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

Canadian Science Advisory Secretariat
Science Advisory Report 2020/049

ADVICE FROM THE ASSESSMENT OF THE RISK TO FRASER RIVER SOCKEYE SALMON DUE TO VIRAL HAEMORRHAGIC SEPTICAEMIA VIRUS IVa (VHSV-IVa) TRANSFER FROM ATLANTIC SALMON FARMS IN THE DISCOVERY ISLANDS AREA, BRITISH COLUMBIA

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

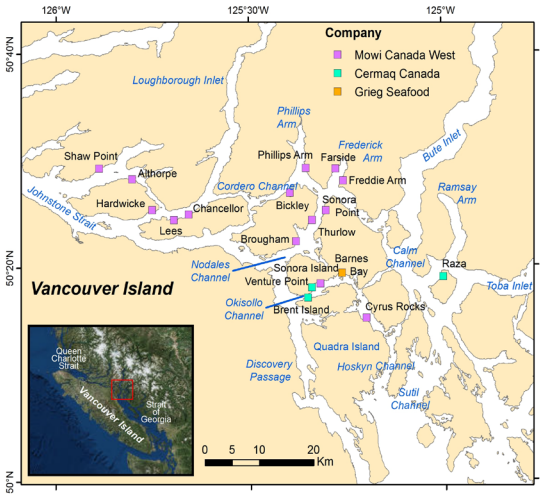

Figure 1. Location of the 18 Atlantic Salmon farms in the Discovery Islands area included in this risk assessment.

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 Atlantic Salmon (*Salmo salar*) reared on 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 ninth risk assessment is focusing on viral haemorrhagic septicaemia virus and is the final individual pathogen

assessment. The risks associated with co-occurrences and coinfections of pathogens also known to cause disease on marine Atlantic Salmon farms in the Discovery Islands area is being considered.

This Science Advisory Report is from the September 15-17, 2020, National Peer Review Meeting on the Assessment of the risk to Fraser River Sockeye Salmon due to Viral Haemorrhagic Septicaemia Virus (VHSV) transfer from Atlantic Salmon located on farms 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

Viral haemorrhagic septicaemia virus IVa (VHSV-IVa) transfer risk assessment

- Viral haemorrhagic septicaemia virus (VHSV) released from farmed Atlantic Salmon (*Salmo salar*) in the Discovery Islands area was assessed to pose minimal risk to Fraser River Sockeye Salmon (*Oncorhynchus nerka*) abundance and diversity under current farm practices.
- The overall likelihood assessment concluded that it is extremely unlikely that juvenile and adult Fraser River Sockeye Salmon would become infected with VHSV released from farmed Atlantic Salmon in the Discovery Islands area, because Sockeye Salmon are not susceptible to VHSV. The uncertainties for the different steps ranged from reasonable certainty to high certainty.
- As the consequences are dependent on the susceptibility of Sockeye Salmon, the magnitude of consequences to the abundance and diversity of Fraser River Sockeye Salmon are both estimated as negligible.
- The assessment relied on the current state of knowledge of VHSV, fish health surveillance data, experimental laboratory studies, historical wild salmon surveys for the presence of fish pathogens in British Columbia, and 2002 to 2019 fish health data on salmon farms.

This risk assessment was informed by a summary of the current state of knowledge on VHSV (Garver and Hawley, in press). The key elements of this review are summarized below.

Characterization of viral haemorrhagic septicaemia virus (VHSV) and viral haemorrhagic septicaemia (VHS)

- Globally, VHSV is the causative agent of the disease VHS, which can occur in a wide range of cultured and wild fish species in both marine and freshwater environments. There are four major genotypes of VHSV that differ in geographic distribution and host-specific virulence. Genotype IVa is the only VHSV genotype found in British Columbia (BC) and the surrounding northeastern Pacific Ocean.
- In British Columbia, VHSV-IVa is endemic in the marine environment where it causes noticeable, recurring mortality events in Pacific Herring (*Clupea pallasii*) and Pacific Sardine (*Sardinops sagax*). Less commonly, the virus has been detected in farmed and wild salmon.
- The low prevalence of VHSV infection and disease reported for farmed salmon in BC is demonstrated through routine monitoring by industry as well as active surveillance carried out by DFO under the Fish Health Audit and Surveillance Program (FHASP).
- Waterborne transmission is a likely route of VHSV infection of susceptible species of fish as consistently demonstrated in bath challenge and cohabitation laboratory studies.

- Laboratory studies exposing Pacific Herring, Atlantic Salmon, and Sockeye Salmon corroborate a gradient of VHSV susceptibility. Pacific Herring were the most susceptible. Atlantic Salmon demonstrated low to moderate susceptibility. Sockeye Salmon, regardless of whether exposed to VHSV through waterborne or cohabitation exposure, for short or long periods, proved refractory to VHSV infection. In addition, there are no confirmed reports of VHSV or VHS in Sockeye Salmon in fish health records, published studies and surveillance studies.
- Sockeye Salmon are not considered susceptible to VHSV based on the World Organisation for Animal Health (OIE) criteria for listing species as susceptible to infection with a specific pathogen.

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 a Framework adapted from international and national risk assessment frameworks (GESAMP, 2008; ISO, 2009; Mandrak et al., 2012). Details about the initiative and the framework are available on the DFO Aquaculture Science Environmental Risk Assessment Initiative webpage. Risk assessments conducted under the Initiative do not include socio-economic considerations.

This advisory report summarizes the consensus advice developed during the September 15-17, 2020, Canadian Science Advisory Secretariat (CSAS) scientific peer-review meeting that included international and national scientific experts. The information and current scientific knowledge about viral haemorrhagic septicaemia virus (VHSV) and the risk assessment were presented in the following documents:

- Characterization of viral haemorrhagic septicaemia virus (VHSV) to inform pathogen transfer risk assessments in British Columbia (Garver and Hawley, in press).
- Assessment of the risk to Fraser River Sockeye Salmon due to viral haemorrhagic septicaemia virus (VHSV) from Atlantic Salmon farms in the Discovery Islands area, British Columbia (Parsons et al., in press).

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

- review the qualitative assessment of the risk to Fraser River Sockeye Salmon abundance and diversity due to VHSV transfer from Atlantic Salmon farms located in the Discovery Islands area;
- review the uncertainties associated with the estimation of the risk to Fraser River Sockeye Salmon abundance and diversity; and
- 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 VHSV transfer from Atlantic Salmon farms in the Discovery Islands area.

ANALYSIS

Characterization of viral haemorrhagic septicaemia virus (VHSV)

The following summary highlights the key aspects of VHSV relevant to the risk assessment; for more details refer to (Garver and Hawley, in press).

Viral haemorrhagic septicaemia virus is an enveloped virus, and the viral genome is a linear single-stranded negative sense RNA (Walker et al., 2018). Additionally, VHSV is the causative agent of the disease viral haemorrhagic septicaemia (VHS) which can occur in a wide range of wild and farmed fish species in both marine and freshwater environments. Typical clinical signs of VHS includes hemorrhages under the skin, lethargy, bulging eyes and darkening of the skin.

There are four major genotypes (I to IV) and nine subtypes which to some degree correlate with geographical distributions (Einer-Jensen et al., 2004; Elsayed et al., 2006; Guðmundsdóttir et al., 2019). In British Columbia, VHSV-IVa is endemic in the marine environment. Given that genotype IVa is the only VHSV type found in BC and the surrounding northeastern Pacific Ocean (Hedrick et al., 2003; Garver et al., 2013), this analysis focuses on this genotype.

Viral haemorrhagic septicaemia virus is listed as reportable to the OIE due to its contagious nature and potential to cause significant disease in fish. VHS is a reportable disease in Canada and as a result any suspicion of the disease or detection of VHSV is required to be reported to the CFIA. VHSV is routinely and actively tested for via quantitative PCR in all farmed salmon samples collected by the DFO's Fish Health Audit and Surveillance Program (FHASP).

In BC, VHSV-IVa was first identified in 1993 from Pacific Herring incurring mortalities in and around the marine waters of Prince Rupert Harbour (Traxler and Kieser, 1994). Since this report, recurring mortality events of Pacific Sardine and Pacific Herring have been reported at various locations in coastal BC from which VHSV-IVa has been identified.

Pacific Herring and other forage species native to the northeastern Pacific Ocean are exceptionally susceptible to VHSV and are considered to be natural reservoir hosts for the virus (Hershberger et al., 2010). In contrast, Pacific salmonids (*Oncorhynchus* spp.) appear to be of negligible susceptibility with VHSV-IVa infections, with rare occurrences in apparently healthy adult fish (Meyers and Winton, 1995). Farmed Atlantic Salmon have low to moderate susceptibility to infection with VHSV-IVa (Lovy et al., 2013; Gross et al., 2019).

While VHSV-IVa is endemic to the marine waters of coastal BC, multiple independent surveys have demonstrated that infection with VHSV is uncommon in wild BC Pacific salmon. Collectively across the studies testing over 10,000 wild Pacific salmon in BC, understanding that there are differences in methodologies, detection of VHSV occurred in less than 1% of the samples tested. Despite residing in VHSV-IVa endemic waters, there has not been a confirmed VHSV infection in Sockeye Salmon (see Table 5 in Garver and Hawley, in press).

Waterborne transmission is the natural and likely dominant route of VHSV infection with laboratory studies effectively transmitting virus through either bath exposure or via cohabitation with infected fish (Lovy et al., 2013). There are no indications or evidence of vertical transmission of VHSV (Bovo et al., 2005). A laboratory study of transmission of VHSV-IVa from Atlantic Salmon to Pacific Herring demonstrated that VHSV-infected Atlantic Salmon can shed virus and can infect a Pacific Herring which is a highly susceptible species (Lovy et al., 2013). In instances where farmed Atlantic Salmon become infected with VHSV, the duration and extent of virus shedding from infected individuals are unknown.

Laboratory studies which immersed Pacific Herring for 24 hours in seawater with 10 plaque forming units (PFU)/mL of VHSV-IVa (a very low virus level typically not detectible using standard laboratory detection methods), initiated infection among the exposed population and caused upwards of 100% mortality (Hershberger et al., 2010). In contrast, Sockeye Salmon exposed to 670 times higher VHSV-IVa levels in saltwater remained free from virus infection revealing their inherent resistance to the virus and improbability of receiving an infectious dose within a natural environment (Gross et al., 2019). VHSV-IVa infection of Sockeye Salmon has only been achieved through the artificial and invasive procedure of injecting virus into fish (n = one of 225 fish) (Gross et al., 2019). However, none of these findings provide sufficient evidence for susceptibility.

The OIE considers a species of aquatic animals to be susceptible to infection with a pathogenic agent when the each of the following criteria are met: (1) transmission has been obtained naturally or by experimental procedures that mimic natural pathways for the infection; (2) the identity of the pathogenic agent has been confirmed in accordance with OIE diagnostic criteria or equivalent; and (3) there is evidence of infection with the pathogenic agent in the suspect host species (OIE, 2019). Consequently, without evidence and confirmation of either natural or non-invasive experimental infections with VHSV, Sockeye Salmon do not fulfill the criteria of a VHSV susceptible species (Garver and Hawley, in press).

Occurrence on Atlantic Salmon farms in BC

Between 2002 and 2018, VHS was diagnosed at the farm-level in 17 of 1459 audits conducted on Atlantic Salmon farms in BC through the FHASP. Between 2002–2019 (excluding 2013–2015), 17 Fish Health Events were attributed to VHS on Atlantic Salmon farms in BC. Between 2011 and 2019, one mortality event attributed to VHS has been reported in BC. The event occurred in March 2012 on an Atlantic Salmon farm located in Fish Health Surveillance Zone 3.3 (Broughton Archipelago), see Garver and Hawley (in press) for further details. The routine monitoring performed by industry, and DFO under the FHASP, provides confidence in the low prevalence of infection and disease in farmed salmon in BC.

Viral haemorrhagic septicaemia virus IVa (VHSV-IVa) transfer risk assessment

The risks to Fraser River Sockeye Salmon abundance and diversity due to VHSV-IVa transfer from Atlantic Salmon farms operating in the Discovery Islands area (see Figure 1) were assessed under current farm practices, including fish health management. The main uncertainties and their impacts, or lack thereof, on the risk estimates are summarized in Table 2. For this risk assessment, VHSV refers to VHSV-IVa.

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

Conceptual model

The risk assessment followed three main steps outlined in Figure 2: likelihood assessment, consequence assessment and risk estimation.

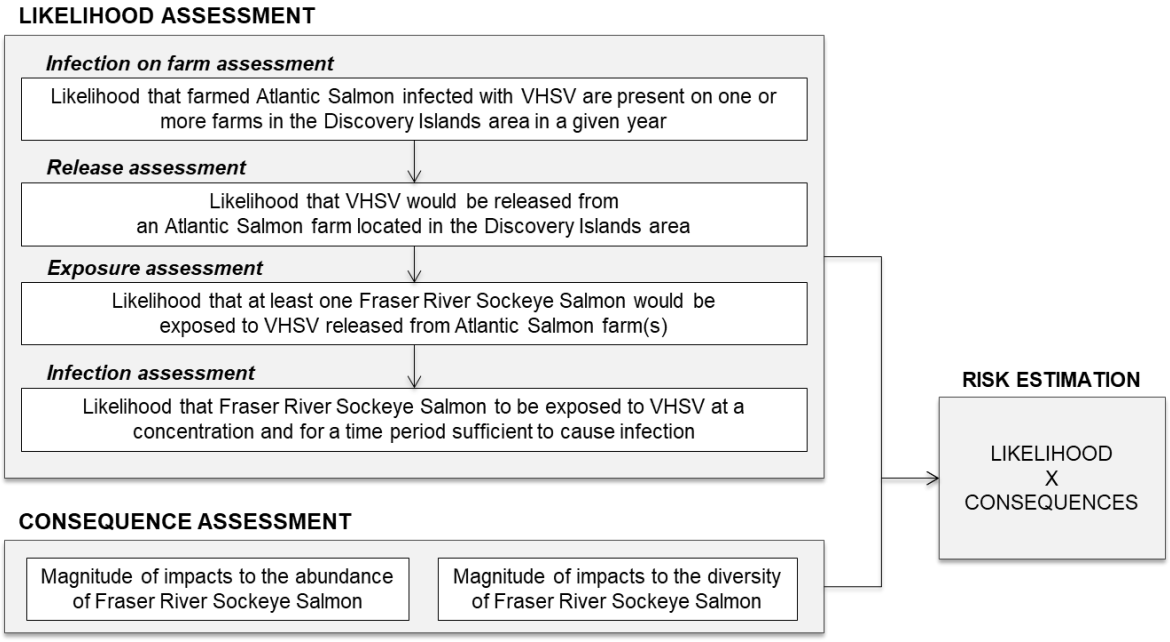

Figure 2. Conceptual model to assess the risks to Fraser River Sockeye Salmon resulting from viral haemorrhagic septicaemia virus (VHSV) attributable to Atlantic Salmon farms located in the Discovery Islands area, BC. Adapted from Mimeault et al. (2017).

Likelihood assessment

The likelihood assessment was conducted through four sequential assessments: 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 maintained. The main considerations and conclusions of each step are reported here.

Farm infection assessment

The farm infection assessment determined the likelihood that farmed Atlantic Salmon infected with VHSV are present on one or more farms in the Discovery Islands area in a given year.

Results from industry surveillance and screening (2011–2019), the FHASP (2002–2018), FHEs (2002–2019) and mortality events (2011–2019) provide evidence of VHSV and/or VHS on Atlantic Salmon farms in the Discovery Islands area in five different years (2003, 2005, 2012, 2014 and 2015).

Based on these data, it was concluded with reasonable certainty that, in any given year, the likelihood of farmed Atlantic Salmon infected with VHSV being present on one or more Atlantic Salmon farms in the Discovery Islands area is unlikely under the current farm management practices.

Release assessment

The release assessment determined the likelihood that VHSV would be released from an Atlantic Salmon farm located in the Discovery Islands area into an environment accessible to Fraser River Sockeye Salmon assuming Atlantic Salmon infected with the virus are present on at least one farm. Two pathways were considered: release through infected farmed Atlantic Salmon and mechanical vectors (e.g., personnel, visitors and wildlife) and fomites (e.g., farm

equipment and vessels). VHSV release from Pacific Herring or other susceptible species in the vicinity of the net-pens was not considered.

Given the evidence of shedding and horizontal transmission (i.e., spread from fish to fish) of VHSV under experimental conditions, it was concluded with high certainty that the virus would be extremely likely to be released from an infected Atlantic Salmon farm into the marine environment.

Laboratory studies have shown that VHSV can be retained on fomites such as pieces of plastic, glass, and fishing lines; however, the duration by which VHSV remains infectious on the objects was dependent upon storage conditions and material type (Pham et al., 2012). Common chemicals used in the aquaculture industry, including disinfectants such as Virkon® Aquatic, Peroxigard™, chlorine compounds and hydrogen peroxide chemicals, have been shown to be efficacious at rendering VHSV inactive when it is exposed at the prescribed concentration for the required contact time (Bovo et al., 2005; Bowker et al., 2016).

As part of conditions of licence, biosecurity and biocontainment practices are required. Low levels of operational deficiencies related to fish health on Atlantic Salmon farms have been documented in DFO's FHASP (see Wade (2017) and Mimeault et al. (2019)). Low levels of operational deficiencies related to fish health on Atlantic Salmon farms in the Discovery Islands area have been documented in DFO's FHASP as summarized by Wade (2017). It was therefore concluded with reasonable certainty that the likelihood of release through vectors or fomites is unlikely under the 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 VHSV would be released from an infected Atlantic Salmon farm.

Exposure assessment

The exposure assessment determined the likelihood that at least one Fraser River Sockeye Salmon would be exposed to VHSV in a given year assuming that the virus has been released from at least one Atlantic Salmon farm in the Discovery Islands area. Two exposure groups were considered: juvenile and adult Fraser River Sockeye Salmon.

The exposure assessment examined whether evidence of VHSV infections and/or VHS on Atlantic Salmon farms occurred during the time period that Fraser River Sockeye Salmon migrate through the Discovery Islands area.

Juvenile lake-type Fraser River Sockeye Salmon migrate through the Discovery Islands area from approximately mid-May to mid-July, while returning adults migrate through the area 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.

Viral haemorrhagic septicaemia virus and/or VHS was reported on Atlantic Salmon farms in the Discovery Islands area once in 18 years during the time period when juvenile Sockeye Salmon are present in the Discovery Islands area. Therefore it is unlikely that at least one juvenile Fraser River Sockeye Salmon would be exposed to VHSV. The conclusion was made with reasonable certainty.

There is no temporal overlap between adult Fraser River Sockeye Salmon and VHSV and/or VHS occurrences on the farms. It was therefore concluded that it is extremely unlikely that at least one adult Fraser River Sockeye Salmon would be exposed to VHSV attributable to an Atlantic Salmon farm located in the Discovery Islands. The conclusion was made with reasonably certainty.

Infection assessment

The infection assessment determined the likelihood that Fraser River Sockeye Salmon would be exposed to VHSV attributable to Atlantic Salmon farms in the Discovery Islands area at a concentration and for a period of time sufficient to cause infection.

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

Laboratory studies have demonstrated that Sockeye Salmon remain free from VHSV infection (genotype IVa) despite exposures to VHSV doses that are lethal to Pacific Herring (Gross et al., 2019). To date, there is no confirmed case of VHSV infection or VHS disease in wild Sockeye Salmon (for a summary of results, see Table 5 in Garver and Hawley (in press)).

Therefore, it was concluded that a VHSV infection in Sockeye Salmon attributable to Atlantic Salmon farms in the Discovery Islands area is extremely unlikely to occur, i.e., has little to no chance to occur (see Table 2 in Parsons et al. in press). This conclusion was made with reasonable certainty.

Overall likelihood assessment

Table 1 summarizes the likelihood assessment. Overall, it was concluded that the likelihood that Fraser River Sockeye Salmon would become infected with VHSV released from Atlantic Salmon farms in the Discovery Islands area is extremely unlikely for juveniles and adults.

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 part of the assessment of the risk to Fraser River Sockeye Salmon due to viral haemorrhagic septicaemia virus transfer from Atlantic Salmon farms in the Discovery Island area. Uncertainties are not combined.

Step		Ranking	
Farm infection assessment	**Likelihood *(uncertainty)***	Unlikely *(Reasonable Certainty)*	
Release assessment	**Release pathways**	**Farmed Atlantic Salmon**	**Mechanical vectors and fomites**
	Likelihood *(uncertainty)*	Extremely Likely *(High Certainty)*	Unlikely *(Reasonable Certainty)*
	Combined likelihood	Extremely Likely	
Exposure assessment	**Exposure groups**	**Juveniles**	**Adults**
	Likelihood *(uncertainty)*	Unlikely *(Reasonable Certainty)*	Extremely Unlikely *(Reasonable Certainty)*
Infection assessment	**Likelihood *(uncertainty)***	Extremely Unlikely *(Reasonable Certainty)*	Extremely Unlikely *(Reasonable Certainty)*
Overall likelihood for each exposure group (combination of all four steps)		Extremely Unlikely	Extremely Unlikely

Consequence assessment

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

Based on the likelihood assessment, it was determined that it is extremely unlikely that Fraser River Sockeye Salmon would become infected with VHSV released from Atlantic Salmon farms in the Discovery Islands area given Sockeye Salmon are not susceptible to VHSV (based on not meeting OIE criteria for determination of susceptible species).

As the consequences are dependent on the susceptibility of Sockeye Salmon, the magnitude of consequences to the abundance and diversity of Fraser River Sockeye Salmon are both estimated as negligible. Without infection, there will be no consequence to the abundance (0% reduction in the number of returning Fraser River Sockeye Salmon which is defined as negligible to the consequences to abundance in Table 3 in Parsons et al. (in press)) and diversity (no loss of Fraser River Sockeye Salmon which is defined as negligible to the consequences to diversity in Table 4 in Parsons et al. in press) of Fraser River Sockeye Salmon attributable to VHSV or VHS from Atlantic Salmon farms in the Discovery Islands area.

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. Risk matrices were developed, as described in Mimeault et al. (2017), and are aligned with relevant scales of consequences for DFO fisheries management and policy purposes, existing policy and current management risk tolerances relevant to the risk assessment.

Under the current farm practices, the risk to the abundance of Fraser River Sockeye Salmon as a result of a VHSV infection attributable to Atlantic Salmon farms in the Discovery Islands area is minimal (Figure 3).

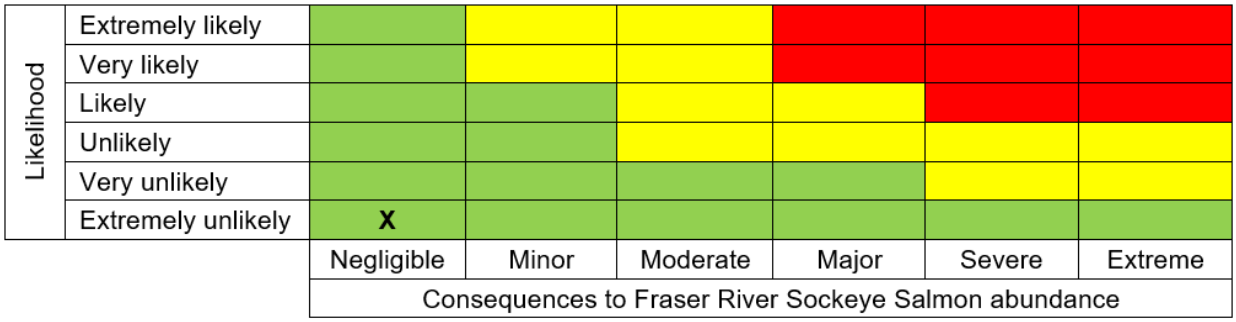

Figure 3. Risk matrix for combining the results of the assessment of the likelihood and consequences to Fraser River Sockeye Salmon abundance. Green, yellow and red, respectively, represent minimal, moderate and high risk.

Under the current farm practices, the risk to the diversity of Fraser River Sockeye Salmon as a result of a VHSV infection attributable to Atlantic Salmon farms in the Discovery Islands area is minimal (Figure 4).

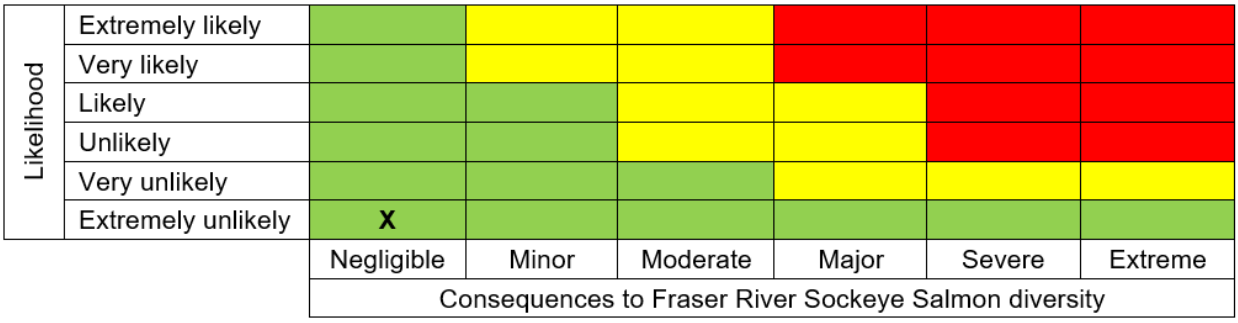

Figure 4. Risk matrix for combining the results of the assessment of the likelihood and consequences to Fraser River Sockeye Salmon diversity. Green, yellow and red, respectively, represent minimal, moderate and high risk.

Sources of Uncertainty

Overall, uncertainty includes both variability, which is a function of the system that is not reducible with additional measurements, and lack of knowledge that may be reduced with additional data or expert opinion (Vose, 2008). There are uncertainties associated with each step of the likelihood assessment.

The main sources of uncertainties, the approach taken to address each of them, and their potential impacts on the results/rankings in this risk assessment are listed in Table 2. As presented in the table, we evaluated each potential source of uncertainty and took it into consideration in our final analysis. We applied different tools/methods available, including making relevant assumptions, using surrogate information, considering worse or worst-case scenario, and sensitivity analysis. Finally, the expected direction and magnitude of each action in addressing the respective source of uncertainty is presented.

For instance, in the exposure assessment step, one of the major sources of uncertainty is “knowledge gaps around the precise migration routes and movements of fish through the channels of the Discovery Islands area”. To account for this uncertainty in the ranking of the likelihood of exposure, we assumed that the fish had random distribution and movement throughout all channels of the Discovery Islands area in each month during their migration window. Therefore, every fish was considered to have a chance to become exposed to infected farm(s). In other words, we highly overestimated the likelihood of exposure for the migratory populations because, in reality, we expect that different populations of Sockeye Salmon (especially, juveniles) use specific pathways/channels along their migration routes and may not meet the only or the few infected farms; thus, they are expected to have substantially lower likelihood of exposure than what we conservatively estimated.

Table 2. The main sources of uncertainty, the considerations used to address them, and their potential impacts on the likelihood rankings and the final conclusions of this risk assessment. 'Impact on assessment ranking' represents the potential impacts of our action to address that specific source of uncertainty. 'Impact on final risk' represents the potential impact of the uncertainty and our respective action on changing the final category of the risk (green, yellow, or red). FHASP: Fish Health Audit and Surveillance Program. VHS: viral haemorrhagic septicaemia. VHSV: viral haemorrhagic septicaemia virus. Arrows indicate increase (up) or decrease (down) in potential likelihood ranking.

Assessment Step	Main source of uncertainty	Considerations and or assumptions used to account for this uncertainty	Impact on assessment ranking	Impact on final risk
Farm infection assessment (Reasonable Certainty)	Are all occurrences of VHS and VHSV infection on farms detected?	Data collection and confirmation from industry and regulatory authorities. Detection of virus in a single fish is assumed to be equivalent evidence of infection a farm-level.	⇳	None because of combination rules – there are other likelihoods both higher and lower that would be carried forward and because the infection assessment determined the overall likelihood.
Release Assessment: Vectors and Fomites (Reasonable Certainty)	Are disinfection protocols specific to VHSV efficacious and are biocontainment protocols consistently implemented?	Characterize the audit deficiency rates as an evaluation of daily practices. One detection indicating no evidence of farm-to-farm transmission in the farm infection data suggests that fish health management practices are effective.	⇳	None because the higher ranking of Release from infected Atlantic Salmon determines this release step.
Exposure assessment (Reasonable Certainty)	How well do we understand proximity of Fraser River Sockeye Salmon to salmon farms during their migration through the Discovery Islands area?	Assume that Sockeye Salmon use all channels and that all Sockeye Salmon have a chance to be exposed to an Atlantic Salmon farm with VHSV infection.	⇧	None because the infection assessment determined the overall likelihood
Infection assessment (Reasonable Certainty)	Have laboratory challenge studies examined the full range of factors that wild Sockeye Salmon can experience in the environmental around salmon farms?	Assume that laboratory studies are applicable as similar studies reach similar conclusions.	⇧	Would need to do consequence assessment if susceptible to determine impact on risk.

CONCLUSIONS

Characterization of viral haemorrhagic septicaemia virus (VHSV)

VHSV-IVa is endemic in the northeastern Pacific Ocean where it can cause significant disease in numerous marine forage fish species such as Pacific Herring and Pacific Sardine. Yet despite the virus' high virulence in marine forage fish species, it is of low virulence in Atlantic and Pacific salmon species. Marine forage fish species can be found in and around marine net-pen farmed salmon have the capacity to shed enormous quantities of VHSV, and they have been shown to be a source of VHSV to farmed salmon.

In wild Pacific salmon, the occurrence of VHSV is uncommon and is undoubtedly a reflection of their refractory nature to VHSV infection as measured in controlled laboratory studies. Specifically, these laboratory studies have demonstrated that Sockeye Salmon remain free from VHSV infection despite exposures to high concentrations of virus that are known to be lethal to Pacific Herring. Furthermore, in wild Sockeye Salmon captured in VHSV-endemic waters, there are no confirmed reports of VHSV in Sockeye Salmon in fish health records, published studies and surveillance studies. Consequently, without evidence of either natural or non-invasive experimental infections with VHSV, Sockeye Salmon do not fulfill the criteria of a VHSV susceptible species as defined by the OIE.

Viral haemorrhagic septicaemia virus IVa (VHSV-IVa) transfer risk assessment

The assessment concluded that VHSV-IVa attributable to Atlantic Salmon farms in the Discovery Islands area poses minimal risk to Fraser River Sockeye Salmon abundance and diversity under the current farm practices.

The conclusion of minimal risk was influenced by the absence of VHSV infection in Sockeye Salmon as the available data indicate that Sockeye Salmon do not fulfill the OIE criteria for susceptibility and therefore not a susceptible species.

RECOMMENDATIONS

- Conclusions of this risk assessment should be reviewed as new research findings fill the knowledge gaps.
- If a subgenotype of VHSV other than IVa were to be reported on Atlantic Salmon farms in the Discovery Islands area, a specific risk assessment on that genotype may need to be undertaken if warranted.

OTHER CONSIDERATIONS

The influence of other VHSV-susceptible hosts on the release of VHSV from Atlantic Salmon farms that are present on and in the vicinity of farms (e.g., Pacific Herring, Pacific Sardine) has not been quantified.

Additionally, the points below should be considered in all fish pathogen transfer risk assessments in the Discovery Islands area.

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

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.

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