Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

National Capital Region

Canadian Science Advisory Secretariat
Science Advisory Report 2019/019

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

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

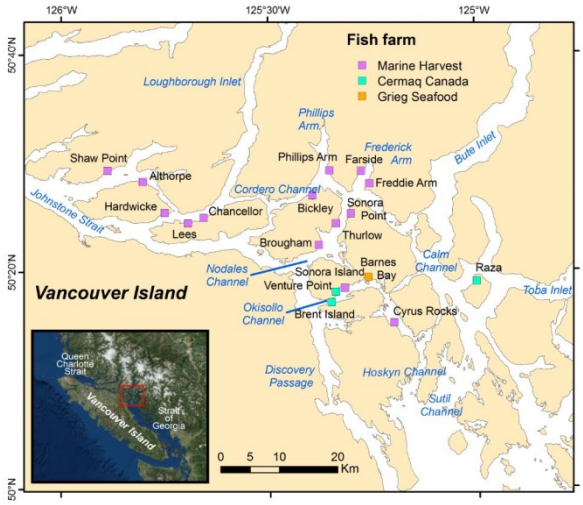

Figure 1. Locations of the 18 Atlantic Salmon farms in the Discovery Islands area stocked at least once between 2010 and 2016.

Context:

Fisheries and Oceans Canada, 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. 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 national advisory meeting on 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 Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

Renibacterium salmoninarum transfer risk assessment

- The assessment was conducted using farm-related and environmental data from 2002–2017, based on the current fish health management practices, and considering relevant scientific information.
- The assessment concluded that *R. salmoninarum* 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 high uncertainty to high certainty (see bullets below and Table 1).
- Two main factors influenced the attribution of minimal risk:
    - in the likelihood steps, it was determined that it is extremely unlikely that Fraser River Sockeye Salmon would become infected with *R. salmoninarum* released from an Atlantic Salmon farm in the Discovery Islands area with uncertainties ranging from high certainty to reasonable uncertainty; and
    - in the consequence steps, it was determined in the very unlikely event that Fraser River Sockeye Salmon would become infected with *R. salmoninarum* due to Atlantic Salmon farms in the Discovery Islands area, the infection would not be expected to spread within wild populations, hence the magnitude of consequences to both Fraser River Sockeye Salmon abundance and diversity would be negligible. The associated uncertainty ranged from reasonable uncertainty to high uncertainty.
- The overall likelihood assessment, including separate farm infection, release, exposure, and infection assessments, was supported by the following key findings:
    - *Renibacterium salmoninarum* and/or bacterial kidney disease (BKD) has been detected on Atlantic Salmon farms in the Discovery Islands area;
    - Sockeye, Chinook (*O. tshawytscha*), Chum (*O. keta*), Coho (*O. kisutch*), Pink (*O. gorbuscha*) and Atlantic salmon are susceptible to *R. salmoninarum* infections and BKD;
    - there is a temporal overlap of migrating juvenile and adult Fraser River Sockeye Salmon and other susceptible Pacific salmon species (Coho, Chinook Chum and Pink salmon) with reports of *R. salmoninarum* on farms in the Discovery Islands area;
    - it was estimated that the potential maximum *R. salmoninarum* waterborne concentrations in net pens were two orders of magnitude below the lowest reported infectious doses for *R. salmoninarum* in Chinook Salmon (Rhodes and Mimeault, 2019).

- Uncertainty: Certainty in this assessment is limited by the lack of knowledge about:
    - how long and how close populations of wild juvenile and adult Pacific salmon are in the vicinity of Atlantic Salmon farms;
    - the prevalence of *R. salmoninarum*-infected Atlantic Salmon on farms in the Discovery Islands area;
    - shedding rates of *R. salmoninarum* infected farmed Atlantic Salmon;
    - the minimum infectious and lethal doses of *R. salmoninarum* for Sockeye Salmon;
    - the proportion of the wild susceptible fish population that would be exposed and become infected with *R. salmoninarum* released from an Atlantic Salmon farm in the Discovery Islands area;
    - BKD mortality in wild Sockeye Salmon and other susceptible Pacific salmon species;
    - the consequences to the abundance and diversity of Fraser River Sockeye Salmon from sub-lethal effects of *R. salmoninarum* infection; and
    - the consequences to subsequent generations related to presence of *R. salmoninarum* in spawning populations.
- 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 *R. salmoninarum* infection on that farm;
    - infected Atlantic Salmon shed *R. salmoninarum* into the surrounding environment;
    - the minimum infectious dose and exposure time for Chinook Salmon was used as a proxy for the minimum infectious dose and exposure time for Sockeye Salmon; and
    - current management practices are followed and will be maintained, including broodstock screening, surveillance for early detection and biosecurity measures.

Additionally, this risk assessment was informed by a summary of the current state of knowledge related to *R. salmoninarum* and BKD (Rhodes and Mimeault, 2019) of which the most relevant elements are summarized below.

Characterization of *Renibacterium salmoninarum* and bacterial kidney disease (BKD)

- Infection with *R. salmoninarum* can lead to the development of BKD in a broad range of salmonids.
- Sockeye, Chinook, and Chum salmon are considered most susceptible to *R. salmoninarum*, Coho and Atlantic salmon are considered to have an intermediate susceptibility and Lake, Brown, Bull and Rainbow and steelhead trout are considered the least susceptible. There are insufficient data to assign different susceptibilities to different life history stages.
- *Renibacterium salmoninarum* is both horizontally and vertically transmitted. Therefore, susceptible fish can become infected through contact with infected fish, contaminated water and/or contaminated equipment, as well as become infected with *R. salmoninarum* passed from female to ova.
- The incubation period *of R. salmoninarum* in Chinook Salmon under experimental conditions in freshwater ranges from 80 days to 12 months as reported in Chinook Salmon under experimental conditions conducted in freshwater. There are no available seawater immersion studies.

- The highest level of mean shedding by individual juvenile Chinook Salmon challenged with *R. salmoninarum* were estimated to be 6.5 x 10^6 and 3.1 x 10^6 cells per fish per hour at 8°C and 12°C, respectively (Purcell et al., 2016).
- Minimum infectious or lethal doses of *R. salmoninarum* for Sockeye Salmon have not been determined.
- In Chinook Salmon fry in freshwater, the lowest concentration of *R. salmoninarum* to cause infection is 7 x 10^8 cells/m^3 at a 24-hour exposure; the lowest concentration required to cause mortality is 3 x 10^{10} cells/m^3 when exposed for 15 minutes.
- BKD has been reported in wild salmonids.
- The survival of *R. salmoninarum* in the marine environment varies and depends on temperature and nutrient availability. *R. salmoninarum* has been reported to survive in raw seawater for seven days at 10°C although viability was reduced to and remained at 1% after 24 hours.

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 do not include socio-economic considerations.

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

- The characterization of *Renibacterium salmoninarum* and bacterial kidney disease (BKD) to inform pathogen transfer risk assessments in British Columbia (Rhodes and Mimeault, 2019); and
- Assessment of the risk to Fraser River Sockeye Salmon due to *Renibacterium salmoninarum* 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 address the following objectives of the meeting, specifically:

- Review the qualitative risk assessment on Fraser River Sockeye Salmon abundance and diversity due to *R. salmoninarum* transferred 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 pathogen transfer from Atlantic Salmon farms in the Discovery Islands area.

ANALYSIS

Characterization of *Renibacterium salmoninarum* and bacterial kidney disease (BKD)

Bacterial kidney disease is a global disease of salmonids caused by the bacterium, *Renibacterium salmoninarum* and can be found in both freshwater and marine environments. BKD can have clinical or subclinical presentations in infected fish and can span a spectrum of manifestations, from acute to chronic. It is deemed endemic in salmonids in Canada and is an annually notifiable disease to the Canadian Food Inspection Agency (CFIA). In Sockeye Salmon, *R. salmoninarum* has been detected in 6% (25/402) of fish caught in offshore coastal waters of BC (Kent et al., 1998); in 0% (0/1530) of juvenile Fraser River Sockeye Salmon caught in the Strait of Georgia, Discovery Islands and Johnstone Strait in May and June from 2010 to 2012 (Mahony et al., 2017); and in 1 to 89% of Fraser River Sockeye Salmon in spawning condition, depending on the year and stock (Mahony et al., 2017).

Comparative studies conducted in freshwater on morbidity and mortality caused by *R. salmoninarum* in salmonids suggest that the Sockeye, Chinook and Chum salmon are more susceptible, Coho and Atlantic salmon have intermediate susceptibility, and Lake (*Salvelinus namaycush*, Brown (*S. trutta*), Bull (*S. confluentus*), Rainbow (*O. mykiss*) trout and steelhead (*O. mykiss*) are less susceptible (see summary in Rhodes and Mimeault (2019)).

Bacterial shedding rates from *R. salmoninarum*-infected or diseased Atlantic Salmon and Sockeye Salmon are unknown. There are two studies that report shedding of *R. salmoninarum* in Chinook Salmon in freshwater (McKibben and Pascho, 1999; Purcell et al., 2016). From these studies, the estimated highest mean shedding rates ranged from 2.1×10^5 (27 g fish) to 6.5×10^6 cells per fish per hour at 8°C, and 3.1×10^6 cells per fish per hour at 12°C in heavily infected (5 g) fish (refer to Rhodes and Mimeault (2019) for details). Subclinically-infected salmon and trout have also been reported to shed the bacteria (Balfry et al., 1996; Griffiths et al., 1998); shedding rates in subclinical fish have not been reported.

Minimum infectious or lethal doses of *R. salmoninarum* have not been determined. However, the lowest concentration reported to have caused infection and mortality in Chinook Salmon under laboratory conditions was used as proxy data for the minimum infectious dose in the Sockeye Salmon risk assessment. The lowest reported concentration of *R. salmoninarum* that caused infection in Chinook Salmon (weight not available) in freshwater was 7×10^2 cells/mL for 24 hours (Elliott and Pascho (1995) as cited in McKibben and Pascho (1999)). The lowest dose of *R. salmoninarum* to cause infection and mortality in Chinook Salmon (48 to 49 g) immersed for 15 minutes in freshwater was 3×10^4 cells/mL (Murray et al., 1992). Total mortality reached 5% approximately 180 days post challenge (Murray et al., 1992).

Experiments using exposure routes that are representative of natural exposure (i.e., immersion or cohabitation) are limited to freshwater. No such studies were found conducted on Sockeye or Atlantic salmon. Using the results from a study with Chinook Salmon (48–49 g), the first mortality detected at the lowest dose (3×10^4 cells/mL for 15 minutes) occurred 85 days post exposure. The cumulative mortality in this experiment reached 5% 180 days post exposure, and

15% after 350 days (Murray et al., 1992); this is indicative of the incubation period, i.e., the time between initial infection and the development of disease symptoms.

Renibacterium salmoninarum can be transmitted both horizontally and vertically. Horizontal transmission can pose an infection threat at any stage post-hatch (Balfry et al., 1996). There is evidence of density-dependent horizontal transmission in free-ranging populations of juvenile Chinook Salmon in the first six months following seawater migration (Rhodes et al., 2006; Rhodes et al., 2011). Vertical transmission, can occur at nearly all stages of ovum development, when the embryo is infected intraovum.

Survival of *R. salmoninarum* in the marine environment varies and depends on temperature, nutrient availability and initial concentration (Balfry et al., 1996). *R. salmoninarum* initial concentration of 5×10^6 cfu/mL (colony forming units (cfu) per fish per hour) has been reported to survive in raw seawater for seven days at 10ºC. Viability was reduced to approximately 40% after eight hours and approximately 1% after 24 hours and remained above 1% to seven days (Balfry et al., 1996).

The vaccine Renogen® has been shown to reduce BKD-related mortalities in Atlantic Salmon during large scale trials (Salonius et al., 2005). There is also evidence that this vaccine may limit the horizontal transmission of *R. salmoninarum* by restricting the shedding of the pathogen in Atlantic Salmon (Griffiths et al., 1998). Eleven weeks following infection, *R. salmoninarum* was detected by PCR in tank water of the control unvaccinated group but not detected in the tanks of vaccinated groups (Griffiths et al., 1998).

Occurrence on Atlantic Salmon farms in BC

Data on the occurrence of BKD on Atlantic Salmon farms in BC were obtained from Fish Health Events (FHE), Fish Health Audit and Surveillance Program (FHASP) and mortality events reports. See Wade (2017) for further details regarding these sources of data. Supplementary industry data on fish health and environmental parameters was also included in the analysis. See Wade (2017) for further details regarding these sources of data. Supplementary industry data on fish health and environmental parameters were also included in the analysis.

Between 2002 and the end of 2017, a total of 57 FHEs attributed to BKD were reported on Atlantic Salmon farms in BC. Between 2002 and the end of 2016, there were a total of 49 farm-level diagnoses of BKD from audit data in BC, 13 of which occurred on farms the Discovery Islands area. Since 2015, most of the Atlantic Salmon farmed in the Discovery Islands area have been vaccinated.

Renibacterium salmoninarum transfer risk assessment

Mimeault et al. (2019) provide the complete assessment of the risk to Fraser River Sockeye Salmon abundance and diversity due to *R. salmoninarum* transferred from Atlantic Salmon farms in the Discovery Islands area of British Columbia. The risks were assessed using fish health data and environmental conditions from 2002–2017, and applying current fish health management practices. The elements most relevant to inform the *R. salmoninarum* transfer risk assessment 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.

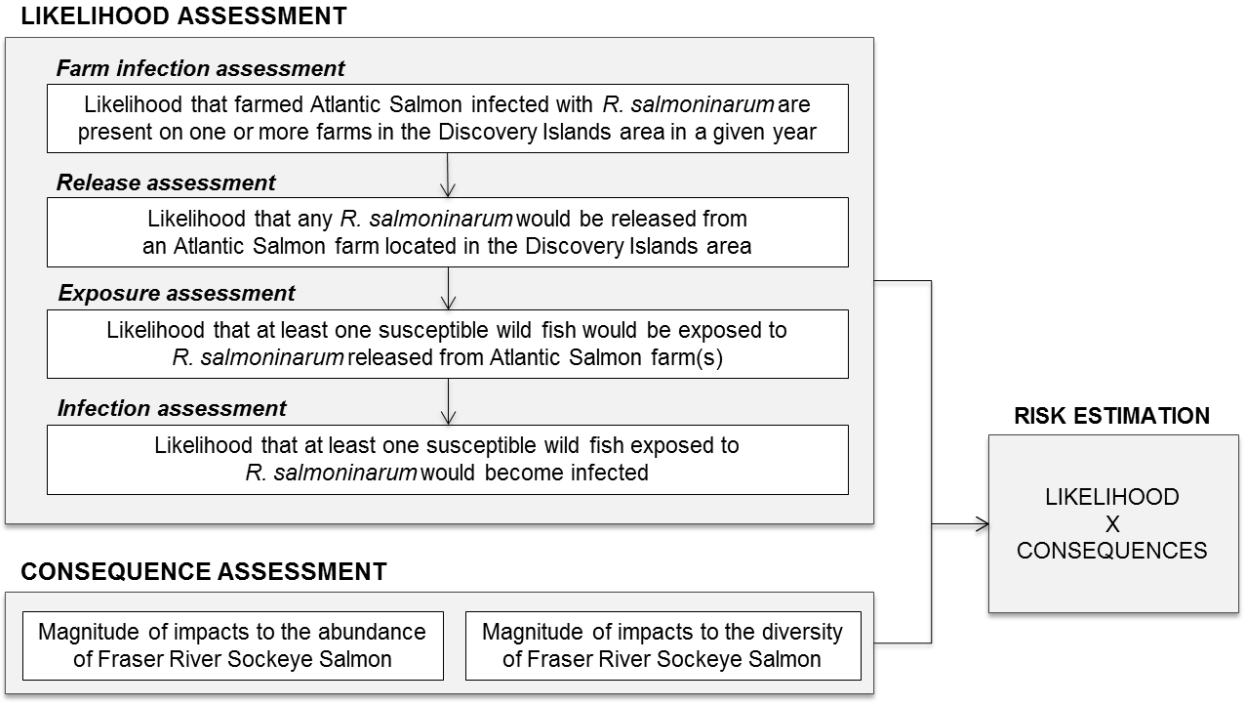

Figure 2. Conceptual model for risk assessment of Renibacterium salmoninarum *transfer from Atlantic Salmon farms located in the Discovery Islands area, BC.*

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. 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) demonstrate that there is evidence of the presence of *R. salmoninarum* and/or BKD on a total of 17 Atlantic Salmon farms in the Discovery Islands area, and on at least one farm every year between 2002 and 2017.

Given evidence of *R. salmoninarum* and/or BKD on at least one farm in all years between 2002 and 2017, it was concluded with reasonable certainty that it is very likely that farmed Atlantic Salmon infected with *R. salmoninarum* could be present on one or more Atlantic Salmon farms in the Discovery Islands area under the current farm practices.

Release assessment

The release assessment determined the likelihood that any *R. salmoninarum* 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 mechanical vectors (e.g., personnel, visitors and wildlife) and fomites (e.g., farm equipment and vessels).

Given evidence that infected Atlantic and Chinook salmon shed *R. salmoninarum* into the surrounding environment (Griffiths et al., 1998) and that Atlantic Salmon are reared in net pens, it was concluded with high certainty that the likelihood of release into the environment from infected Atlantic Salmon is extremely likely under current management practices.

Given that the relevant biosecurity practices are part of licence requirements and are specified in Salmonid Health Management Plans and related SOPs, and the low levels of operational deficiencies that could affect fish health, it was 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 *R. salmoninarum* 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 *R. salmoninarum* in a given year, assuming that *R. salmoninarum* has been released from at least one Atlantic Salmon farm in the Discovery Islands area.

Three exposure groups were considered: juvenile and adult Fraser River Sockeye Salmon, and other susceptible Pacific salmon species (Chinook, Chum, Coho and Pink salmon) occurring in the Discovery Islands area, and one exposure route (waterborne).

The exposure assessment examined whether *R. salmoninarum* infections on farms occurred during the same time period that other susceptible Pacific salmon species are known to be in the Discovery Islands area.

Renibacterium salmoninarum has been reported on at least one Atlantic Salmon farm in the Discovery Islands area in all months of the year. However, no mortality events (2011–2017) attributed to BKD have been reported 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, whereas returning adults migrate through from approximately late-June to early-October (reviewed in Grant et al. (2018)). To account for annual variations in migration timing, it was assumed that juveniles could be present in the Discovery Islands area from the beginning of May through the end of July. Similarly, for returning adults, it was assumed that adult Sockeye Salmon could be present in the Discovery Islands area from the beginning of June through to the end of October. Other susceptible Pacific salmon species can be found in the Discovery Islands area from mid-March to October (Zetterberg and Carter, 2010; Zetterberg et al., 2012) . Chinook Salmon may reside in the area all year-round (Zetterberg and Carter, 2010; Zetterberg et al., 2012). Consequently, there is potential for temporal overlap between *R. salmoninarum* released from infected Atlantic Salmon farms and all exposure groups in the Discovery Islands area.

Out of the 16 years in which evidence of *R. salmoninarum* and/or BKD has been recorded on farms since 2002, in 11 years these reports occurred during the months when juvenile Fraser River Sockeye Salmon are expected to be present in the Discovery Islands area. In 13 of the 16 years, *R. salmoninarum* and/or BKD was reported during the months when adult Fraser River Sockeye Salmon are expected to be present in the Discovery Islands area.

Given the temporal overlap with reports of *R. salmoninarum* on farms, it was concluded with reasonable certainty that the likelihood of at least one juvenile or adult Fraser River Sockeye Salmon to be exposed to *R. salmoninarum* released from Atlantic Salmon farm(s) in the Discovery Islands area is very likely.

Renibacterium salmoninarum and/or BKD has been reported in all months of the year (2002–2018) , Chinook, Chum and Coho salmon can be present at the same time as an Atlantic Salmon farm is infected.

As there is less known about the migration and residency patterns of Pacific salmon species other than Fraser River Sockeye Salmon through the Discovery Islands area, it was concluded with reasonable uncertainty that it is extremely likely for at least one individual of other susceptible Pacific salmon species other than Fraser River Sockeye Salmon to be exposed to *R. salmoninarum* released from Atlantic Salmon farms located in the Discovery Islands area.

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 *R. salmoninarum* released from Atlantic Salmon farm(s) operating in the Discovery Islands area.

The duration of exposure to Atlantic Salmon farms is not known. A recent telemetry study (Rechisky et al., 2018) reported observations with tagged Sockeye Salmon suggesting transient interactions with farm infrastructure. Further, Mimeault et al. (2017) used information about migration timing, estimates of migration speed and distance, to estimate that juvenile Fraser River Sockeye Salmon could encounter Atlantic Salmon farms over three to eight days during their migration through the Discovery Islands area.

Estimates of the concentration of *R. salmoninarum* shed from infected Atlantic Salmon were calculated using: estimated prevalence rates (3% from a survey of industry veterinarians (BC Centre for Aquatic Health Sciences (2010); a shedding rate (6.5×10^6 cells per fish per hour) derived from laboratory studies of highly infected juvenile Chinook Salmon (Purcell et al. (2016); estimated bacterial decay rate (2.3/day); the average number of fish per farm (514,000)) (data provided by DFO Aquaculture Management)); and the average farm volume (195,000 m^3) in the Discovery Islands area (Mimeault et al., 2017). Based on calculations outlined in the risk assessment (Mimeault et al., 2019), the waterborne concentration after 24 hours of constant shedding was estimated to be 1.2×10^7 cells/m^3. This is considered to be an overestimate representing a worst-case scenario as it does not account for bacterial decay and hydrodynamic dispersion.

Applying the calculated decay (2.3 per day for *R. salmoninarum* in seawater), the maximum *R. salmoninarum* waterborne concentration on an average sized Atlantic Salmon farm was estimated to be 5.6×10^5 cells/m^3 without considering hydrodynamic dispersal.

This estimated concentration is approximately 125 times lower than the 24-hr infectious concentration (7×10^8 cells/m^3) in Chinook Salmon (Elliott and Pascho, 1995), which represents the lowest infectious dose reported in Pacific salmon. The lowest lethal dose of *R.*

salmoninarum reported in Chinook Salmon is 3 x 10^{10}cells/m^3. In Rhodes and Mimeault (2019), the susceptible species were ranked: Sockeye, Chinook, and Chum (*O. keta*) salmon being the most susceptible species, Coho (*O. kisutch*) and Atlantic Salmon having an intermediate susceptibility and Lake (*Salvelinus namaycush*), Brown (*S. trutta*), Bull (*S. confluentus*) and Rainbow (*O. mykiss*) and steelhead trout (*O. mykiss*) as being the least susceptible. Given that the estimated waterborne concentration of *R. salmoninarum* on Atlantic Salmon farms is approximately 125 times lower than the lowest dose reported to cause infection in Chinook Salmon it was concluded with reasonable certainty that the likelihood of at least one Fraser River Sockeye Salmon, to become infected with *R. salmoninarum* released from Atlantic Salmon farm(s) in the Discovery Islands area through waterborne exposure is extremely unlikely.

Overall likelihood assessment

Table 1 summarizes the likelihood assessment. It was concluded that the likelihood that Atlantic Salmon farms in the Discovery Islands area release *R. salmoninarum* into an environment and subsequently expose Fraser River Sockeye Salmon and other susceptible Pacific salmon species at a concentration and for a period of time sufficient to cause infection and disease is extremely unlikely for all exposure groups. 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 Renibacterium salmoninarum *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 of farm infection**	Very likely *(reasonable certainty)*		
Release assessment	**Release pathways**	**Farmed Atlantic Salmon**	**Mechanical vectors and fomites**	
	Likelihood of release	Extremely likely *(high certainty)*	Unlikely *(reasonable certainty)*	
	Combined likelihoods of release	Extremely likely		
Exposure and infection assessments	**Exposure groups**	**Juvenile Fraser River Sockeye Salmon**	**Adult Fraser River Sockeye Salmon**	**Other susceptible Pacific salmon species**
	Likelihood of exposure	Very likely *(reasonable certainty)*	Very likely *(reasonable certainty)*	Extremely likely *(reasonable uncertainty)*
	Likelihood of infection	Extremely unlikely *(reasonable uncertainty)*	Extremely unlikely *(reasonable uncertainty)*	Extremely unlikely *(reasonable uncertainty)*
Combined exposure and infection likelihoods for each exposure group		Extremely unlikely	Extremely unlikely	Extremely unlikely
Combined likelihoods (farm infection, release, exposure and infection) for each exposure group		Extremely unlikely	Extremely unlikely	Extremely unlikely

Consequence assessment

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

Based on the likelihood assessment, it was determined that it is very likely that some Atlantic Salmon infected with *R. salmoninarum* would be present on up to four farms in the Discovery Islands area in a given year. The likelihood assessment also concluded that it was extremely unlikely for juvenile or adult Fraser River Sockeye Salmon to become infected.

Figure 3 illustrates the potential outcomes resulting from the infection of at least one susceptible wild fish with *R. salmoninarum* released from Atlantic Salmon farms located in the Discovery Islands area.

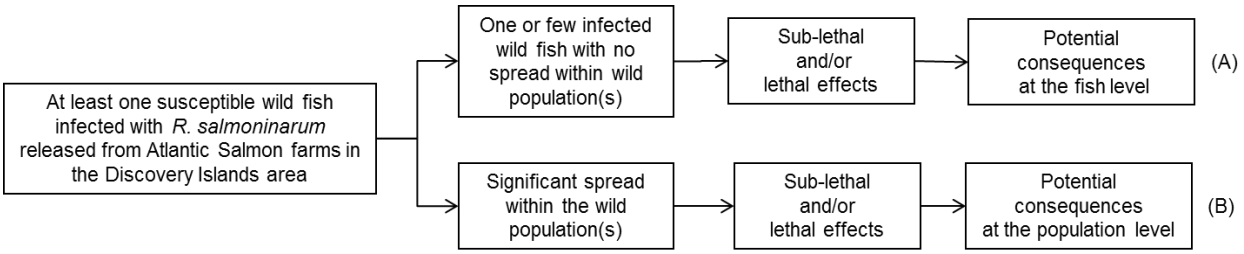

Figure 3. Potential outcomes resulting from at least one susceptible wild fish infected with Renibacterium salmoninarum *released from Atlantic Salmon farms located in the Discovery Islands area.*

Following exposure of Fraser River Sockeye Salmon to at least one farm with *R. salmoninarum* infected Atlantic Salmon in the Discovery Islands area, and using an estimate of time until acute disease development of 80 days (Chinook Salmon, (Murray et al., 1992)), any exposed juvenile Fraser River Sockeye Salmon would be expected to show signs of *R. salmoninarum* infection once in the open ocean.

The potential for the infection to spread in the population depends on the probability of susceptible individuals contacting an infectious individual. This depends, among other things, on the population density. There are no experimental data on wild fish population density during BKD epizootics. On an Atlantic Salmon farm during a BKD FHE, daily mortality is very low (0.01–0.04%) for a period of several months. This suggests limited spread at those densities (which is higher than those estimated for Sockeye Salmon in the open ocean). Therefore, should one or a few fish become infected, with limited spread within the population, sub-lethal and or lethal effects may result in consequences at the fish level (Pathway A).

It was concluded to be extremely unlikely for juvenile Fraser River Sockeye Salmon exposed to estimated concentrations of *R. salmoninarum* released from Atlantic Salmon farms with 3% of the farm population infected with *R. salmoninarum* to result in an infection that would spread and establish within the population. Consequently, it is concluded that the potential magnitude of consequences to the population abundance of Fraser River Sockeye Salmon would be negligible. Due to the reliance on surrogate data, this conclusion was made with reasonable uncertainty.

Adult Fraser River Sockeye Salmon exposed to one or more Atlantic Salmon farms with *R. salmoninarum* infected fish in the Discovery Islands area will have approximately a month between exposure and spawning. Given that the time required between exposure to a low concentration of *R. salmoninarum* from infected farms and spawning is unlikely to be long enough to allow for disease development in adult Fraser River Sockeye Salmon, it was determined that the potential magnitude of the consequence to the population abundance of Fraser River Sockeye Salmon would be negligible. This was concluded with reasonable uncertainty because of the reliance on surrogate data for the incubation time.

Since the direct magnitude of consequences to Fraser River Sockeye Salmon were determined to be negligible and there is no evidence to suggest that indirect consequences would be of higher magnitude than direct ones, it was concluded with high uncertainty that the potential magnitude of indirect consequences to both the abundance and diversity of Fraser River Sockeye Salmon resulting from a *R. salmoninarum* infection of other susceptible Pacific salmon species attributable to Atlantic Salmon farms in the Discovery Islands area would be negligible.

Impacts on diversity were considered based on a negligible (i.e., <1% reduction in return adult Fraser River Sockeye Salmon) consequence to abundance. Therefore the cumulative effect of successive years of exposure to farm-origin *R. salmoninarum* will also be negligible.

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 and policy purposes, 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 *R. salmoninarum* infection attributable to Atlantic Salmon farms operating in the Discovery Islands area is minimal (Figure 4).

Likelihood							
	Extremely likely						
	Very likely						
	Likely						
	Unlikely						
	Very unlikely						
	Extremely unlikely	X					
		Negligible	Minor	Moderate	Major	Severe	Extreme
		Consequences to Fraser River Sockeye Salmon abundance					

Figure 4. Risk matrix for combining the results of the assessment of the likelihood of Renibacterium salmoninarum *infection in wild fish 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 *R. salmoninarum* infection attributable to Atlantic Salmon farms operating in the Discovery Islands area is minimal (Figure 5).

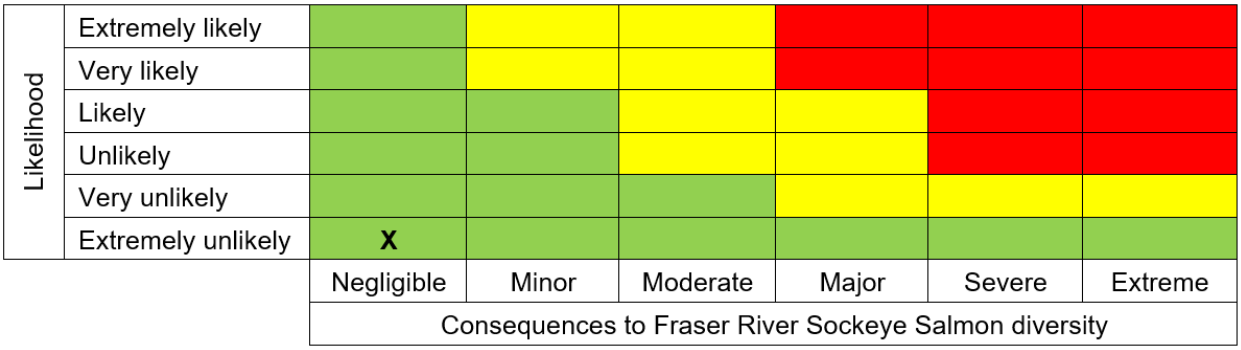

Figure 5. Risk matrix for combining the results of the assessment of the likelihood of Renibacterium salmoninarum *infection in wild fish attributable to Atlantic Salmon farms in the Discovery Islands area and magnitude of consequences to Fraser River Sockeye Salmon diversity. Green, yellow and red, 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 about the prevalence of *R. salmoninarum*-infected Atlantic Salmon on farms in the Discovery Islands area and the consequent need to rely on expert opinion collected through a survey answered by fish health professionals to estimate BKD prevalence on Atlantic Salmon farms;
- the lack of information about shedding rates in *R. salmoninarum* carriers, infected and diseased farmed Atlantic Salmon;
- the lack of information about the minimum infectious and lethal doses of *R. salmoninarum* in Sockeye Salmon;
- the variability and knowledge gaps about precise migration routes of juvenile Fraser River Sockeye Salmon in the Discovery islands area; and
- the lack of data to estimate the proportion of the population that would be exposed and infected with *R. salmoninarum* released from an Atlantic Salmon farm in the Discovery Islands area.

Uncertainties in the consequence assessment

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

- of the consequences at the individual and at the population levels resulting from sub-clinical infection with *R. salmoninarum;*

- the absence of data on BKD mortality in wild Sockeye Salmon and other wild susceptible fish;
- the need to rely on mortality rates observed during FHEs attributed to BKD on Atlantic Salmon farms in the Discovery Islands area as proxies for mortality rates in wild populations; and
- the use of incubation period from freshwater laboratory experiments with Chinook Salmon.

CONCLUSIONS

Characterization of *Renibacterium salmoninarum* and bacterial kidney disease (BKD)

Bacterial kidney disease is a global disease of salmonids caused by *Renibacterium salmoninarum* and is found in both freshwater and marine environments. BKD can have clinical or subclinical presentations in infected fish and can range from acute to chronic. *R. salmoninarum* can be transmitted both horizontally and vertically. Both symptomatic and asymptomatic fish shed the bacteria, although there are only limited available data on shedding rates in small, highly infected Chinook Salmon in freshwater, but no data from other species or in saltwater. Differential species susceptibility is reported: Sockeye Salmon are more susceptible to infection than Atlantic Salmon.

Atlantic Salmon farms in the Discovery Islands area of BC have frequently reported evidence of *R. salmoninarum* and/or BKD; however, due to factors such as the relatively slow growth rate of the bacteria and farm fish health practices, the on-farm prevalence and daily mortality rates are very low (0.01–0.04%).

Information important for informing a risk assessment is primarily derived from experiments with Chinook Salmon in freshwater. This includes information on shedding rates, minimum infectious or lethal doses, exposure duration, and mortality rates. There are no mortality data associated with *R. salmoninarum* infection in wild fish.

Renibacterium salmoninarum transfer risk assessment

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

There are considerable sources of uncertainties associated with the determination of risk to Fraser River Sockeye Salmon due to *R. salmoninarum* attributable to Atlantic Salmon farms in the Discovery Islands area, particularly as they relate to actual prevalence on farms, the extent of interactions between wild salmonid populations and farms in the Discovery Islands area, and *R. salmoninarum* infection dynamics in Sockeye Salmon.

Conclusions of this risk assessment should be reviewed as new research findings fill knowledge gaps.

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.

The application of laboratory studies of pathogens to the assessment of risk is influenced by the experimental methods and design, particularly as it relates to the determination of shedding rates and minimum infectious and lethal doses.

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, these changes would warrant further analysis or consideration in the risk estimate.

LIST OF MEETING PARTICIPANTS

Name	Affiliation
Ackerman, Paige	Fisheries and Oceans Canada
Bianucci, Laura	Fisheries and Oceans Canada
Boily, France	Fisheries and Oceans Canada
Bruneau, Nathalie	Canadian Food Inspection Agency (CFIA)
Bruno, David	Marine Scotland Science
Burgetz, Ingrid	Fisheries and Oceans Canada
Byrne, Philip	Fisheries and Oceans Canada
Fuller, Chad	First Nations Fisheries Committee of BC
Gardner, Ian	Atlantic Veterinary College UPEI
Garver, Kyle	Fisheries and Oceans Canada
Hewison, Tim	Grieg Seafood
Higgins, Mark	Fisheries and Oceans Canada
Holt, Carrie	Fisheries and Oceans Canada
Jakob, Eva	Aqua Nutrition Cargill
Johnson, Stewart	Fisheries and Oceans Canada
Jones, Simon	Fisheries and Oceans Canada
Malcolm, Gabrielle	Fisheries and Oceans Canada
Milligan, Barry	Cermaq Canada
Mimeault, Caroline	Fisheries and Oceans Canada
Olivier, Gilles	Fisheries and Oceans Canada
Parsons, Jay	Fisheries and Oceans Canada
Paylor, Adrienne	Fisheries and Oceans Canada

Name	Affiliation
Peterman, Randall	Simon Fraser University
Powell, Mark	Institute of Marine Research
Proboszcz, Stan	Watershed Watch
Rhodes, Linda	National Oceanographic Atmospheric Administration
Roth, Myron	BC Ministry of Agriculture
Saksida, Sonja	Canadian Food Inspection Agency (CFIA)
Siah, Ahmed	BC Centre for Aquatic Health Sciences
Struthers, Alistair	Fisheries and Oceans Canada
Trudel, Marc	Fisheries and Oceans Canada
Wade, Joy	Fundy Aqua Services
Wan, Di	Fisheries and Oceans Canada
Werring, John	David Suzuki Foundation

(comments only):

Name	Affiliation
Dalsgaard, Inger	Technical University of Denmark
Davies, Robert	University of Glasgow
Purcell, Maureen	U.S. Geological Survey
Stevenson, Roselynn	University of Guelph
St-Hilaire, Sophie	Atlantic Veterinary College UPEI

SOURCES OF INFORMATION

This Science Advisory Report is from the November 6–8, 2018 national advisory meeting on 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 Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Balfry, S. K., Albright, L. J. and Evelyn, T. P. T. 1996. Horizontal transfer of *Renibacterium salmoninarum* among farmed salmonids via the fecal-oral route. Dis. Aquat. Org. 25(1-2): 63-69.

BC Centre for Aquatic Health Sciences. 2010. Evaluation of bacterial kidney disease (BKD) impacts on the Canadian salmon aquaculture industry: Final report. Cambell River, BC. 70 p.

Cohen, B. I. 2012. Recommendations, summary, process. *In* The uncertain future of Fraser River Sockeye. Minister of Public Works and Government Services Canada. Publishing and Depository Services, Ottawa, ON. Vol 3: 211 p.

DFO. 2010. Pathways of effects for finfish and shellfish aquaculture. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/071. 22 p.

Elliott, D. G. and Pascho, R. J. 1995. Juvenile fish transportation: impact of bacterial kidney disease on survival of spring/summer Chinook salmon stock. 1993 Annual Report for the U.S. Fish & Wildlife Service. U.S. Army Corps of Engineers. Walla Walla, WA, USA.

GESAMP. 2008. Assessment and communication of environmental risks in coastal aquaculture. *In* Reports and Studies GESAMP. Rome, Italy. FAO 76: 198 p.

Grant, S. C. H., Holt, C., Wade, J., Mimeault, C., Burgetz, I. J., Johnson, S. and Trudel, M. 2018. Summary of Fraser River Sockeye Salmon (*Oncorhynchus nerka*) ecology to inform pathogen transfer risk assessments in the Discovery Islands, BC. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/074. v + 30 p.

Griffiths, S. G., Melville, K. J. and Salonius, K. 1998. Reduction of *Renibacterium salmoninarum* culture activity in Atlantic salmon following vaccination with avirulent strains. Fish Shellfish Immunol. 8(8): 607-619.

ISO. 2009. Risk management - Risk assessment techniques. *In* International Standard. IEC/FDIS 31010. 90 p.

Kent, M. L., Traxler, G. S., Kieser, D., Richard, J., Dawe, S. C., Shaw, R. W., Prosperi-Porta, G., Ketcheson, J. and Evelyn, T. P. T. 1998. Survey of salmonid pathogens in ocean-caught fishes in British Columbia, Canada. J. Aquat. Anim. Health 10(2): 211-219.

Mahony, A. M., Johnson, S. C., Neville, C. M., Thiess, M. E. and Jones, S. R. M. 2017. *Myxobolus arcticus* and *Parvicapsula minibicornis* infections in sockeye salmon *Oncorhynchus nerka* following downstream migration in British Columbia. Dis. Aquat. Org. 126(2): 89-98.

McKibben, C. L. and Pascho, R. J. 1999. Shedding of *Renibacterium salmoninarum* by infected Chinook salmon *Oncorhynchus tschawytscha*. Dis. Aquat. Org. 38: 75-79.

Mimeault, C., Wade, J., Boily, F., Johnson, S., Jones, S. R. M., Aubry, P., Malcolm, G., Foreman, M. G. G., Chandler, P. C., Wan, D., Garver, K. A., Holt, C., Burgetz, I. J. and Parsons, G. J. 2019. Assessment of the risk to Fraser River Sockeye Salmon due to *Renibacterium salmoninarum* transfer from Atlantic Salmon farms in the Discovery Islands area, British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/019. In press.

Mimeault, C., Wade, J., Foreman, M. G. G., Chandler, P. C., Aubry, P., Garver, K. A., Grant, S. C. H., Holt, C., Jones, S., Johnson, S., Trudel, M., Burgetz, I. J. and Parsons, G. J. 2017. Assessment of the risk to Fraser River Sockeye Salmon due to infectious hematopoietic necrosis virus (IHNV) transfer from Atlantic Salmon farms in the Discovery Islands, British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/075. vii + 75 p.

Murray, C. B., Evelyn, T. P. T., Beacham, T. D., Barner, L. W., Ketcheson, J. E. and Prosperi-Porta, L. 1992. Experimental induction of bacterial kidney disease in chinook salmon by immersion and cohabitation challenges. Dis. Aquat. Org. 12(2): 91-96.

Purcell, M. K., McKibben, C. L., Pearman-Gillman, S., Elliott, D. G. and Winton, J. R. 2016. Effects of temperature on *Renibacterium salmoninarum* infection and transmission potential in Chinook salmon, *Oncorhynchus tshawytscha* (Walbaum). J. Fish Dis. 39(7): 787-798.

Rechisky, E. L., Stevenson, C., Porter, A. D., Welch, D. W., Furey, N. B., Healy, S., Johnston, S. and Hinch, S. G. 2018. Telemetry-based estimates of early marine survival and residence time of juvenile sockeye salmon in the Strait of Georgia and Queen Charlotte Strait, 2017. *In* State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2017. Can. Tech. Rep. Fish. Aquat. Sci. 3266. viii + 245 p.

Rhodes, L. D., Durkin, C., Nance, S. L. and Rice, C. A. 2006. Prevalence and analysis of *Renibacterium salmoninarum* infection among juvenile Chinook salmon *Oncorhynchus tshawytscha* in North Puget Sound. Dis. Aquat. Org. 71(3): 179-190.

Rhodes, L. D. and Mimeault, C. 2019. Characterization of *Renibacterium salmoninarum* and bacterial kidney disease to inform pathogen transfer risk assessments in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/018. vii + 46 p.

Rhodes, L. D., Rice, C. A., Greene, C. M., Teel, D. J., Nance, S. L., Moran, P., Durkin, C. A. and Gezhegne, S. B. 2011. Nearshore ecosystem predictors of a bacterial infection in juvenile Chinook salmon. Mar. Ecol. Prog. Ser. 432: 161-172.

Salonius, K., Siderakis, C., MacKinnon, A. M. and Griffiths, S. G. 2005. Use of *Arthrobacter davidanieli* as a live vaccine against *Renibacterium salmoninarum* and *Piscirickettsia salmonis* in salmonids. Dev. Biol. (Basel) 121: 189-197.

Vose, D. 2008. Risk analysis: a quantitative guide. 3rd ed. Wiley, Chichester, England. 735 p.

Zetterberg, P. R. and Carter, E. W. 2010. Strait of Georgia sport fishery creel survey statistics for salmon and groundfish, 2008. 2929. Can. Manuscr. Rep. Fish. Aquat. Sci. xiv + 123 p.

Zetterberg, P. R., Watson, N. M. and O'Brien, D. S. 2012. Strait of Georgia recreational fishery statistics for salmon and groundfish, 2010. Can. Manuscr. Rep. Fish. Aquat. Sci. 3000. xii + 106 p.

THIS REPORT IS AVAILABLE FROM THE:

Canadian Science Advisory Secretariat (CSAS)
National Capital Region
Fisheries and Oceans Canada
200 Kent Street
Ottawa, ON K1A 0E6

Telephone: 613-990-0293
E-Mail: csas-sccs@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-5087

Correct Citation for this Publication:

DFO. 2020. Advice from the assessment of the risk to Fraser River Sockeye Salmon due to *Renibacterium salmoninarum* transfer from Atlantic Salmon farms in the Discovery Islands area, British Columbia. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2019/019.

Aussi disponible en français :

MPO. 2020. Avis découlant de l'évaluation du risque pour le saumon rouge du fleuve fraser attribuable au transfert de la bactérie Renibacterium salmoninarum à partir de fermes d'élevage de saumon atlantique situées dans la région des îles Discovery (Colombie-Britannique). Secr. can. de consult. sci. du MPO, Avis sci. 2019/019.