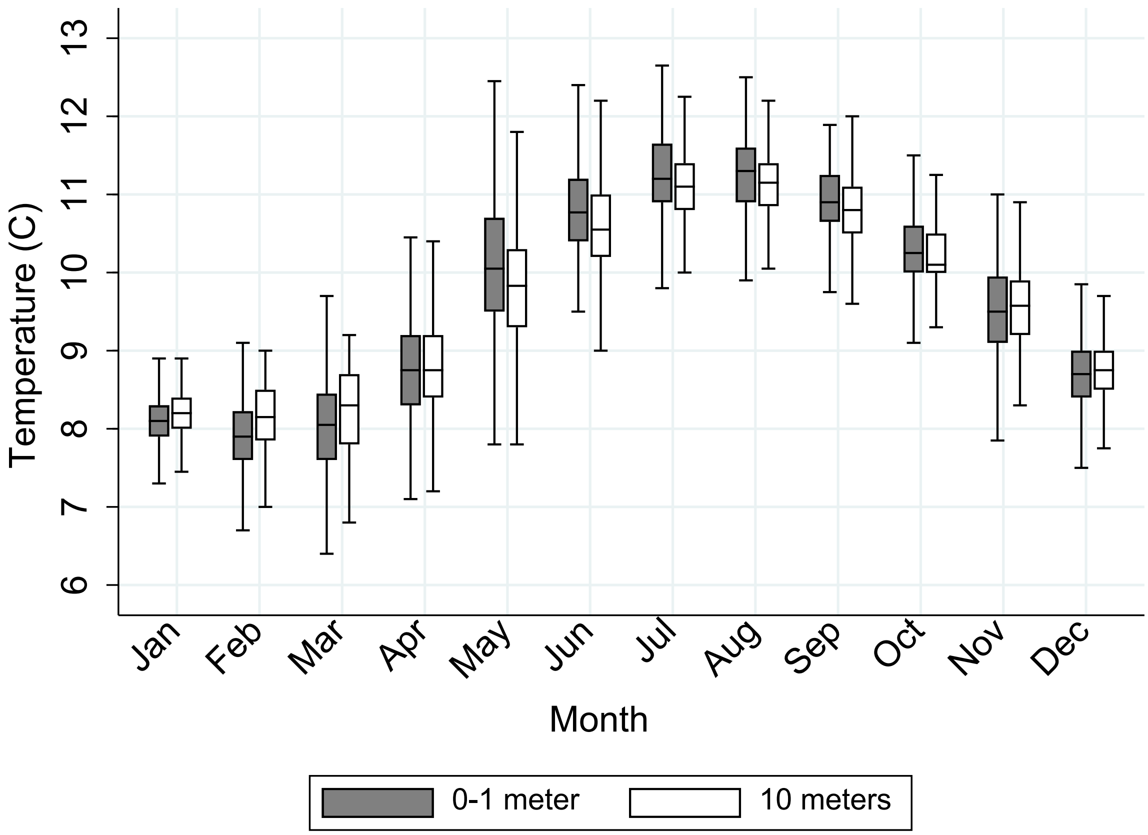

Figure 6. Distribution of temperatures (degree Celcius) recorded on active Atlantic Salmon farms in the Discovery Islands area at <1 and 10 meters depth, between 2014 and 2018 (five years). Each box represents the interquartile range (IQR = Q3 – Q1), including the median line. Whiskers indicate the upper (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.

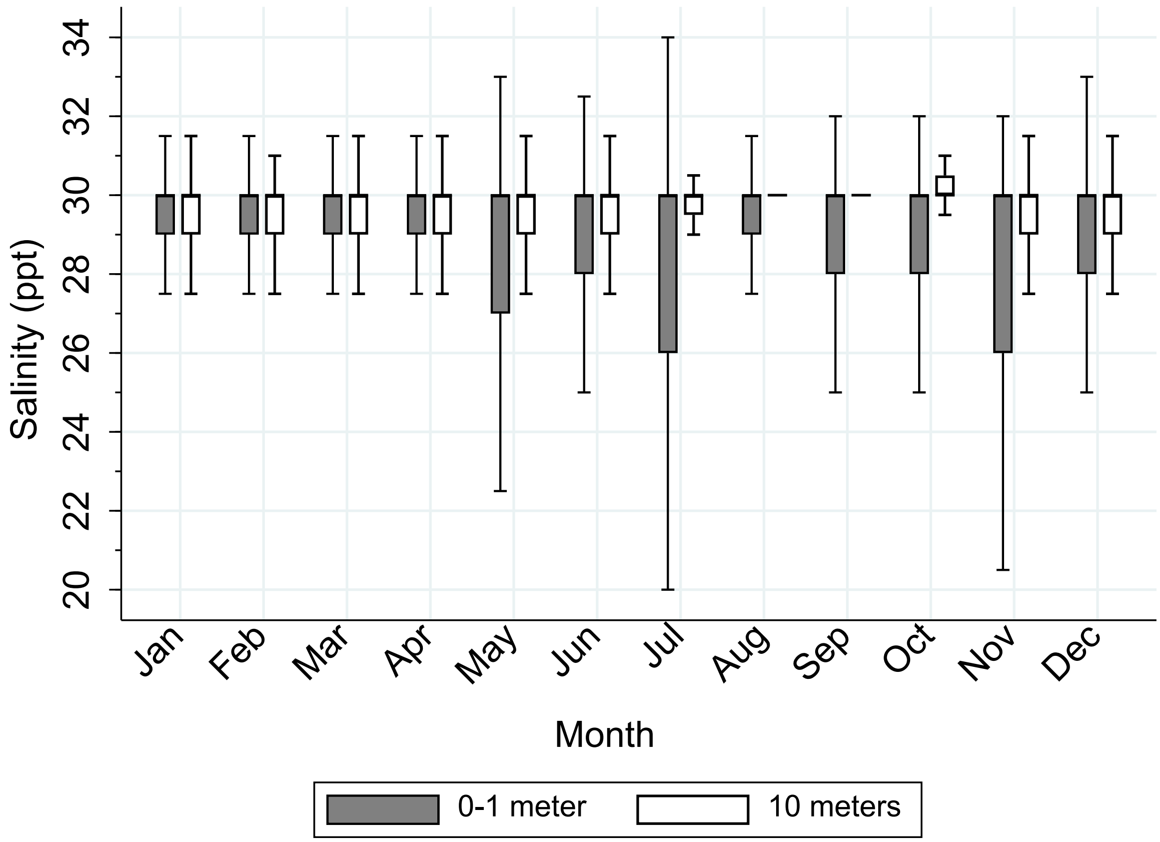

Figure 7. Distribution of salinities (ppt) recorded on active Atlantic Salmon farms in the Discovery Islands area at <1 and 10 meters depth, between 2014 and 2018 (5 years). Each box represents the interquartile range (IQR = Q3 – Q1), including the median line. Whiskers indicate the upper (Q3 + (1.5 × 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. Note that all medians are at or very close to 30 ppt. Data source: BC Salmon Farmers Association, 2019.

3.3.3 Assumptions

- *Tenacibaculum maritimum* 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 12 presents the main factors contributing to and limiting the likelihood of Fraser River Sockeye Salmon to be exposed to *T. maritimum* attributable to Atlantic Salmon farm(s) in the

Discovery Islands area. These factors were used to determine the likelihood and uncertainty rankings based on the definitions in Tables 2, 5 and 6.

Table 12. Factors contributing to and limiting the likelihood that at least one Fraser River Sockeye Salmon would be exposed to Tenacibaculum maritimum *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; • There is temporal overlap between Fraser River Sockeye Salmon migration (May through October) and mouthrot diagnoses on Atlantic Salmon farms in the Discovery Islands area (all months of the year); • Spanish isolates of *T. maritimum* are shown to be able to survive in seawater up to five days; and • Horizontal transmission of BC isolates of *T. maritimum* has been shown under experimental conditions.	• Atlantic Salmon farms are not found in all channels of the Discovery Islands area; and • Atlantic Salmon farms occupy a very small surface area and volume of the Discovery Islands area and width of channels.

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

3.3.4.1 Exposure of juvenile Fraser River Sockeye Salmon

It was concluded that the likelihood of at least one juvenile Fraser River Sockeye Salmon to be exposed to *T. maritimum* attributable to Atlantic Salmon farms located in the Discovery Islands area through waterborne exposure is **very likely** under the current farm practices given temporal overlap with mouthrot on farms and the potential for horizontal transmission of the bacteria. Of the 13 years in which mouthrot was reported (since 2002), 11 years had evidence of mouthrot during the time period that juveniles are present in the Discovery Islands area. This conclusion was made with **reasonable certainty** given that data on mouthrot occurrences on farms and the concurrent presence of juvenile Fraser River Sockeye Salmon in the Discovery Islands area are abundant (but not comprehensive) and robust. In addition, there is strong evidence regarding horizontal transmission and survival of the bacterium in the marine environment.

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 *T. maritimum* attributable to an Atlantic Salmon farm located in the Discovery Islands area through waterborne exposure is **very likely** under the current farm practices given the temporal overlap with mouthrot on the farms. Of the 13 years in which mouthrot was reported on farms (since 2002), 10 were during the time period that adults are present in the Discovery Islands area. This conclusion was made with **reasonable certainty** given that data on mouthrot occurrences on farms and the concurrent presence of adult Fraser River Sockeye Salmon in the Discovery Islands area are abundant (but not comprehensive) and robust. In addition, there is strong evidence regarding horizontal transmission and survival of the bacterium in the marine environment.

3.4 INFECTION ASSESSMENT

3.4.1 Question

Assuming that Fraser River Sockeye Salmon have been exposed to *T. maritimum* released from Atlantic Salmon farms in the Discovery Islands area, what is the likelihood that they are exposed to a concentration and for a period time sufficient to cause infection?

3.4.2 Considerations

Considerations include Sockeye Salmon susceptibility to *T. maritimum* infection; factors contributing to disease; duration of exposure of Fraser River Sockeye Salmon to farms; *T. maritimum* minimum infectious and lethal dose; *T. maritimum* infection pressure from farms; and hydrodynamic dispersal of *T. maritimum*.

3.4.2.1 Sockeye Salmon susceptibility to *Tenacibaculum maritimum* infection

No reference could be found describing the bacterial isolation of *T. maritimum* or mouthrot in Sockeye Salmon (Wade and Weber, 2020). However, Nekouei et al. (2018) reported the molecular detection of *T. maritimum* in 0.25% (five of 2,006) of juvenile Fraser River Sockeye Salmon screened using high-throughput microfluidics qPCR. In this study, given that testing was done on a pool of tissues, including gill samples, detection was not necessarily indicative of infection with the bacterium. Additionally, the diagnostic performance of the high-throughput qPCR method used in this study has not yet been diagnostically validated.

As of late 2019, mouthrot has not been reported in wild salmonids (including Sockeye Salmon) in BC or Washington State (reviewed in Wade and Weber (2020)) and the susceptibility of Sockeye Salmon to *T. maritimum* infection and disease is unknown. However, two FHEs attributed to mouthrot in farmed Chinook Salmon have been reported in 2002 and 2009 in BC (none in the Discovery Islands area) (summarized in Wade and Weber (2020)). *Tenacibaculum maritimum* genetic material has also been detected in juvenile Coho Salmon sampled in BC (85 of 2622) using high-throughput microfluidics qPCR (Nekouei et al., 2019).

Given the molecular detection of *T. maritimum* in juvenile Fraser River Sockeye Salmon (Nekouei et al., 2018) and FHEs attributed to mouthrot reported in farmed Chinook Salmon in BC (reviewed in Wade and Weber (2020)), Sockeye Salmon were assumed to be susceptible to infection with *T. maritimum* in this risk assessment.

Relative life-stage susceptibility to infection with *T. maritimum* or mouthrot in farmed Atlantic and Chinook Salmon suggest a decrease in susceptibility to the disease with age as mouthrot has not been reported in the second year of the production cycle of farmed salmon in BC (B. Boyce, pers. comm., 2019; T. Hewison and P. Whittaker, pers. comm., 2019). Weights of Atlantic Salmon on farms in the Discovery Islands area during FHEs attributed to mouthrot ranged between 0.15 and 0.49 kg (median=0.28), corresponding to typical weights of fish during the first year of production cycle at sea.

3.4.2.2 Factors contributing to disease

Infections with *T. maritimum* have been documented in association with handling events such as counting, size-classification and transport (Alsina and Blanch, 1993; Cepeda and Santos, 2002) and recent transfer to sea cages (Wakabayashi et al., 1984; Pepin and Emery, 1993).

Some potential predisposing factors for Atlantic Salmon smolts to contract mouthrot include feeding on hard pellets, fish biting net surfaces and stress-induced lesions/abrasions in the mouth (Kent and Poppe, 1998).

In the laboratory, abrasion of the gill epithelium has been shown to increase the severity and rate of disease progression in Atlantic Salmon smolts, depending on the strain of *T. maritimum* (Powell et al., 2004). Abrading of periodontal tissue by feeding on spiny crustaceans including crab larvae and amphipods has also been hypothesized as an entry point for bacteria (Kent and Poppe, 1998). However, pre-exposure scarification or abrasion is not necessary for infection with *T. maritimum* (Avendaño-Herrera et al., 2006a) including infection of with BC strains (Frisch et al., 2018b).

Mouthrot mainly affects smolts recently transferred into salt water (Frelier et al., 1994; Ostland et al., 1999; Frisch, 2018; Frisch et al., 2018b). There have been no reports of mouthrot in the second year of production cycles in BC. Environmental factors such as warm water temperatures and high salinity have been suggested as two factors associated with mouthrot (reviewed in Wade and Weber 2020)).

3.4.2.3 Duration of exposure of Fraser River Sockeye Salmon to farms

The duration over which Fraser River Sockeye Salmon could be exposed to *T. maritimum* released from an Atlantic Salmon farm in the Discovery Islands area depends on the time Fraser River Sockeye Salmon spend in the Discovery Islands area and in the vicinity of farms.

3.4.2.3.1 Residence time of Fraser River Sockeye Salmon in Discovery Islands area

Grant et al. (2018) estimated the residence time in the Discovery Islands area to be of five to 14 days for juvenile and three days for adult Sockeye Salmon in the Discovery Islands area. However, most Atlantic Salmon farms are located over approximately 75 km of the estimated 140 km length of the Discovery Islands area. Assuming a constant migration speed and unidirectional movement, Mimeault et al. (2017) estimated that juveniles could encounter farms over three to eight days and returning adults over two days on their migration through the Discovery Islands area. Stevenson et al. (2019) reported that juvenile Fraser River Sockeye Salmon from Chilko Lake spent an average of 7.6 days in the Discovery Islands to Johnstone Strait region, with 14.5 km/day average migration speed.

3.4.2.3.2 Fraser River Sockeye Salmon in proximity to Atlantic Salmon farms

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

The above study was repeated in 2018 with Sockeye Salmon captured in the Okisollo Channel and released in the Strait of Georgia. This time, receivers were deployed at a total of four stocked farms. The median time that juvenile fish spent near individual stocked salmon farms was 11.4 minutes (E. Rechisky, Kintama Research Services Ltd., 755 Terminal Avenue North, Nanaimo, BC V9S 4K1, pers. comm., 2019). The apparent difference in exposure times between 2017 and 2018 is, however, more likely to be related to a difference in study design or interannual variation (swim speeds through Discovery Passage, an area without farms was slower in 2018) rather than to farm status (E. Rechisky, pers. comm., 2019).

Overall, juvenile Sockeye Salmon migrate rapidly past salmon farms, and are generally within detection range of individual farms for less than 20 minutes (E. Rechisky, pers. comm., 2019).

3.4.2.4 *Tenacibaculum maritimum* minimum infectious and lethal dose

The most relevant infectious doses for this risk assessment would be the minimum dose required to infect Sockeye Salmon with Western Canadian strains of *T. maritimum*. In the absence of this information, immersion studies conducted in other salmonids were used as surrogate information in this risk assessment. As injection is not a natural route of exposure, injection challenge experiments were not considered in estimating the minimum infectious or lethal doses.

Frisch et al. (2018b) conducted an experiment to determine if mouthrot could be induced in Norwegian Atlantic Salmon smolts challenged with *T. maritimum* isolates collected from outbreaks in Western Canada. These fish were transferred from freshwater to seawater 24 hours prior to the beginning of the experiment (Frisch et al., 2018b). The concentration and bath duration required to induce mortality in 40 g Norwegian Atlantic Salmon varied between isolates (Frisch et al., 2018b). Based on this experiment, the lowest concentrations of Western Canadian strains of *T. maritimum* that caused mortality in Atlantic Salmon ranged between 6.36×10^5 and 1.78×10^7 cells/mL, depending on the isolates (Table 13). The variation in mortality among isolates at similar bath concentrations in this study demonstrates that there are differences in pathogenicity between isolates (Frisch et al., 2018b).

Table 13. Summary of Western Canadian Tenacibaculum maritimum *isolates concentrations and bath duration required to induce mortality in Norwegian Atlantic Salmon smolts under experimental conditions. Adapted from Frisch et al. (2018b).*

***Tenacibaculum maritimum* isolate**	**Highest concentration (cells/mL) without mortality (bath duration)**	**Lowest concentration (cells/mL) that induced mortality (bath duration)**	**Cumulative percent mortality for the lowest concentration that induced mortality**
TmarCan15-1	3.80×10^6 (1.5 and 5.0 hours)	5.74×10^6 (5.0 hours)	75-90
TmarCan16-1	--	6.36×10^5 (5.0 hours)	100
TmarCan16-2	1.28×10^7 (5.0 hours)	--	--
TmarCan16-5	7.30×10^6 (5.0 and 7.5 hours)	1.78×10^7 (5.0 hours)	84-95 (shedders only)
TmarCan16-6	--	1.52×10^7 (5.0 and 7.5 hours)	100

3.4.2.5 *Tenacibaculum maritimum* infection pressure from farms

Quantifying the infection pressure attributable to an infected farm requires an estimation of the number of infected fish on farm, the shedding rate in infected fish and the volume of the farm.

Although the average volume of Atlantic Salmon farms in the Discovery Islands area has been estimated to be approximately 195,000 m^3 (Mimeault et al., 2017), given that the shedding rate in *T. maritimum*-infected fish has not been quantified, it is not possible to estimate the infection pressure attributable to a *T. maritimum*-infected Atlantic Salmon farm in the Discovery Islands area.

3.4.2.6 Hydrodynamic dispersal of *Tenacibaculum maritimum*

Modelling the hydrodynamic dispersion of a pathogen in the marine environment requires an ocean and circulation model, the infection pressure attributable to the source and information about the survival of the pathogen in the marine environment.

There is an existing ocean and circulation model available for the Discovery Islands area (Foreman et al., 2012) that has been used to model hydrodynamic dispersion of infectious hematopoietic necrosis virus (IHNV) between farms (Foreman et al., 2015a) and dispersion of IHNV in the Discovery Islands area (Mimeault et al., 2017). In general, it is expected that tidal currents and water movements disperse and dilute the concentration of bacteria released from the farms.

It was, however, not possible to model the dispersal of *T. maritimum* from infected Atlantic Salmon farms in the Discovery Islands area for this risk assessment given the lack of empirical data to estimate the infection pressure attributable to a *T. maritimum*-infected farm(s) (see above).

3.4.3 Assumptions

- Sockeye Salmon have been exposed to *T. maritimum* released from Atlantic Salmon farm(s) in the Discovery Islands area;
- Sockeye Salmon are susceptible to infection with *T. maritimum;*
- All Fraser River Sockeye Salmon are equally susceptible to infection with *T. maritimum* regardless of their stocks of origin; and
- Fraser River Sockeye Salmon entering the Discovery Islands area are naïve to *T. maritimum*, i.e., they have not been previously exposed to the bacterium.

3.4.4 Likelihood of infection

Table 14 presents the main factors contributing and limiting the likelihood that Fraser River Sockeye Salmon would become infected with *T. maritimum* released from Atlantic Salmon farm(s) located in the Discovery Islands area. These factors were used to determine the likelihood and uncertainty rankings based on the definitions in Tables 2, 5 and 6.

Table 14. Factors contributing to and limiting the likelihood that the exposed Fraser River Sockeye Salmon to Tenacibaculum maritimum *from Atlantic Salmon farms in the Discovery Island area would become infected.*

Contributing factors	Limiting factors
• Genetic material of *T. maritimum* has been detected from juvenile Sockeye Salmon; • Mouthrot has been reported in farmed Atlantic and Chinook salmon in BC, as well as farmed Rainbow Trout in the Pacific Northwest of the US; • Juvenile Sockeye Salmon could encounter Atlantic Salmon farms over three to eight days during their migration through the Discovery Islands area; and • Returning adult Sockeye Salmon could encounter Atlantic Salmon farms over two days during their migration through the Discovery Islands area.	• There are no published reports of mouthrot in Sockeye Salmon; • Based on telemetry tracking studies, juvenile Sockeye Salmon spend limited time (< 20 minutes) in the vicinity of fallowed or stocked farms (i.e., short duration of exposure is expected); • Lowest concentrations of the BC isolates of *T. maritimum* required to induce mortality ranged between 6.36×10^5 and 1.78×10^7 cells/mL; • Genetic material of *T. maritimum* have only been detected from a very small proportion of juvenile Fraser River Sockeye Salmon (0.25%); and • Farmed adult Atlantic and Chinook salmon have not been diagnosed with mouthrot.

Likelihood of infection was considered for two exposure groups: (1) juvenile Fraser River Sockeye Salmon; (2) adult Fraser River Sockeye Salmon.

3.4.4.1 Infection of juvenile Fraser River Sockeye Salmon

It was concluded that the likelihood of juvenile Fraser River Sockeye Salmon to become infected with *T. maritimum* attributable to Atlantic Salmon farms in the Discovery Islands area through waterborne exposure under the current farm practices is **unlikely** given the limited and short direct interaction of Fraser River Sockeye Salmon with farm sites. This conclusion was made with **high uncertainty** given insufficient knowledge and lack of data to estimate the infection pressure from the farms and the minimum infectious dose of *T. maritimum* in Sockeye Salmon.

3.4.4.2 Infection of adult Fraser River Sockeye Salmon

It was concluded that the likelihood of adult Fraser River Sockeye Salmon to become infected with *T. maritimum* attributable to Atlantic Salmon farms in the Discovery Islands area through waterborne exposure under the current farm practices is **very unlikely** given (1) the limited and short direct interaction with farm sites, (2) that adults cannot get into the net pens and would therefore be expected to be exposed to a lower concentration of *T. maritimum* compared to juveniles; and (3) that mouthrot has only been reported during the first year at sea (in juveniles) on Atlantic and Chinook Salmon farms in BC, suggesting that adults are not susceptible to mouthrot. This conclusion was made with **reasonable uncertainty** given surrogate data available on the potential resistance of adults to the infection (or mouthrot) and a lack of data on minimum infectious dose and infection dynamics of *T. maritimum* in Sockeye Salmon.

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, exposure and infection assessments.

Table 15 summarizes the likelihood assessment. Overall, it was concluded that the likelihood that Fraser River Sockeye Salmon would become infected with *T. maritimum* released from Atlantic Salmon farms in the Discovery Islands area is **unlikely** and **very unlikely** for juveniles and adults, respectively.

Table 15. 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 Tenacibaculum maritimum *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 *(high certainty)*	Likely *(reasonable uncertainty)*
	Combined likelihood	Extremely likely	
Exposure assessment	**Exposure groups**	**Juveniles**	**Adults**
	Likelihood *(uncertainty)*	Very likely *(reasonable certainty)*	Very likely *(reasonable certainty)*
Infection assessment	**Likelihood *(uncertainty)***	Unlikely *(high uncertainty)*	Very unlikely *(reasonable uncertainty)*
Overall likelihood for each exposure group (combination of all four steps)		Unlikely	Very unlikely

4 CONSEQUENCE ASSESSMENT

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

Based on the likelihood assessment, it was determined that it is **unlikely** that juvenile and **very unlikely** that adult Fraser River Sockeye Salmon would become infected with *T. maritimum* released from Atlantic Salmon farms in the Discovery Islands area. Assuming that Fraser River Sockeye Salmon would have been infected with *T. maritimum* attributable Atlantic Salmon farms, the consequence assessment explores the potential magnitude of impacts to the number of returning adults and diversity of Fraser River Sockeye Salmon.

Figure 8 illustrates two potential outcome pathways resulting from one or more Fraser River Sockeye Salmon infected with *T. maritimum* released from infected Atlantic Salmon farms located in the Discovery Islands area.

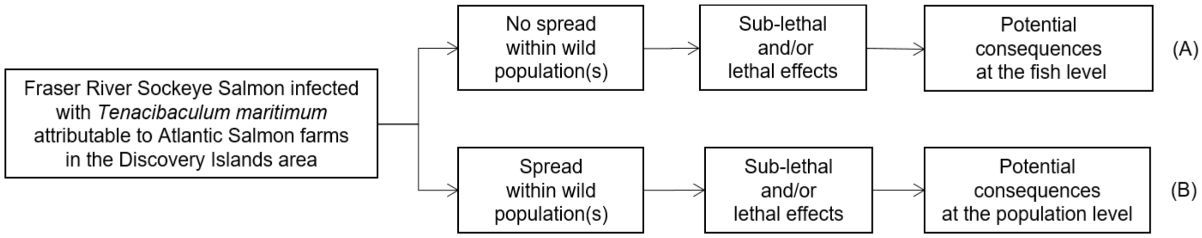

Figure 8. Potential outcome pathways resulting from susceptible wild fish infected with Tenacibaculum maritimum *attributable to Atlantic Salmon farms located in the Discovery Islands area.*

4.1 QUESTION

Assuming that susceptible Fraser River Sockeye Salmon have become infected with *T. maritimum* released from infected Atlantic Salmon farm(s) in the Discovery Islands area, what is the potential magnitude of impact on the number of returning adults and diversity of Fraser River Sockeye Salmon?

4.2 CONSIDERATIONS

In this section, we turn our focus to the population-level consequences of infection. Considerations include the infection dynamics and virulence of *T. maritimum*; the prevalence of infection with *T. maritimum* in migratory Sockeye Salmon; mortality attributable to mouthrot; *T. maritimum* sublethal infections; Fraser River Sockeye Salmon ecology; and stock-specific susceptibility.

4.2.1 Infection dynamics and virulence of *Tenacibaculum maritimum*

Of most relevance to this risk assessment would be the infection dynamics and virulence of Western Canadian *T. maritimum* isolates in wild Sockeye Salmon. In the absence of such information, and given that infection dynamics of *T. maritimum* or mouthrot has not been described in any wild Pacific salmon, studies conducted with other salmonids and outbreaks on salmon farms are described as surrogate information.

In a study under experimental conditions, when concentrations were sufficient to cause mortality, the time period between exposure and first mortality varied between three and 11 days in Norwegian Atlantic Salmon smolts exposed to Western Canadian *T. maritimum* isolates depending on the isolate, concentration and duration of exposure (Frisch et al., 2018b). This study also demonstrated substantial differences in virulence among these isolates as lowest concentrations required to induce mortality in smolts through five-hour bath challenges ranged from 6.36×10^5 to 1.78×10^7 cells/mL.

On salmon farms located on the West Coast of North America, mortalities showing clinical signs of mouthrot can occur as early as two days post-transfer to saltwater and most commonly occur within the first few weeks (Frisch, 2018). According to the Atlantic Salmon farming companies operating in the Discovery Islands area, mouthrot outbreaks can start up to six weeks after seawater entry of smolts. When the initial cases of disease are diagnosed within one or more cages, the disease has already affected multiple cages and a farm-level treatment with choice antibiotics will often be applied (B. Boyce, pers. comm., 2019; T. Hewison and P. Whittaker, pers. comm., 2019; K. Frisch, 203-919 Island Highway, Campbell River, BC, Canada V9W 2C2, pers. comm., 2019).

Only one publication has described a mouthrot outbreak under farm conditions in the absence of treatment. Frelier et al. (1994) examined fish from three farms (one Atlantic Salmon farm, one

Chinook Salmon farm and one Rainbow Trout farm) for necrotizing stomatitis (mouthrot) in Puget Sound, Washington, USA, in 1990 and 1991. Disease outbreaks occurred from April to July at temperatures ranging from 8 to 12°C and salinity from 29 to 32 ppt. Morbidity and mortality occurred three to eight weeks following introduction to sea water (Frelier et al., 1994). Cumulative pen mortality of smolts with characteristic oral lesions typically ranged between 5 and 10% during the first six weeks after introduction, and occasionally reached 30% (Frelier et al., 1994).

4.2.2 Prevalence of *Tenacibaculum maritimum* in Sockeye Salmon

Nekouei et al. (2018) reported the detection prevalence of *T. maritimum* in juvenile Fraser River Sockeye Salmon sampled along their out-migration route in the spring and summer of 2012 and 2013 to be 0.25% (five of 2,006). The authors tested a total of 2,006 Sockeye Salmon sampled in both freshwater (n=896) and seawater (n=1,110), using Fluidigm Biomark™ qPCR platform. The prevalence of detection was defined as the number of test-positive salmon divided by the total number of salmon tested with conclusive results (Nekouei et al., 2018). In this study, all five molecular detections were from salmon sampled in seawater in 2012: one sampled in the Discovery Islands area and the other four from salmon sampled around Johnstone Strait (O. Nekouei, Fisheries and Oceans Canada, 200 Kent, Ottawa, ON K1A 0E6, pers. comm., 2019). Note that in 2012, there were no corresponding reports of mouthrot on farms in the Discovery Islands area (Table 11).

There are no reports on *T. maritimum* infection in adult Sockeye Salmon, or of mouthrot in juvenile or adult Sockeye Salmon. Additionally, no gross signs of mouthrot were reported in the 2,419 Sockeye Salmon collected through DFO juvenile salmon health surveys conducted between 2010 and 2012 (S. Johnson, Fisheries and Oceans Canada, 3190 Hammond Bay Road, Nanaimo, BC V9T 6N7, pers. comm. 2020).

4.2.3 Mortality attributable to mouthrot

There are no reports of mortality of wild Pacific salmon in BC associated with *T. maritimum* or mouthrot.

Frelier et al. (1994) reported on outbreaks without treatment of necrotizing stomatitis (mouthrot) that occurred on four salmonid farms in 1990 and 1991 in Puget Sound, WA, USA. Morbidity and mortality attributed with the disease were observed in smolts after three to eight weeks of seawater entry. Cumulative pen-level mortalities with characteristic oral lesions during the first six weeks post introduction were typically 5-10%, but occasionally reached as high as 30%. Detailed examination of fish on three of the farms demonstrated lesions of ulcerative stomatitis in Atlantic Salmon and Rainbow Trout. The disease was not identified in any of the Chinook Salmon smolts examined in this study.

In a series of experimental trials, Frisch and colleagues studied the potential consequences of challenges of Norwegian Atlantic Salmon with different isolates of *T. maritimum* collected from outbreaks of mouthrot on Atlantic Salmon farms in BC. They used various combinations of high bacterial concentrations (8.75×10^5 to 3.74×10^7 cells/mL) and exposure durations (1.5 to 7.5 h) to reproduce the disease and induce mortality. Cumulative mortality varied between 0 and 100%, depending on the isolate, concentration, and duration of each experiment. They demonstrated significant differences in the genetics, antibody response, and pathology of BC strains of *T. maritimum* compared to other strains causing tenacibaculosis (Frisch et al., 2017; Frisch et al., 2018a; Frisch et al., 2018b).

Active Atlantic Salmon producing companies in the Discovery Islands area are applying antibiotic treatments once initial cases of mouthrot are diagnosed on their farms; therefore, the total cumulative mortalities attributed to mouthrot without treatment cannot be determined. The treatment is very efficacious and reduces associated mortalities within two to three days (B. Boyce, pers. comm., 2019; T. Hewison and P. Whittaker, pers. comm., 2019).

4.2.4 *Tenacibaculum maritimum* sublethal infections

Mouthrot can cause lethargy, emaciation, and anorexia; some fish may exhibit head shaking or flashing (Kent, 1992). Yellow bacterial mats around the palate, teeth and vomer are present early in an infection (Kent, 1992). As disease progresses, fish develop multiple ulcers in the mouth with large yellow bacterial mats (Kent, 1992; Frelier et al., 1994). Lesions are characteristically associated with regions of dentition including premaxilla, dentary, vomer and palatine bones and may result in tooth loss (Frelier et al., 1994). Lesions may extend to the branchial arches and esophagus; in severe cases the lower and upper jaw may be completely eroded (Kent, 1992). Severely infected fish cease feeding (Kent, 1992). All of this can lead to significant economic losses on farms with outbreaks of the disease (Hewison and Ness, 2015).

There is no report of the disease in wild Pacific salmon. The current state of knowledge is not sufficient to quantify sublethal impacts of infection with *T. maritimum* in wild salmon populations. However, assuming that similar clinical signs occur in individual wild salmon due to the infection, affected out-migrating juvenile Fraser River Sockeye Salmon may be expected to be more prone to predation and concurrent infections.

4.2.5 Fraser River Sockeye Salmon ecology

4.2.5.1 Cyclic dominance

Some Fraser River Sockeye Salmon stocks are cyclic where abundance varies by year with a persistent single large (dominant) cycle year followed by three smaller (subdominant or weak) cycle years. Consequently, cyclic stocks are characterized by large returns once every four years (Grant et al., 2018) while non-cyclic stocks are not.

Of approximately 20 Sockeye Salmon populations in the Fraser River watershed that are counted routinely, eight exhibit persistent four-year cycles with a predominant-year cycle line every four years (DFO, 1998).

4.2.5.2 Conservation units

The fundamental unit used to assess biodiversity among Pacific salmon is the conservation unit (CU). For Fraser River Sockeye Salmon there are 24 CU's, where each CU "is a group of wild salmon sufficiently isolated from other groups that, if extirpated, is very unlikely to recolonize naturally within an acceptable timeframe, such as a human lifetime or a specified number of salmon generations" (DFO, 2005).

The Wild Salmon Policy defines three zones of biological status (Red, Amber and Green) (DFO, 2005). The status of each Fraser River Sockeye Salmon CU has been determined, integrating relevant metrics for each CU to generate a final status assessment (DFO, 2013; Grant and Pestal, 2013). Out of the 24 Fraser River Sockeye Salmon CU's, seven are in the Red status zone and four are in the Red/Amber zone, which are poor status zones (Grant and Pestal, 2013). The factors that contribute to the designation of each of these CU's vary, although these CU's generally have low abundances, and also may have experienced recent declines in abundance and productivity (Grant and Pestal, 2013). Since CU's with low abundances are at higher risk of extirpation (Grant et al., 2011; Holt and Bradford, 2011), factors that decrease survival in these CU's in particular will further increase their risk of extirpation and possibly reduce effectiveness of recovery actions.

4.2.6 Stock-specific susceptibility

To date, Sockeye Salmon susceptibility to *T. maritimum* infections remains unknown. Consequently, there is no information to determine if and how susceptibility to infection with *T. maritimum* and clinical manifestations from such infections vary between Fraser River Sockeye Salmon stocks.

4.3 ASSUMPTIONS

- Sockeye Salmon is susceptible to *T. maritimum* infections;
- Juvenile Fraser River Sockeye Salmon with molecular detection of *T. maritimum* were truly infected and the infection was attributable to Atlantic Salmon farms in the Discovery Islands area;
- All juvenile Fraser River Sockeye Salmon stocks have the same susceptibility to the infection with *T. maritimum* and its potential consequences;
- The mortality rates at the population level in juvenile Fraser River Sockeye Salmon are comparable to those reported on Atlantic Salmon farms; and
- The marine mortality rates due to causes other than infection with *T. maritimum* is the same in infected and non-infected juveniles.

4.4 MAGNITUDE OF CONSEQUENCES

The potential magnitude of consequence on both the abundance and diversity of Fraser River Sockeye Salmon resulting from the exposure to an Atlantic Salmon farm infected with *T. maritimum* was assessed and rankings were determined referring to consequence to abundance (Table 3), consequences to diversity (Table 4) and uncertainty (Table 5) definitions.

It can be assumed that the potential adverse impacts of infection with *T. maritimum* is only relevant to out-migrating juveniles and not to returning adults given the following aspects of the epidemiology of mouthrot in farmed salmon in BC:

- mouthrot mainly affects smolts recently transferred into salt water (Frisch et al., 2018b);
- there are no reports of mouthrot in the second year of production cycles in BC, suggesting that older fish have very low susceptibility to the infection or disease; and
- *Tenacibaculum maritimum* is a known saltwater infectious agent (Wakabayashi et al., 1986; Ostland et al., 1999). Grant et al. (2018) estimated that returning Fraser River Sockeye Salmon can travel the distance between the southeastern limit of the Discovery Islands area and Mission, close to the mouth of the Fraser River, in approximately three to four days. Hence, even if an effective exposure happened to some naïve adults around the Discovery Island area, freshwater would be expected to inhibit further spread within the population of returning adults, limiting potential adverse effects.

Therefore, the consequence assessment focuses only on the potential impacts resulting from juvenile Fraser River Sockeye Salmon infection.

There is very limited data specific to wild Sockeye Salmon, *T. maritimum* and mouthrot to inform an analysis and estimation of the magnitude of consequences to Fraser River Sockeye Salmon abundance and diversity. Therefore, surrogate data and information from other species, in addition to the limited Sockeye Salmon specific data, were used to quantitatively model mortality estimates for juvenile Fraser River Sockeye Salmon resulting from infection with *T. maritimum* attributable to Atlantic Salmon farms in the Discovery Islands area.

The probability distribution of juvenile Fraser River Sockeye Salmon mortality attributable to infection with *T. maritimum* was generated as the product of (1) the estimated prevalence of infection in the juveniles based on the molecular detections reported in Nekouei et al. (2018) (Section 4.2.2) and (2) the surrogate mortality rate from farmed fish reported in Frelier et al. (1994) (Section 4.2.3). The cumulative mortality rate reported during an outbreak in farmed smolts is considered to be an overestimate of the actual mortality for juvenile Fraser River Sockeye Salmon given the higher density of farmed fish compared to wild fish, and the prolonged exposures of farmed fish within a cage, compared to the transient exposure of juvenile Fraser River Sockeye Salmon during migration through the Discovery Islands area.

4.4.1 Potential impacts on abundance

In a best-case scenario, there would be no spread of the infection within the migratory populations (Pathway A in Figure 8); hence, no adverse consequences would be expected at the population level.

Assuming that a *T. maritimum* infection attributable to Atlantic Salmon farms in the Discovery Islands would spread within the population (Pathway B in Figure 8), two scenarios were developed in which the estimated prevalence varied based on molecular detections reported in Nekouei et al. (2018). As samples were collected over two years (2012 and 2013) and positive detections were only reported in one of the two years (2012):

- Scenario 1 uses the weighted average of prevalence in 2012 and 2013 (0.66%) as a conservative scenario based on overall estimate of prevalence; and
- Scenario 2 only uses prevalence in 2012 (2.4%) as a worst-case scenario excluding the year without detection.

Beta distributions were used to propagate the measurement uncertainty about these two estimates (e.g., sampling methods) (see Appendices for more details).

Both scenarios used the surrogate cumulative mortality from farmed fish described in Frelier et al. (1994). The proportions of mortality attributable to mouthrot on the farms ranged between 0 and 30% with a presumptive mode of 10% (see Section 4.2.3). A Pert distribution was applied to propagate the measurement uncertainty around these estimates (see Appendix for more details). Although 30% mortality among potentially infected farmed Atlantic Salmon in BC is considered to be an overestimation, we applied this percentage as the theoretical upper limit due to a lack of information in Sockeye Salmon and to generate a worst-case scenario based on the only available study reporting an outbreak of mouthrot in salmonids in the absence of treatment.

The probability distributions for prevalence and mortality were generated using 100,000 iterations in R (version 3.5.2). In order to produce the probability/uncertainty distributions for the potential mortality in juvenile Fraser River Sockeye Salmon under the two scenarios, the prevalence of *T. maritimum* infection (Beta distributions) and the cumulative mortality attributable to mouthrot (Pert distributions) were multiplied. Table 16 presents the summary statistics of the two final distributions. Refer to the Appendix for a more detailed description of this process and visualization of the respective distributions.

Table 16. Summary statistics for simulated distributions of the probability of mortality in juvenile Fraser River Sockeye Salmon due to infection with Tenacibaculum maritimum *released from Atlantic Salmon farms in the Discovery Islands area. Mortality is defined as the number of death due to infection with* T. maritimum *over the total migratory population per year. Two scenarios are considered based on the prevalence of infection reported in Nekouei et al. (2018) (Scenario 1: reasonable and Scenario 2: worst-case).*

Statistics	***Tenacibaculum maritimum*-associated mortality in juvenile Fraser River Sockeye Salmon (%)**	
	Scenario 1 (reasonable)	**Scenario 2 (worst case)**
Min	<0.01	<0.01
2.5%	0.01	0.05
25%	0.05	0.17
50%	0.08	0.29
75%	0.12	0.44
97.5%	0.24	0.87
99%	0.29	1.00
Max	0.59	2.40

Under Scenario 1, *T. maritimum*-associated mortality in juvenile Fraser River Sockeye Salmon migrating through the Discovery Islands area in each year was estimated to vary between zero and 0.59% with a median of 0.08% (Table 16). Under this scenario, there was 99% certainty that the mortality attributable to *T. maritimum* infections from Atlantic Salmon farms would be less than 0.29% (Figure 9), hence 99% certainty that loss at the population level would be negligible according to Table 3.

Under Scenario 2, *T. maritimum*-associated mortality in juvenile Fraser River Sockeye Salmon migrating through the Discovery Islands area in each year was estimated to vary between zero and 2.4% with a median of 0.29% (Table 16). Under this scenario, there was 99% certainty that the mortality attributable to *T. maritimum* infections from Atlantic Salmon farms would be less than 1% (Figure 9), hence 99% certainty that loss at the population level would be negligible according to Table 3.

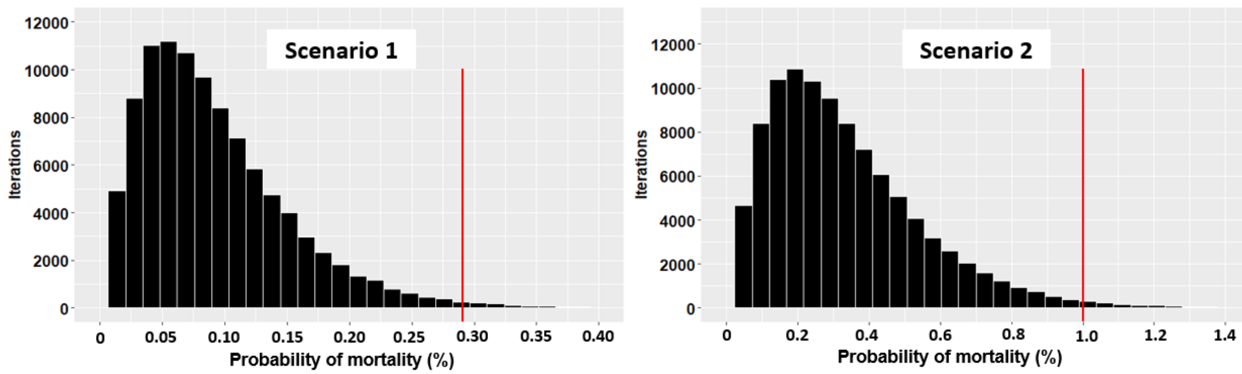

Figure 9. Simulated distributions of the probability of mortality in juvenile Fraser River Sockeye Salmon due to infection with Tenacibaculum maritimum *released from Atlantic Salmon farms in the Discovery Islands area. Mortality is defined as the number of deaths due to infection with* T. maritimum *over the total migratory population per year. Two scenarios are considered based on the prevalence of infection reported in Nekouei et al. (2018) (Scenario 1: reasonable and Scenario 2: worst-case). The vertical lines represent the 99th percentile of the distributions.*

Sublethal consequences of infection with *T. maritimum* cannot be estimated due the lack of relevant information (see Section 4.2.4). However, to provide a very conservative deterministic estimate, if we assume all detections are truly infected (maximum prevalence of 5/208) and all infected fish die (i.e., the absolute worst-case scenario for consequences of infection), the overall population-level mortality would be 2.4%, which corresponds to a minor loss at the population level according to Table 3.

It is possible that the samples collected in Nekouei et al. (2018) may have missed some infected Sockeye Salmon that quickly died/disappeared (e.g., subject to predation) after exposure to the farm-origin bacteria, and therefore, they were not captured in the samples. Conversely, the prevalence of infection in the consequence assessment may be implausibly overestimated given that: (1) samples in this study were homogenates of five different tissues including gills and therefore, molecular detections of *T. maritimum* cannot readily be interpreted representing infected Sockeye Salmon; (2) all five detections were in a year with no corresponding FHE attributed to mouthrot on farms (2012) and there were zero detections in samples from the year with two FHEs on farms (2013); and (3) the diagnostic performance of the high-throughput qPCR method used in this study has not yet been diagnostically validated. The uncertainties related to this study have been addressed through the use of a conservative and a worst-case scenario described above.

Overall, it was concluded that the potential magnitude of consequences to the abundance of Fraser River Sockeye Salmon would be **negligible** given the reported proportion of detection of *T. maritimum* in juvenile Fraser River Sockeye Salmon and the reported mortality attributed to mouthrot in farmed salmon (as surrogate information). This conclusion was made with **reasonable uncertainty** given that only one study provided estimates of the prevalence of infection in juvenile Fraser River Sockeye Salmon and using surrogate mortality data.

4.4.2 Potential impacts on diversity

The determination of the potential impacts on Fraser River Sockeye Salmon diversity resulting from infection with *T. maritimum* attributable to Atlantic Salmon farms in the Discovery Islands area is based on the potential impact on abundance over two generations (eight years for Fraser River Sockeye Salmon).

Based on occurrence of mouthrot on farms between 2002 and 2018 (Table 11), *T. maritimum* infection on Atlantic Salmon farms has occurred in 11 of 17 years (P = 65%) during the out-migration window of juvenile Fraser River Sockeye Salmon. Hence, juveniles can be expected to potentially be exposed to Atlantic Salmon farms infected with *T. maritimum* during their out-migration on average in five (65% × 8) of eight years. Additionally, in years with exposure and subsequent infection, there is 99% certainty that mortality attributable to *T. maritimum* infections from Atlantic Salmon farms would not exceed 1% (see Section 4.4.1).

Therefore, it was concluded that the potential magnitude of consequences to the diversity Fraser River Sockeye Salmon would be **negligible** over two generations (eight years) given the lack of infection on farms in some years (three of eight) and the very low probability of population mortality (<1%) in years with the evidence of infection on farms (five of eight). This conclusion was made with **reasonable uncertainty** given reliance on a single study for prevalence of infection (based on molecular detection) and the use of surrogate data for mortality, and the uncertainty regarding the susceptibility of Fraser River Sockeye Salmon to infection with *T. maritimum*.

5 RISK ESTIMATION

5.1 ABUNDANCE

The risk to the abundance of Fraser River Sockeye Salmon due to infections with *T. maritimum* attributable to Atlantic Salmon farms in the Discovery Islands area (Table 17) was estimated using the risk matrix combining the results of the likelihood assessment and the results of the consequence assessment to Fraser River Sockeye Salmon abundance (Figure 3).

Table 17. Risk estimation to the abundance of Fraser River Sockeye Salmon resulting from Tenacibaculum maritimum *attributable to Atlantic Salmon farms located in the Discovery Islands area under current farm practices.*

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

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

5.2 DIVERSITY

The risk to the diversity of Fraser River Sockeye Salmon due to infections with *T. maritimum* attributable to Atlantic Salmon farms in the Discovery Islands area (Table 18) was estimated using the risk matrix combining the results of the likelihood assessment and the results of the consequence assessment to Fraser River Sockeye Salmon diversity (Figure 4).

Table 18. Risk estimation to the diversity of Fraser River Sockeye Salmon resulting from Tenacibaculum maritimum *attributable to Atlantic Salmon farms located in the Discovery Islands area under current farm practices.*

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

It was concluded that, under the current farm practices, the risk to the diversity of Fraser River Sockeye Salmon as a result of a *T. maritimum* 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). Main uncertainties in this risk assessment are related to both the likelihood and consequence assessments.

The main uncertainty in this risk assessment relates to the susceptibility of Sockeye Salmon to infection with *T. maritimum.* To date, evidence of the pathogen in Sockeye Salmon is limited to its molecular detection. There is no evidence of *T. maritimum* isolation or clinical signs attributed to the pathogen in Sockeye Salmon. Taking a conservative approach in this risk assessment, Sockeye Salmon were assumed to be susceptible to infection with *T. maritimum*. Other uncertainties in the likelihood and consequence assessments are listed below.

6.1 LIKELIHOOD ASSESSMENT

Given the combination rules (section 2.2.5.4), the overall ranking of the likelihood assessment was determined by the infection assessment ranking. Uncertainties related to this step are therefore the most relevant to this risk assessment.

The main uncertainties in the infection assessment are due to lack of knowledge (i) to estimate the *T. maritimum* infection pressure attributable to Atlantic Salmon farms (given that the prevalence of the bacterium on farms and the shedding rates from *T. maritimum*-infected Atlantic Salmon in BC are unknown); and (ii) to determine the minimum infectious dose of *T. maritimum* in Sockeye Salmon.

Given the limited and short direct interaction of Fraser River Sockeye Salmon with farm sites, we concluded that infection with *T. maritimum* would "occasionally" occur. However, given the lack of knowledge and reliance on data in surrogate species, this ranking was made with high uncertainty.

The ranking for the likelihood of infection should be reviewed if and when the above knowledge gaps are addressed. Revised rankings could either be higher or lower than the current one. For instance, if Sockeye Salmon were shown to be more susceptible than Atlantic Salmon to infection with *T. maritimum*, the likelihood of infection would be increased and vice versa.

6.2 CONSEQUENCE ASSESSMENT

The main uncertainties in the consequence assessment are related to the lack of knowledge about (i) the susceptibility of Sockeye Salmon to infection with *T. maritimum* and development of mouthrot; (ii) the true prevalence of *T. maritimum* in migrating Fraser River Sockeye Salmon attributable to Atlantic Salmon farms in the Discovery Islands area (as explained above); and (ii) the mortality rate attributable to infection with *T. maritimum* in Sockeye Salmon.

The prevalence of *T. maritimum* infection in migrating Fraser River Sockeye Salmon attributable to Atlantic Salmon farms in the Discovery Islands area was estimated based on the molecular detection prevalence of the bacterium in Fraser River Sockeye Salmon sampled along their out-migration route. Given that those estimates relied only on a single study, two scenarios were developed to explore the consequences, including a worst-case scenario for the infection.

The mortality rate attributable to infection with *T. maritimum* in Sockeye Salmon was estimated based on mortality reported in farmed salmonids as surrogate rates, which is considered to represent a worst-case scenario (i.e., an overestimation of mortality) given the difference in the density and duration of exposure to the bacterium between wild and farmed populations.

The current state of knowledge is also not sufficient to quantify the sublethal impacts of infection with *T. maritimum* in wild salmon. To address this, all infected fish were assumed to die, representing a worst-case scenario and providing overestimation of the sublethal effects.

Finally, stock-specific data on the infection prevalence and mortality rates are not available. Therefore, it was assumed all stocks have the same susceptibility to the infection and its potential consequences. In general, under the worst-case scenario, the mortality estimates were very low; hence, we did not expect that this source of uncertainty would affect our final conclusions of the long-term risk estimation.

7 CONCLUSIONS

The assessment concluded that *T. maritimum* 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 attribution of the minimal risk was mainly influenced by two factors. First, it is unlikely that juvenile and very unlikely that adult Fraser River Sockeye Salmon would become infected with *T. maritimum* attributable to Atlantic Salmon farms in the Discovery Islands area given that mouthrot mainly affects farmed Atlantic Salmon smolts; that the disease has rarely been reported in farmed Pacific salmon suggesting a relatively low susceptibility; and that Fraser River Sockeye Salmon have limited and short interaction with Atlantic Salmon farms in the Discovery Islands area. Second, based on the detection prevalence of *T. maritimum* in juvenile Fraser River Sockeye Salmon, infection with the bacterium attributable to Atlantic Salmon farms in the Discovery Islands area is expected to result in negligible impacts to Fraser River Sockeye Salmon abundance and diversity.

Uncertainty remains around the susceptibility of Sockeye Salmon to infection with *T. maritimum* and the long-term impacts of a sublethal infection in specific and vulnerable stocks of Fraser River Sockeye Salmon that may have repeated exposures to infected farms over consecutive years. The important sources of uncertainty were evaluated and documented with the likelihood rankings and final conclusions, adopting a conservative approach. The conclusions of this risk assessment should be revised as new and relevant information becomes available.

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9 APPENDIX

This appendix expands on the quantitative approach used to estimate mortality in juvenile Fraser River Sockeye Salmon resulting from infection with *T. maritimum* attributable to Atlantic Salmon farms in the Discovery Islands area and includes the distributions mentioned in the consequence assessment.

The probability distribution of mortality in juvenile Fraser River Sockeye Salmon attributable to infection with *T. maritimum* was generated as the product of distributions representing (1) the estimated prevalence of infection in the juveniles and (2) the surrogate mortality rate from farmed fish.

Beta distribution is commonly used to propagate uncertainty about proportions (e.g., prevalence estimates) in quantitative risk analysis (Vose, 2008) and was therefore applied to propagate the uncertainty measurement about the estimated prevalence of *T. maritimum* infection in the juveniles. This distribution has two shape parameters of ‘a’ and ‘b’. The Beta distribution is the conjugate prior (i.e., it has the same functional form) to the Binomial likelihood function in Bayesian inference and, as such, is often used to describe the uncertainty about a binomial probability, given a number of trials ‘n’ have been made with a number of recorded successes ‘s’. In these situations, ‘a’ is set to the value (s + x) and ‘b’ is set to (n - s + y), where Beta(x, y) is the prior (Vose, 2008). Because no information on the prevalence of infection with *T. maritimum* in juvenile Sockeye Salmon was available prior to the study by Nekouei et al. (2018), an uninformative prior was used (i.e., x = 1 and y = 1). In applying the Beta distribution to this risk assessment, ‘n’ is the number of sampled fish and ‘s’ is the number of positive detections; therefore, parameter ‘a’ is the number of positive samples + 1; and ‘b’ is the number of negative samples + 1.

The Pert distribution is used for modeling expert estimates, where one is given the expert's minimum, most likely and maximum estimates (Vose, 2008). Given the limited available data to estimate mortality attributable to mouthrot, a Pert distribution was applied to propagate the measurement uncertainty around this parameter. Pert distribution is a version of the Beta distribution and requires three parameters: minimum (a), mode (b) and maximum (c) (similar to a triangle distribution). In our case, these parameters were extracted from the only available study by Frelier et al. (1994).

The Beta and Pert distributions were multiplied to produce probability distributions for the potential mortality in juvenile Fraser River Sockeye Salmon under the two scenarios.

9.1 SCENARIO 1

Scenario 1 used 0.66% (5/758) for the prevalence of infection with *T. maritimum* in juvenile Fraser River Sockeye Salmon (the weighted average of 5/208 in 2012 and 0/550 in 2013 where denominators are number of samples taken from the Discovery Islands area and further north; O. Nekouei, pers. comm., 2019). Consequently, the estimated prevalence of *T. maritimum* infection attributed to Atlantic Salmon farms in the Discovery Islands area is represented by Beta(6, 754). The cumulative mortality attributable to mouthrot on the farms at the cage-level ranged between 0 and 30%, with a presumptive mode of 10% (Frelier et al., 1994). These estimates were represented by Pert(0, 0.1, 0.3). Figure 10 illustrates the above distributions and their product representing the potential mortality in juvenile Fraser River Sockeye Salmon under this scenario.

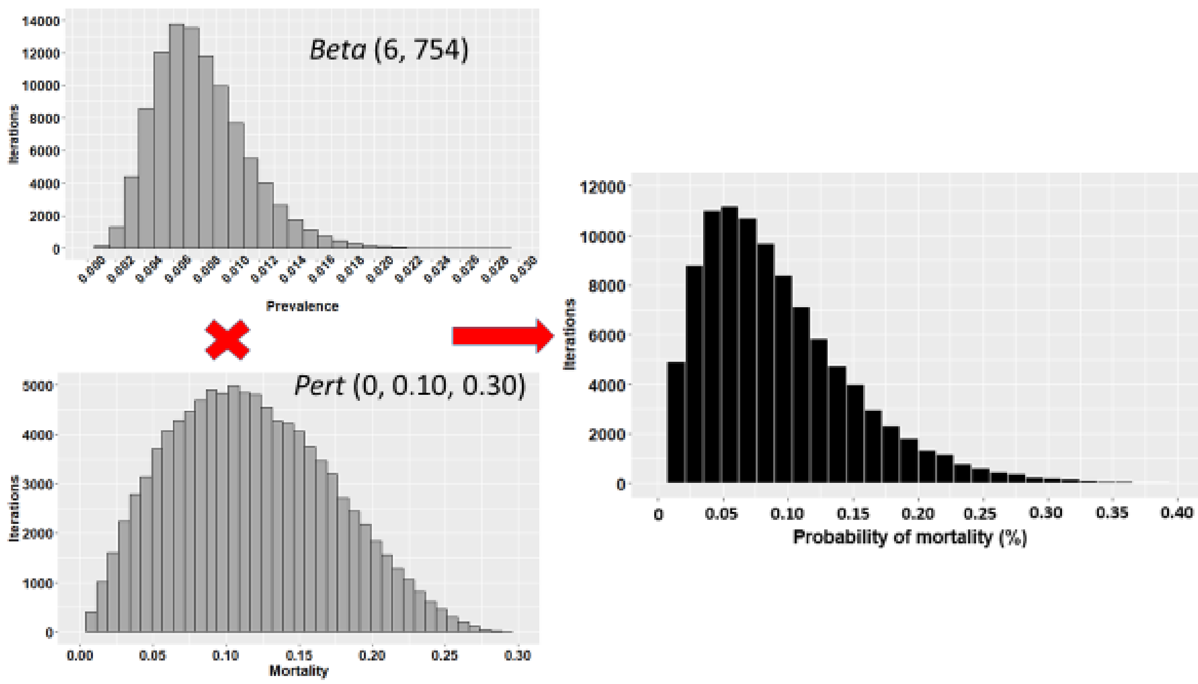

Figure 10. Probability distributions under Scenario 1. Beta(6, 754) represents the estimated prevalence of infection with Tenacibaculum maritimum*; five detections out of 758 juvenile Fraser River Sockeye Salmon sampled from the Discovery Islands area and after (towards Haida Gwaii) in 2012 and 2013; (2) Pert(0, 0.1, 0.3) represents the proportions of mortality attributable to mouthrot on the farms which ranged between 0 and 30% with a presumptive mode of 10% (surrogate information); and (3) the product of these two distributions representing the probability distribution for the potential mortality in juvenile Fraser River Sockeye Salmon attributable to* T. maritimum *on Atlantic Salmon farms in the Discovery Islands area under current farm practices. The distributions were generated in R (version 3.5.2) using 100,000 iterations.*

9.2 SCENARIO 2

Scenario 2 used 2.4% (5/208) for the prevalence of infection with *T. maritimum* in juvenile Fraser River Sockeye Salmon based on the positive detections collected from the Discovery Islands area and further north in 2012 only. Consequently, the estimated prevalence of *T. maritimum* infection attributed to Atlantic Salmon farms in the Discovery Islands area is represented by Beta(6, 204). The cumulative mortality attributable to mouthrot on the farms is the same as the one used in Scenario 1, represented by Pert(0, 0.1, 0.3). Figure 11 illustrates the above distributions and their product representing the potential mortality in juvenile Fraser River Sockeye Salmon under this scenario.

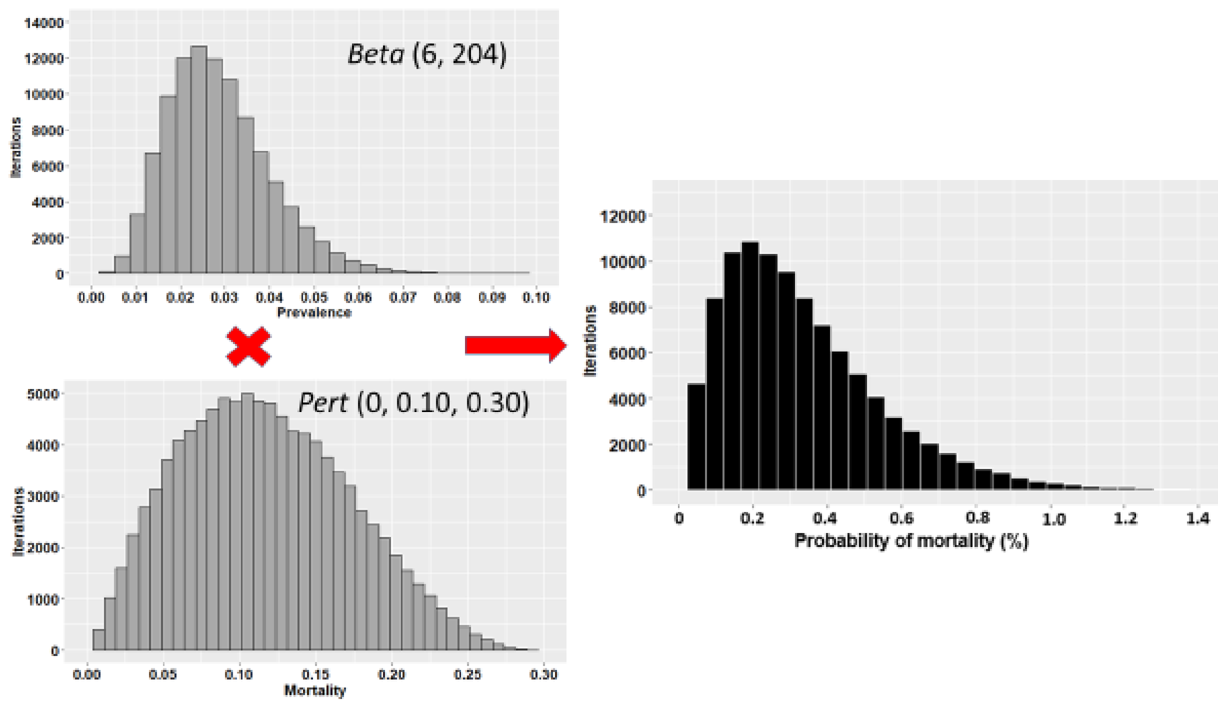

Figure 11. Probability distributions under Scenario 2.Beta(6, 204) represents the estimated prevalence of infection with Tenacibaculum maritimum*; five detections out of 208 juvenile Fraser River Sockeye Salmon sampled from the Discovery Islands area and after (towards Haida Gwaii) in 2012; (2) Pert(0, 0.1, 0.3) represents the proportions of mortality attributable to mouthrot on the farms which ranged between 0 and 30% with a presumptive mode of 10% (surrogate information); and (3) the product of these two distributions representing the probability distribution for the potential mortality in juvenile Fraser River Sockeye Salmon attributable to* T. maritimum *on Atlantic Salmon farms in the Discovery Islands area under current farm practices. The distributions were generated in R (version 3.5.2) using 100,000 iterations.*