Fisheries and Oceans Canada | Pêches et Océans Canada
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National Capital Region

Canadian Science Advisory Secretariat
Science Advisory Report 2019/018

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

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

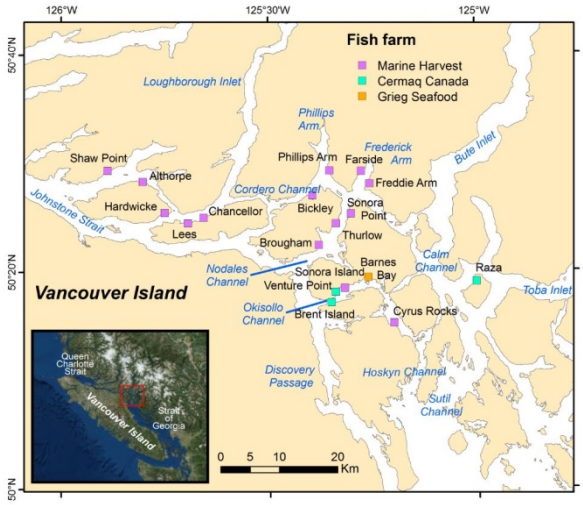

Figure 1. Locations of the 18 Atlantic Salmon farms in the Discovery Islands area stocked at least once between 2010 and 2016.

Context:

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

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

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

agent of bacterial kidney disease (BKD) and Yersinia ruckeri the causative agent of enteric redmouth disease (ERM). These bacterial pathogens are known to cause disease and have been reported by the industry and/or have been diagnosed through the DFO Fish Health Audit and Surveillance Program on Atlantic Salmon farms in the Discovery Islands area between 2002–2016. The risks associated with other pathogens also known to cause disease on marine Atlantic Salmon farms in the Discovery Islands area will be assessed in subsequent processes.

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

SUMMARY

Yersinia ruckeri Transfer Risk Assessment

- The assessment was conducted using farm-related data from 2002–2017, the current fish health management practices, and considering relevant scientific information.
- The assessment concluded that *Y. ruckeri* attributable to Atlantic Salmon (*Salmo salar*) farms operating in the Discovery Islands area poses minimal risk to Fraser River Sockeye Salmon (*Oncorhynchus nerka*) abundance and diversity. During this assessment uncertainties were evaluated at each step and ranged from reasonable certainty to high certainty (see below and Table 1).
- Two main factors influenced the attribution of minimal risk:
    - it is extremely unlikely that at least one Sockeye Salmon would become infected with *Y. ruckeri* released from an Atlantic Salmon farm in the Discovery Islands area. because *Y. ruckeri* is primarily a freshwater pathogen (low survival in saltwater); and
    - even in the extremely unlikely event that wild Sockeye Salmon would become infected with *Y. ruckeri* due to Atlantic Salmon farms in the Discovery Islands area, the magnitude of consequences to both Fraser River Sockeye Salmon abundance and diversity would be negligible because the infection would not be expected to spread within wild populations.
- The overall likelihood assessment, including separate farm infection, release, exposure, and infection assessments, was supported by the following key findings:
    - *Yersinia ruckeri* is primarily a freshwater trout pathogen with survival greatly reduced in the marine environment;
    - limited presence of *Y. ruckeri* and/or enteric redmouth disease (ERM) on Atlantic Salmon farms in the Discovery Islands area (4 of 16 years);
    - Atlantic Salmon are susceptible to *Y. ruckeri* infections and ERM;
    - there is no information on Sockeye Salmon susceptibility;
    - *Yersinia ruckeri* has been isolated from Sockeye Salmon, but disease or outbreaks have not been confirmed in either freshwater or in seawater;
    - there is temporal overlap of out-migrating juvenile lake-type Fraser River Sockeye Salmon with reports of *Y. ruckeri* on farms in the Discovery Islands area; however, there is no temporal overlap with adults.
- Uncertainty: Certainty in this risk assessment is limited by the lack of knowledge about:

  - the persistence, infectivity and virulence of *Y. ruckeri* in seawater or, in salmonids in BC once outside of freshwater;
  - shedding rates in *Y. ruckeri* infected Atlantic Salmon;
  - the susceptibility, and the minimum infectious and lethal doses of *Y. ruckeri* in Sockeye Salmon.

- For the purpose of the risk assessment, a number of key assumptions were made:
  - positive detection of the pathogen on an Atlantic Salmon farm in the Discovery Islands area is evidence of *Y. ruckeri* infection on that farm;
  - infected Atlantic Salmon shed *Y. ruckeri* into the surrounding environment;
  - Sockeye Salmon are susceptible to *Y. ruckeri;* and
  - current management practices are followed and will be maintained, including vaccination in hatcheries supplied with surface water, surveillance for early detection and biosecurity measures.

Characterization of *Yersinia ruckeri* and enteric redmouth disease (ERM)

- Infection with *Y. ruckeri* can lead to the development of ERM in a broad range of host-species including several salmonid and non-salmonid species, but primarily in freshwater.
- Rainbow Trout (*O. mykiss*) is considered to be the most susceptible species to *Y. ruckeri* and Atlantic Salmon considered less susceptible. All salmonid life history stages are susceptible, but the disease is most acute in Rainbow Trout fry and fingerlings (freshwater) and presents as chronic in older larger fish.
- *Yersinia ruckeri* is horizontally transmitted, therefore, susceptible fish can become infected through contact with infected fish, contaminated water and/or contaminated equipment.
- The incubation period of *Y. ruckeri* reported in Rainbow Trout and Atlantic Salmon ranges from 5 to 10 days at 13–15 ^{o}C under experimental conditions conducted in freshwater. There are no available saltwater immersion challenges, and no studies on Sockeye Salmon.
- Under experimental conditions, carrier fish (steelhead trout (*O. mykiss*)) did not shed enough bacteria to cause infection in other steelhead trout unless they were stressed.
- Minimum infectious or lethal doses of *Y. ruckeri* in Sockeye Salmon have not been determined.
- There are no morbidity or mortality data associated with *Y. ruckeri* infection in wild fish.
- The survival of *Y. ruckeri* in the aquatic environment is dependent on salinity. *Y. ruckeri* has been reported to survive in saltwater for up to 32 days (Barnes, 2011). At lower salinities (0–20 ppt), *Y. ruckeri* has been reported to survive for four months.

INTRODUCTION

This risk assessment was conducted under the DFO Aquaculture Science Environmental Risk Assessment Initiative, implemented as a structured approach to provide risk-based science advice to further support sustainable aquaculture in Canada. Risk assessments conducted under this initiative follow the Aquaculture Science Environmental Risk Assessment Framework which is consistent with international and national risk assessment frameworks (GESAMP, 2008; ISO, 2009). Details about the initiative and the framework are available on the DFO Aquaculture Science Environmental Risk Assessment Initiative webpage. All risk assessments

conducted under the Initiative are science-based and do not include socio-economic considerations.

This advisory report is one of four summarizing the consensus advice developed during the November 6–8, 2018 Canadian Science Advisory Secretariat (CSAS) scientific peer-review meeting that included international and national scientific experts. The information and current scientific knowledge about *Y. ruckeri* and the risk assessment were summarized and reviewed in the following documents:

- The characterization of *Yersinia ruckeri* and enteric redmouth disease (ERM) to inform pathogen transfer risk assessments in British Columbia (Wade, 2019).
- Assessment of the risk to Fraser River Sockeye Salmon due to *Yersinia ruckeri* on Atlantic Salmon farms in the Discovery Islands area, British Columbia (Mimeault et al., 2019).

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

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

ANALYSIS

Characterization of *Yersinia ruckeri* and enteric redmouth disease (ERM)

Yersinia ruckeri is an opportunistic, gram-negative enterobacterium that causes enteric redmouth disease (ERM), a septicemic bacterial disease. It rarely causes disease in healthy, unstressed fish. ERM is primarily a freshwater disease of salmonids, although it has been found in some marine fish species.

The following information, unless otherwise stated, refers to *Y. ruckeri* and ERM in freshwater.

ERM is primarily a freshwater disease of salmonids, although it has been found in some marine fish species. ERM is considered one of the most significant diseases of freshwater trout aquaculture, as outbreaks are common in Rainbow Trout. Although it is most often reported in freshwater species or freshwater life history stages (i.e., parr), it can also occur in saltwater. ERM has been reported to occur in Atlantic Salmon smolts 3–6 weeks post saltwater transfer (Carson and Wilson, 2009). Outbreaks are common in Rainbow Trout. Outbreaks have occurred in freshwater in Atlantic Salmon and have occurred in saltwater in farmed Atlantic Salmon in BC. *Y. ruckeri* has been isolated and disease reported from 1–3 kg Atlantic Salmon from a marine farm in Norway (Sparboe et al., 1986) and *Y. ruckeri* has been isolated from one wild Atlantic Salmon found in freshwater after spending two years at sea in Scotland (Petrie et al., 1996). Outbreaks could not be confirmed in Sockeye Salmon; however, *Y. ruckeri* has been isolated from Sockeye Salmon, but it is not known if the isolates were from fish in the freshwater or marine life history phases (Wade, 2019).

Temperature and salinity greatly affect the establishment and severity of infection. The disease has been reported to be most contagious when water temperatures are between 15–20 ºC; this is presumed to refer to freshwater species as mortalities can be reduced by increasing salinity (e.g., from 96.5% mortality in freshwater to 75% mortality in 9 ppt water (Altinok and Grizzle, 2001)).

Incubation period varies depending on the virulence of the strain, environmental conditions and species. Chronically infected fish can be carriers of *Y. ruckeri*, periodically shedding pathogen into the water and therefore serving as a reservoir for infection. However, it has been demonstrated in steelhead trout that unless stressed, known carriers did not transmit *Y. ruckeri*. There are no data available on estimated bacterial shedding rates from *Y. ruckeri*-infected fish.

Yersinia ruckeri spreads horizontally between fish by direct contact with infected fish, contaminated water and/or contaminated equipment (Tobback et al., 2007; Eissa et al., 2008). *Y. ruckeri* can survive for many months in water (fresh or brackish) and sediments after an outbreak; and it can be isolated from sewage and biofilms on hard surfaces (Dudley et al., 1980; Coquet et al., 2002; Tobback et al., 2007). Survival in water is sensitive to temperature and salinity where survival is greatest in salinities less than 15 ppt and at lower temperatures (i.e., 6 ºC vs.18 ºC) (Diler and Ekici, 2003; Karatas et al., 2004).

Although ERM can often be prevented, it is primarily controlled with antibiotics and vaccines, and to a lesser extent, immunostimulants and probiotics. In BC, vaccination of Atlantic Salmon for ERM varies among companies depending on water sources and clinical history of hatcheries. Ermogen® (manufactured by Elanco) is the only *Y. ruckeri* vaccine licenced for use in Canada; however, it was not possible to obtain efficacy data as it is proprietary.

Occurrence on Atlantic Salmon farms in BC

In order to complete the risk assessment, disease data were collated from various sources and analyzed. DFO collects pathogen related data in three different forms as a requirement of licence including: Fish Health Event (FHE) data, audit data and mortality events. See Wade (2017) for further details regarding these three sources of data. In addition to these sources of data, fish health and environmental data were provided by industry to DFO under a confidentiality agreement for the risk assessment. These are data which industry collect for their own farm management but are not required to report to DFO.

Between 2002 and the end of 2017, five FHEs attributed to ERM were reported on Atlantic Salmon farms in BC. Between 2002 and the end of 2016, there were six farm-level diagnoses of ERM in BC, one of which occurred on a farm in the Discovery Islands area.

Yersinia ruckeri Transfer Risk Assessment

Mimeault et al. (2019) provide the complete assessment of the risk to Fraser River Sockeye Salmon abundance and diversity, under current fish health management practices, due to *Y. ruckeri* transferred from Atlantic Salmon farms in the Discovery Islands area of BC. The elements most relevant are summarized here.

Current fish health management practices include regulatory requirements (e.g., Salmonid Health Management Plan (SHMP) and accompanying proprietary Standard Operating Procedures (SOPs) and regulation of movement of live fish) and additional voluntary industry practices (e.g., vaccination and additional surveillance and testing).

Conceptual model

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

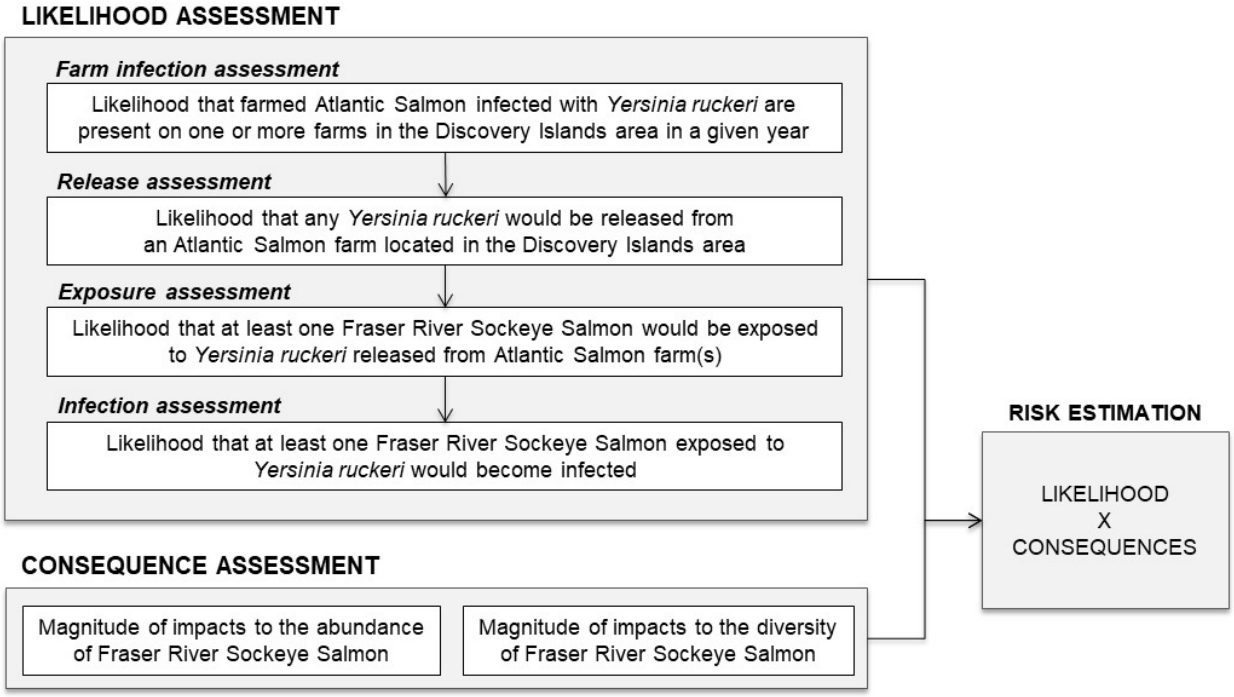

Figure 2. Conceptual model for risk assessment of Yersinia ruckeri *transfer from Atlantic Salmon farms located in the Discovery Islands area, BC. Adapted from (Mimeault et al., 2017) .*

Likelihood assessment

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

Farm Infection assessment

Results from industry surveillance and screening (2011–2017), the Fish Health Audit and Surveillance Program (2002–2016), FHEs (2002–2017) and mortality events (2011–2017) provide evidence that *Y. ruckeri* and/or ERM occurred at least once on a total of four Atlantic Salmon farms in the Discovery Islands area in four different years (2006, 2007, 2011, and 2014).

Given evidence of *Y. ruckeri* and/or ERM in four of 16 years (2002–2017), it was concluded with reasonable certainty that it is very unlikely that farmed Atlantic Salmon infected with *Y. ruckeri* could be present on one or more Atlantic Salmon farms in the Discovery Islands area under the current farm practices.

Release assessment

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

As Atlantic Salmon are reared in net pens and can shed *Y. ruckeri* into the surrounding environment, it was concluded with reasonable certainty that the likelihood of release into the environment from infected Atlantic Salmon is extremely likely under current management practices.

As part of licence requirements, biosecurity and biocontainment practices are specified in Salmonid Health Management Plans and associated SOPs. Low levels of operational deficiencies related to fish health on Atlantic Salmon farms in the Discovery Islands area have been documented in DFO's Fish Health Audit and Surveillance Program and summarized by Wade (2017), it was therefore concluded with reasonable certainty that the likelihood of release through vectors or fomites is unlikely under current fish health management practices.

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

Exposure assessment

The exposure assessment determined the likelihood that at least one susceptible fish would be exposed to *Y. ruckeri* in a given year, assuming that *Y. ruckeri* has been released from at least one Atlantic Salmon farm in the Discovery Islands area.

Two potential exposure groups were considered: juvenile and adult Fraser River Sockeye Salmon during migration through the Discovery Islands area.

The exposure assessment compared the temporal and spatial concurrence of *Y. ruckeri* released from Atlantic Salmon farms and Fraser River Sockeye Salmon in the Discovery Islands area.

Yersinia ruckeri has been reported on at most one Atlantic Salmon farm in the Discovery Islands area. It has been reported in the months of March, May, November and December either through the Fish Health Audit and Surveillance Program or industry surveillance and screening. No FHEs or mortality events attributed to ERM have ever been reported on Atlantic Salmon farms in the Discovery Islands area.

Juvenile lake-type Fraser River Sockeye Salmon migrate through the Discovery Islands area from approximately mid-May to mid-July (Grant et al., 2018), which overlaps with the time period when *Y. ruckeri* and/or ERM have been reported. Returning adults migrate through the Discovery Islands area from approximately late-June to early-October (Grant et al., 2018); therefore, there is no temporal overlap for returning adults.

Given the limited temporal overlap with reports of *Y. ruckeri* on farms, it was concluded with reasonable certainty that the likelihood for at least one juvenile Fraser River Sockeye Salmon to be exposed to *Y. ruckeri* released from Atlantic Salmon farm in the Discovery Islands area is very unlikely. The likelihood for at least one adult Fraser River Sockeye Salmon to be exposed

to *Y. ruckeri* from Atlantic Salmon farm located in the Discovery Islands area is extremely unlikely with reasonable certainty.

Infection assessment

The infection assessment determined the likelihood that at least one susceptible wild fish would become infected, assuming at least one susceptible wild fish has been exposed to *Y. ruckeri* released from Atlantic Salmon farm(s) operating in the Discovery Islands area.

There are no studies that estimate the minimum infectious or lethal concentrations of *Y. ruckeri* in fish through exposure routes that mimic natural transmission pathways in fresh or saltwater. However, given that *Y. ruckeri* has been detected on Atlantic Salmon farms in the Discovery Islands area without an attributable FHE (which can be used as a proxy for an outbreak), it is reasonable to assume that the waterborne *Y. ruckeri* concentration on those farms remained lower than that required to spread the disease within the Atlantic Salmon farms.

Given that Atlantic Salmon farms are considered to represent a negligible infection pressure, and that no evidence of disease in Sockeye Salmon could be confirmed, it was concluded with reasonable certainty that the likelihood of at least one juvenile or adult Fraser River Sockeye Salmon to become infected with *Y. ruckeri* released from an Atlantic Salmon farm located in the Discovery Islands area is extremely unlikely under current fish health management practices.

Overall likelihood assessment

Table 1 summarizes the likelihood assessment. It was concluded that the likelihood that juvenile or adult Fraser River Sockeye Salmon would become infected with *Y. ruckeri* attributable to Atlantic Salmon farms located in the Discovery Islands area is extremely unlikely. Refer to Mimeault et al. (2019) for more details on the combination of likelihood rankings.

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

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

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

Consequence assessment

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

Based on the likelihood assessment, it was determined that it is extremely unlikely that *Y. ruckeri* released from Atlantic Salmon farms in the Discovery Islands area would subsequently infect adult or juvenile Fraser River Sockeye Salmon. In addition, in years in which no *Y. ruckeri* infections occurred, no consequence can be attributed to the abundance and diversity of Fraser River Sockeye Salmon.

In 16 years of farm data from multiple sources, *Y. ruckeri* has not caused a Fish Health Event; and has been attributed to a farm-level diagnosis once as a result of an audit, diagnosed as a mixed etiology case with mouthrot. *Y. ruckeri* has been identified in individual farmed fish;

however, outbreaks on Atlantic Salmon farms have not occurred. Based on the diagnostic record, it is unreasonable to expect that more than one farm would be infected at a given time and that there would not be enough spread within the farmed population to cause an outbreak.

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

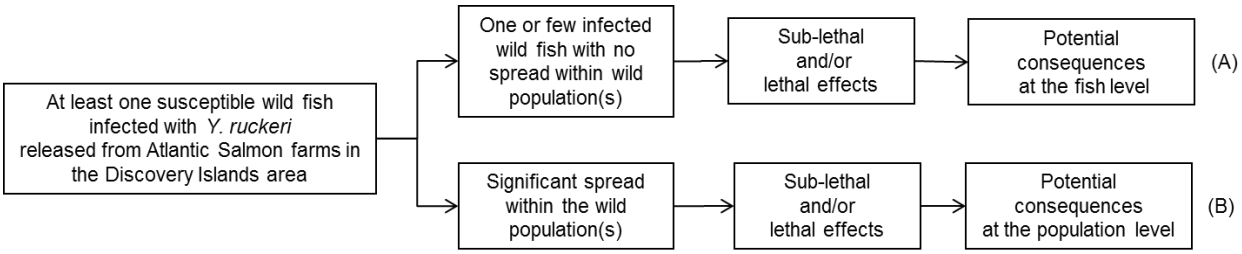

Figure 3. Potential outcomes (A and B) resulting from at least one susceptible wild fish infected with Yersinia ruckeri *released from Atlantic Salmon farms located in the Discovery Islands area.*

As *Y. ruckeri* is primarily a freshwater pathogen, that *Y. ruckeri* infections in farmed Atlantic Salmon do not appear to spread within farms in the Discovery Islands area (see infection assessment), and Fraser River Sockeye Salmon are transient in the Discovery Islands, it was concluded that it would be unreasonable to expect that a minimum infectious dose for Sockeye Salmon would be achieved. Therefore, it was concluded that no or at most, very few Fraser River Sockeye Salmon would become infected, which will lead to negligible consequences at the population level. Outcome B was therefore not considered (Figure 3). Should one or a few fish become infected, with no spread within the population, sub-lethal and/or lethal effects would result in potential consequences to the fish level (Outcome A).

As the potential consequences to Fraser River Sockeye Salmon from exposure to *Y. ruckeri* released from Atlantic Salmon farms in the Discovery Islands area was concluded to be at the individual fish level, the consequences to diversity from exposure to *Y. ruckeri* over two Sockeye Salmon generations (eight years) was considered but determined to not represent a greater potential consequence than at the fish level.

Overall, it was concluded with high certainty that the potential magnitude of consequences to the abundance and diversity of returning Fraser River Sockeye Salmon resulting from a *Y. ruckeri* infection of either juvenile or adult Fraser River Sockeye Salmon attributable to an Atlantic Salmon farm in the Discovery Islands area would be negligible under current fish health management practices.

Risk estimation

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

Under the current fish health management practices, the risk to the abundance of Fraser River Sockeye Salmon as a result of a *Y. ruckeri* infection attributable to Atlantic Salmon farms operating in the Discovery Islands area is minimal (Figure 4).

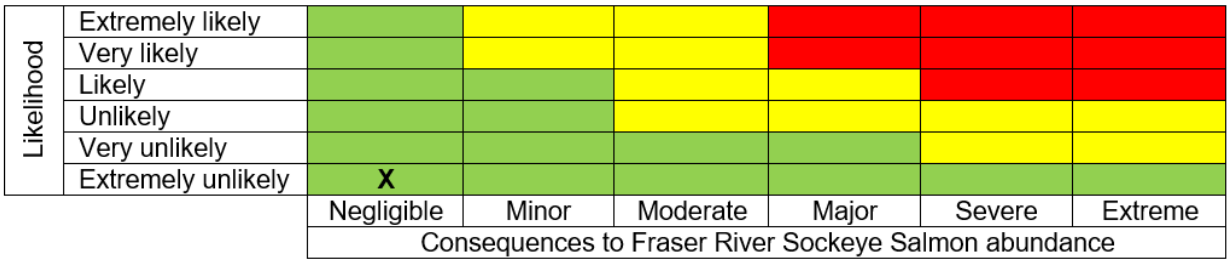

Figure 4. Risk matrix for combining the results of the assessment of the likelihood of Yersinia ruckeri *infection in Sockeye Salmon attributable to Atlantic Salmon farms in the Discovery Islands area and magnitude of consequences to Fraser River Sockeye Salmon abundance. Green, yellow and red, respectively,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

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

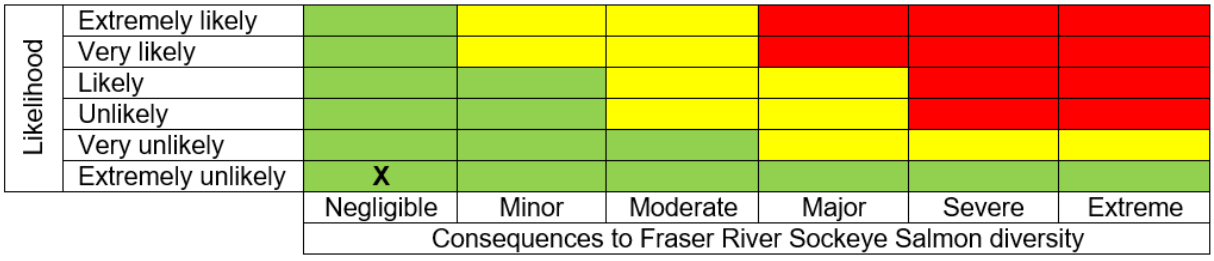

Figure 5. Risk matrix for combining the results of the assessment of the likelihood of Yersinia ruckeri *infection in Sockeye Salmon attributable to Atlantic Salmon farms in the Discovery Islands area and magnitude of consequences to Fraser River Sockeye Salmon diversity. Green, yellow and red, respectively,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

Sources of Uncertainty

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

Uncertainties in the likelihood assessment

The main uncertainties related to the likelihood assessment are attributed to the lack of information on shedding rates, the minimum infectious or lethal doses of *Y. ruckeri* in Sockeye Salmon, as well as the persistence, infectivity and virulence of *Y. ruckeri* in seawater, or in salmonids in the marine phases.

CONCLUSIONS

Characterization of *Yersinia ruckeri* and enteric redmouth disease (ERM)

Yersinia ruckeri is an opportunistic pathogen that rarely causes disease in healthy, unstressed fish. The development of ERM following exposure to *Y. ruckeri* will depend on the management, water source and vaccination history. ERM is primarily a freshwater disease of salmonids,

although it has been found in some marine fish species. Outbreaks are common in Rainbow Trout. Outbreaks have occurred in freshwater in Atlantic Salmon and in saltwater in farmed Atlantic Salmon in BC. Outbreaks could not be confirmed in Sockeye Salmon but *Y. ruckeri* has been isolated from the species; however, it is not known if the isolates were from fish in the freshwater or marine life history phases.

Temperature and salinity greatly affect the establishment and severity of infection. The disease has been reported to be most contagious when water temperatures are between 15–20 ºC; this is presumed to refer to freshwater species. An outbreak of ERM in Atlantic Salmon in sea cages in Norway was reported to occur after handling and grading at 10 ºC.

Mortalities can be greatly reduced by increasing salinity (e.g., from 96.5% in freshwater to 75% in 9 ppt water). Incubation period varies depending on the virulence of the strain, environmental conditions and species. In a bath challenge in spring water, the incubation period in Atlantic Salmon (average weight 2.15 g) at 12.5 ºC was determined to be 10 days with a mortality of 54% within 21 days. Chronically infected fish can be carriers of *Y. ruckeri*, periodically shedding pathogen into the water and therefore serving as a reservoir for infection. However, it has been demonstrated in steelhead trout that unless stressed, known carriers did not transmit *Y. ruckeri*.

Yersinia ruckeri survives well in the environment outside of a host. It can survive for many months in fresh or brackish water after an outbreak; it can also survive for many months in sediment. It can be isolated from sewage and readily forms biofilms on hard surfaces. Survival in water is sensitive to temperature and salinity. In general, survival is greatest in salinities less than 15 ppt and at lower temperatures (i.e., 6 ºC vs.18 ºC).

Yersinia ruckeri Transfer Risk Assessment

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

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

Sources of uncertainties in this risk assessment are related to the lack of knowledge of the susceptibility of Sockeye Salmon to *Y. ruckeri,* the shedding rates of *Y. ruckeri* in healthy and heavily infected Atlantic Salmon in seawater, and the infectious, lethal doses for Sockeye Salmon in the seawater.

OTHER CONSIDERATIONS

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

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

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

This risk assessment is based on current industry size and practices. If there is a change in the size or practices of the Atlantic Salmon aquaculture industry in the Discovery Islands area, further analyses or consideration in the risk estimate would be required.

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