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ADVICE FROM THE ASSESSMENT OF THE RISK TO FRASER RIVER SOCKEYE SALMON DUE TO PISCINE ORTHOREOVIRUS (PRV) TRANSFER FROM ATLANTIC SALMON FARMS IN THE DISCOVERY ISLANDS AREA, BRITISH COLUMBIA

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

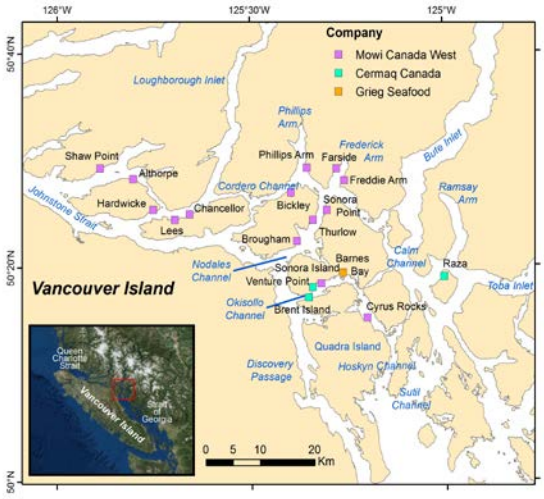

Figure 1. Location of the 18 Atlantic Salmon farms in the Discovery Islands area stocked at least once between 2010 and 2016.

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 (Salmo salar) 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 sixth risk assessment is focusing on piscine orthoreovirus (PRV). 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 January 28-30, 2019 national peer review meeting on Assessment of the risk to Fraser River Sockeye Salmon due to piscine orthoreovirus (PRV) transfer 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

Piscine Orthoreovirus (PRV-1) Transfer Risk Assessment

- PRV-1 released from Atlantic Salmon (*Salmo salar*) farms operating in the Discovery Islands area was assessed to pose minimal risk to Fraser River Sockeye Salmon (*Oncorhynchus nerka*) abundance and diversity. The uncertainties ranged from high certainty to high uncertainty (see below and Table 1).
- The assessment was conducted using relevant scientific information related to piscine orthoreovirus (PRV-1), including farm-related fish health data, current fish health management practices, surveys and studies from enhanced and wild salmon in British Columbia.
- The risk assessment was conducted based on the findings that all active farms likely become positive for PRV-1 and Fraser River Sockeye Salmon are susceptible to PRV-1 infection.
- The risk assessment assumed:
    - continuous PRV-1 shedding from farms, that the exposure time and dose are sufficient to cause infection in at least one Fraser River Sockeye Salmon when they migrate through the Discovery Islands; and
    - that results for laboratory studies on the impact of PRV-1 infection in juvenile Sockeye Salmon are indicative of what occurs in marine environments.
- The overall Likelihood Assessment concluded that at least one Fraser River Sockeye Salmon, at either the juvenile or adult stage, becoming infected with PRV-1 attributable to Atlantic Salmon from in Discovery Islands area is very likely with the uncertainties for the different steps ranging from high certainty to high uncertainty.
- The Consequence Assessment concluded that the potential magnitude of consequences to Fraser River Sockeye Salmon abundance and diversity is negligible with reasonable certainty for juveniles and reasonable uncertainty for adults. The levels of the uncertainty of this conclusion were discussed and participants came to different conclusions on the applicability and abundance of the data to support uncertainty estimates.
- The main uncertainties in this risk assessment are:
    - the high uncertainty related to the likelihood of infection of Fraser River Sockeye Salmon with PRV-1 from infected Atlantic Salmon farms given the lack of data to estimate the concentration of PRV-1 attributable to infected Atlantic Salmon farms, and given that the exposure duration required for infection with PRV-1 to occur and the minimum PRV-1 infectious dose for Sockeye Salmon are unknown; and

- the reasonable uncertainty related to the consequence assessment given the applicability of proxy data and laboratory studies to estimate consequences for adult Sockeye Salmon.

This risk assessment was informed by a summary of the current state of knowledge related to piscine orthoreovirus (PRV) and associated diseases (Polinski and Garver, 2019) of which the key elements are summarized below.

Characterization of Piscine Orthoreovirus (PRV) and Associated Diseases

- Of the three known PRV genogroups, PRV-1 occurs in BC, Norway and other areas. The variant of PRV-1 found in British Columbia is the subject of the risk assessment.
- Data from Norway suggests there is variation in the virulence among strains of PRV-1. BC PRV-1 has less genetic variability and less virulence for Atlantic Salmon than Norwegian PRV-1.
- PRV-1 is ubiquitous and highly prevalent in marine net-pen farmed Atlantic and Chinook salmon of British Columbia. PRV-1 has a wide geographic distribution among wild Pacific salmon (BC, Alaska and Washington) but at a lower prevalence than farmed salmon and with species/stock-specific variation.
- Evidence of infection for PRV-1 relies on the use of molecular methods which detect the presence of PRV-1 genetic material; however, this does not indicate infective PRV-1.
- PRV-1 infects red blood cells. In laboratory challenge trials with juvenile Atlantic or Sockeye salmon, high loads of PRV-1 have been reported. However, it was not predictive of development of disease.
- Farmed and wild salmon of British Columbia appear most likely to become infected with PRV-1 in seawater, although infections in juvenile salmon have been reported in freshwater.
- Sockeye Salmon appear less susceptible to infection relative to Atlantic Salmon in British Columbia following experimental exposure.
- In marine net-pens, PRV-1 has been associated with severe heart inflammation in farmed Atlantic Salmon and jaundice/anemia syndrome in farmed Chinook Salmon in British Columbia; but a causal relationship has not been established.
- In laboratory challenge trials with juvenile Atlantic Salmon, when high viral loads were generated, the BC variant of PRV-1 enhanced prevalence of minor to moderate heart lesions, without any fish mortality, clinical signs or anaemia.
- In four laboratory challenge trials with juvenile Sockeye Salmon, high viral loads of PRV-1 were generated without any fish mortalities, clinical signs or anaemia. The histopathology results could not be attributed to PRV-1.
- No impairment of respiratory function has been demonstrated in BC PRV-1 infected juvenile Atlantic or Sockeye salmon under experimental conditions.
- Based on observations described above, current evidence does not support the conclusion that BC PRV-1 causes disease or mortality in Sockeye Salmon.

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 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[1] advice developed during the January 28-30, 2019 Canadian Science Advisory Secretariat (CSAS) scientific peer-review meeting that included international and national scientific experts. The information and current scientific knowledge about piscine orthoreovirus (PRV) and associated diseases and the risk assessment were presented in the following documents:

- Characterization of piscine orthoreovirus (PRV) and associated diseases to inform pathogen transfer risk assessments in British Columbia (Polinski and Garver, 2019).
- Assessment of the risk to Fraser River Sockeye Salmon due to piscine orthoreovirus (PRV) 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 meet the remaining objectives of the meeting, specifically:

- review the qualitative assessments of the risk to Fraser River Sockeye Salmon abundance and diversity due to PRV-1 transferred 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 PRV transferred from Atlantic Salmon farms in the Discovery Islands area.

ANALYSIS

Characterization of Piscine Orthoreovirus (PRV) and Associated Diseases

The following analysis highlights key aspects of PRV and associated diseases that are relevant for the risk assessment; for more details refer to Polinski and Garver (2019).

PRV is a non-enveloped, double stranded RNA virus within the *Reoviridae* family (Palacios et al., 2010; Kibenge et al., 2013) that has only been recently identified, infects the red blood cells (erythrocytes) of salmon. Evidence of PRV infection, relies on molecular detection for the presence of PRV genetic material and this is not synonymous with infectivity. There are three

[1] See the “Uncertainties in the consequence assessment” section, below.

distinct genogroups: PRV-1, PRV-2 and PRV-3 (Dhamotharan et al., 2018; Kuehn et al., 2018), but to date, only PRV-1 has been detected in British Columbia.

PRV-1 predominantly infects salmon, although the detection prevalence in Pacific salmon can vary considerably between species and stocks, with more frequent detections in Coho and Chinook Salmon as compared to Chum, Pink, Sockeye salmon and steelhead trout. Juvenile Sockeye Salmon had lower prevalence and intensity of PRV infections than juvenile Atlantic Salmon when cohabitated with PRV-1 positive Atlantic Salmon (Garver et al., 2016a), indicating that Sockeye Salmon are less susceptible to PRV-1 infection than Atlantic Salmon.

Differences in the virulence of PRV-1 strains have been reported: in Norway, PRV-1 has been demonstrated, through controlled laboratory studies, to cause severe heart lesions (Wessel et al., 2017) in conjunction with occasional skeletal muscle lesions similar to those observed on heart and skeletal muscle inflammation (HSMI) diseased salmon farms (Kongtorp et al., 2004b; Kongtorp and Taksdal, 2009; Mikalsen et al., 2012; Finstad et al., 2014; Lund et al., 2017). By contrast, in Pacific Canada, BC PRV-1 has failed to cause severe heart lesions or skeletal muscle inflammation following experimental challenge of Atlantic or Pacific salmon (Garver et al., 2016a; Polinski et al., 2019; Zhang et al., 2019). Additionally, the clinical signs of jaundice syndrome or anemia have not been reproduced in naive Chinook, Coho or Sockeye salmon in laboratory challenge trials in the West Coast of North America despite the successful passage and development of high-load PRV-1 blood infections (Garver et al., 2016b; BCSFA, 2018; Polinski et al., 2019).

Regional variations in the virulence of PRV-1 have also been reported in farmed Atlantic Salmon. In Norway, most farmed Atlantic Salmon become positive with PRV-1, but only some develop disease. Although clinical outbreaks of HSMI in farmed Atlantic Salmon of Norway are reasonably common, it is not clear why some farms in Norway experience high losses due to HSMI while others do not. In Pacific Canada, although PRV-1 is highly prevalent in farmed Atlantic Salmon and two subclinical farm-level cases of HSMI-like disease have been reported (Di Cicco et al., 2017; Polinski et al., 2019), the clinical presentation of the disease did not meet the case definition of HSMI as originally used in Norway (Kongtorp et al., 2004a; Kongtorp et al., 2004b).

PRV spreads horizontally (from fish to fish) during laboratory cohabitation studies (Garver et al., 2016a; Wessel et al., 2017). PRV infected salmon are therefore considered a main transmission source of the virus, but to date, the rate and duration at which PRV is shed from an infected fish remains unknown. Poor viral transmission has been demonstrated via cohabitation during the late infectious stage, suggesting natural shedding of virus might be minimal during persistent infections and may even cease entirely over time (Garver et al., 2016a).

To date, in controlled experimental trials, neither BC nor Norwegian variants of PRV-1 has caused clinical morbidity or mortality in salmon even during extreme blood infections (Garver et al., 2016a; Takano et al., 2016; Wessel et al., 2017; Polinski et al., 2019), nor has it contributed to clinical morbidity or mortality during experimental trials in conjunction with stressors such as smoltification, viral co-infection, hypoxia, or exhaustive chasing (Garver et al., 2016a; Lund et al., 2016; Polinski et al., 2016; Lund et al., 2017; Zhang et al., 2019).

To date, four studies have been conducted to determine if Sockeye Salmon exposed to PRV develop disease. Collectively, these studies demonstrate that Sockeye Salmon can become highly infected with PRV, yet a disease state is not established regardless of whether the salmon were exposed to PRV via intraperitoneal injection or through cohabitation with PRV-infected Atlantic Salmon (Garver et al., 2016a; Garver et al., 2016b; Polinski et al., 2016).

Despite developing high load, persistent, systemic PRV infections, Sockeye Salmon incurred no weight loss, morbidity or significant pathology across multiple tissues (i.e., gill, skeletal muscle, eye, heart, spleen, liver, kidney, pyloric caeca, brain and intestine) and time points (1 to 41 weeks post exposure) (Garver et al., 2016a; Garver et al., 2016b; Polinski et al., 2016). In addition, in the most recent study, the physiological respiratory function of PRV-infected Sockeye Salmon was assessed, as performed on Atlantic Salmon (Zhang et al., 2019), and revealed PRV infections to be inconsequential to Sockeye Salmon respiratory function (Polinski et al., manuscript in preparation). Furthermore, in a field study of adult Chilko or Shuswap Sockeye Salmon returning to the Fraser River, it was identified that the presence of PRV on or in the gills of fish migrating through Discovery or Juan De Fuca sea channels had no significant effect on the likelihood that they would reach their spawning grounds (Miller et al., 2014).

Piscine Orthoreovirus (PRV) Transfer Risk Assessment

The risks to Fraser River Sockeye Salmon abundance and diversity due to PRV transferred from Atlantic Salmon farms operating in the Discovery Islands area (see Figure 1) were assessed under current health management practices.

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., surveillance and testing, use of nursery sites). There is no commercial vaccine available for PRV nor are there treatments available for PRV-infected Atlantic Salmon.

Given that PRV-1 is the only genogroup detected in Pacific Canada to date (Polinski and Garver, 2019), it was the single genogroup considered in this risk assessment.

Conceptual Model

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

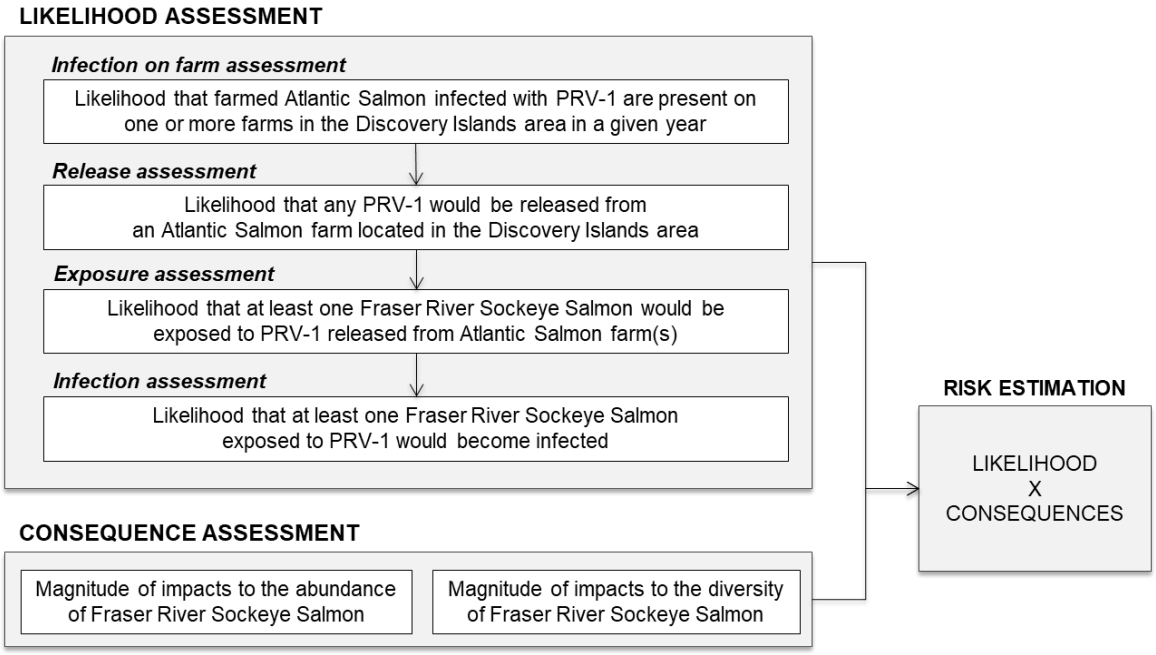

Figure 2. Conceptual model to assess the risks to Fraser River Sockeye Salmon resulting from piscine orthoreovirus-1 (PRV-1) attributable to Atlantic Salmon farms located in the Discovery Islands area, BC. Adapted from (Mimeault et al., 2017).

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 will be 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 PRV are present on one or more farms in the Discovery Islands area in a given year.

Following seawater transfer, Atlantic Salmon in BC have been documented to become PRV-1 positive by approximately three to four months (Di Cicco et al., 2017; Laurin et al., 2019), or 100 to 200 days, independent of location or time of stocking (Polinski and Garver, unpublished data). Once PRV-1 is present on a salmon farm, it is expected to reach 100% prevalence within the population within a few months of the initial infection (Di Cicco et al., 2017; Polinski et al., 2019).

Given evidence that all Atlantic Salmon farms become positive for PRV-1 following seawater transfer it was concluded with high certainty that the likelihood that farmed Atlantic Salmon infected with PRV are present on one or more Atlantic Salmon farms in the Discovery Islands area is extremely likely under the current fish health management practices.

Release assessment

The release assessment determined the likelihood that any PRV-1 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 PRV-1 are present on at least one farm. 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 that PRV-1 infected Atlantic Salmon are considered to be a source of the virus (Polinski and Garver, 2019) and that Atlantic Salmon are reared in net pens, it was concluded with high certainty that the likelihood of the virus to be released into the environment from infected Atlantic Salmon is extremely likely.

As part of licence requirements, biosecurity and biocontainment practices are specified in Salmonid Health Management Plans (SHMPs) and associated Standard Operating Procedures (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 that the likelihood of release through vectors or fomites is unlikely under current fish health management practices. This conclusion was made with reasonable uncertainty as it was assumed biocontainment measures in place are effective against PRV-1.

The overall likelihood of release was obtained by adopting the highest likelihood of the release pathways. It is therefore extremely likely that PRV-1 would be released from an Atlantic Salmon farm should it become infected.

Exposure assessment

The exposure assessment determined the likelihood that at least one Fraser River Sockeye Salmon would be exposed to PRV-1 in a given year assuming that PRV-1 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. Waterborne exposure was considered the most relevant exposure route for this risk assessment.

The exposure assessment examined whether PRV-1 infections on Atlantic Salmon farms occurred during the same period of time that Fraser River Sockeye Salmon are known to be in the Discovery Islands area.

PRV-1 has been reported on Atlantic Salmon farms in the Discovery Islands area throughout the year (Mimeault et al., 2019); since shedding rates are unknown, continuous shedding from the farms was assumed.

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 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.

While there are interannual variations in the Fraser River Sockeye Salmon migration timing, PRV-1 infections have been reported throughout the year on Atlantic Salmon farms in the Discovery Islands area. It was concluded that it is extremely likely that at least one juvenile or adult Fraser River Sockeye Salmon will be exposed to PRV-1 released from Atlantic Salmon farm(s) in the Discovery Islands area in a given year. The conclusion was made with reasonable certainty.

Infection assessment

The infection assessment determined the likelihood that at least one Fraser River Sockeye Salmon will be infected with PRV-1 in a given year, assuming at least one Sockeye Salmon has been exposed to PRV-1 released from Atlantic Salmon farm(s) in the Discovery Islands area.

Infections depend on the concentration of pathogens to which the host is being exposed and the duration of exposure. Laboratory studies have demonstrated that Sockeye Salmon are susceptible to PRV-1 infections through cohabitation (Garver et al., 2016a; Garver et al., 2016b; Polinski et al., 2016); however, the minimum concentration and time required to infect them is unknown. PRV-1 infections on Atlantic Salmon farms in BC take several months between initial infection and 100% infection prevalence (Di Cicco et al., 2017; Polinski and Garver unpublished data).

The duration of exposure of Fraser River Sockeye Salmon to Atlantic Salmon farms is not precisely known. 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 and two days for the adults through the Discovery Islands area. Further, a summary of recent telemetry studies (Rechisky et al., 2018) confirmed that tagged Sockeye Salmon occurred in the proximity to fallowed farms for a brief period (i.e., minutes).

Given that the viral shedding rate in PRV-1-infected Atlantic Salmon, or other salmonids, has not been quantified (Polinski and Garver, 2019), it was not possible to estimate the concentration of PRV-1 shed from a PRV-1-infected Atlantic Salmon farm in the Discovery Islands area. Additionally, there are no data on the decay rate of PRV in the marine environment. Consequently, it was not possible to model the dispersal of PRV-1 from infected Atlantic Salmon farms in the Discovery Islands area for this risk assessment given that the viral infection pressure attributable to a PRV-1-infected farm could not be estimated.

Whether exposure to PRV-1 at environmentally relevant concentrations on and around Atlantic Salmon farms and for the period of time that Fraser River Sockeye Salmon migrate through the Discovery Islands area where farms are present (three to eight days for juveniles, two days for adults in Mimeault et al. (2017) based on Grant et al. (2018)) will result in infection in Sockeye Salmon is not known. However, since Sockeye Salmon are susceptible to PRV-1 infection and have been shown to become infected at four weeks of cohabitation with PRV-1 infected Atlantic Salmon (Garver et al., 2016a), it was concluded with high uncertainty that it is very likely that at least one Fraser River Sockeye Salmon, at the juvenile and adult life stage, would become infected with PRV attributable to Atlantic Salmon farms in the Discovery Islands area under current farm practices.

Overall likelihood assessment

Table 1 summarizes the likelihood assessment. It was concluded that the likelihood that at least one Fraser River Sockeye Salmon would become infected with PRV released from Atlantic Salmon farms in the Discovery Islands area is very likely for both juveniles and adults. This conclusion was driven by the likelihood of infection which is highly uncertain given the lack of data about PRV shedding rates from PRV-infected Atlantic Salmon, PRV decay rates in the marine environment, and the minimum dose of PRV required to infect Sockeye Salmon.

Uncertainties can be reported combined or separately. In this risk assessment, following advice from the peer-review of Mimeault et al. (2017) recommended separately reporting the

uncertainties for each step in the likelihood assessment as it was determined to be more transparent in describing weaknesses in the available data.

Table 1. Summary of the likelihood and uncertainty rankings for the likelihood assessment of the piscine orthoreovirus (PRV) risk assessment. Descriptions of the uncertainties can be found with each likelihood assessment steps; uncertainties are not combined. 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**	Extremely likely *(high certainty)*	
Release assessment	**Release pathways**	**Farmed Atlantic Salmon**	**Mechanical vectors and fomites**
	Likelihood of release	Extremely likely *(high certainty)*	Unlikely *(reasonable uncertainty)*
	Combined likelihoods of release	Extremely likely	
Exposure and infection assessments	**Exposure groups**	**At least one juvenile Fraser River Sockeye Salmon**	**At least one adult Fraser River Sockeye Salmon**
	Likelihood of exposure	Extremely likely *(reasonable certainty)*	Extremely likely *(reasonable certainty)*
	Likelihood of infection	Very likely *(high uncertainty)*	
Combined exposure and infection likelihoods for each exposure group		Very likely	Very likely
Combined likelihoods (farm infection, release, exposure and infection) for each exposure group		Very likely	Very likely

Consequence Assessment

The consequence assessment aims to determine the potential magnitude of impacts of PRV-1 attributable to infected Atlantic Salmon farms in the Discovery Islands area on the abundance of returning adults and diversity of Fraser River Sockeye Salmon, assuming that at least one Fraser River Sockeye Salmon would have been infected with the virus. Of most relevance to this risk assessment are the consequences of PRV-1 infection in Sockeye Salmon.

Juvenile Fraser River Sockeye Salmon

To date, there are three published studies (Garver et al., 2016a; Garver et al., 2016b; Polinski et al., 2016) and another in preparation, reporting on the impacts of PRV-1 infection in juvenile Sockeye Salmon. Together, these studies looked at multiple endpoints at different time points

over all phases of a PRV infection. Despite successful infection with the virus, no weight loss, no change in the ratio of volume of red blood cells to blood, no anemia, no consequences to respiratory functioning, no consistent tissue lesions, and no mortality could be attributed to the presence of PRV in juvenile Sockeye Salmon. In one study (Garver et al., 2016a), significant swelling of liver cells were observed in two PRV-infected Sockeye Salmon six months following challenge; a role for PRV involvement in these lesions was not conclusive.

Assuming that results from laboratory studies on the impact of PRV-1 infection in juvenile Sockeye Salmon are indicative of what occurs in the marine environment, it was concluded with reasonable certainty[2] that the potential magnitude of consequences to Fraser River Sockeye Salmon abundance and diversity would be negligible.

Adult Fraser River Sockeye Salmon

To date, the only study reporting on the impacts of PRV-1 infection in adult Sockeye Salmon looked at two Fraser River Sockeye Salmon stocks. While infection with PRV-1 in the marine environment was associated with migratory losses as fish entered the river for one stock, the opposite was reported in the other stock. Additionally, the odds ratio of mortality to spawning grounds between infected and uninfected individuals was not significant in both stocks (Miller et al., 2014).

Given the limited information specific to PRV-1 infections in adult Sockeye Salmon, surrogate data from different species and life stages were also considered. Notwithstanding that PRV-1 responses vary amoung salmon species, there are only rare occurrences of diseases associated with PRV-1 in farmed adult Atlantic Salmon or farmed Chinook Salmon (Di Cicco et al., 2018) in BC despite the ubiquitous nature and high prevalence of the virus. Additionally, based on studies conducted with juvenile Sockeye Salmon, PRV-1 from Pacific Canada appears to be of low virulence under laboratory conditions when using high viral loads (Garver et al., 2016a; Garver et al., 2016b; Polinski et al., 2016; Polinski and Garver, 2019).This study can be used as a proxy to adult Sockeye Salmon, hence PRV-1 is also expected to be of low virulence in adults.

The time between waterborne exposure and development of detectable PRV-1 infection from laboratory studies is four weeks in Atlantic and Sockeye salmon (Garver et al., 2016a). In the marine environment, Atlantic Salmon become PRV-1 positive following approximately three to four months after seawater transfer (Di Cicco et al., 2017; Polinski and Garver, unpublished data). Furthermore, it appears that PRV-1 transmission does not occur for approximately three weeks following infection (Polinski and Garver, 2019). Therefore, if returning adults were to become infected with PRV-1 in the Discovery Islands area, no significant spread of infection prior to spawning would be expected because the timeframe to reach the spawning grounds (up to 35 days) is shorter than the time required for an exposed salmon to become infectious.

Given that PRV-1 infection in returning Sockeye Salmon did not affect the odds of dying before reaching spawning grounds, that a PRV-1 infection is not expected to spread within adult Sockeye Salmon, and that PRV-1 appears to be of low virulence in juvenile Sockeye Salmon, it was concluded that the potential magnitude of consequences to Fraser River Sockeye Salmon

[2] See the “uncertainties in the consequence assessment” section, below.

abundance and diversity would be negligible. Due to the partial reliance on surrogate data from different life stage and different species, this conclusion was made with reasonable uncertainty[3].

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 PRV-1 infection attributable to Atlantic Salmon farms in the Discovery Islands area is minimal (Figure 3).

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

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. The "X" indicates the estimated risk.

[3] See the "Uncertainties in the consequence assessment" section, below.

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

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

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. The "X" indicates the estimated risk.

Sources of Uncertainty

Total 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).

Uncertainties in the likelihood assessment

The main uncertainties in the likelihood assessment are attributed to the lack of data on the effectiveness of biocontainment practices specifically for PRV-1; the lack of knowledge on the source(s) of PRV-1; the lack of knowledge on the survival of PRV-1 in the marine environment; the variability and knowledge gaps about precise migration routes of lake-type Fraser River Sockeye Salmon through the Discovery Islands area; the limited knowledge of the extent of Fraser River Sockeye Salmon interactions with Atlantic Salmon farms; the lack of knowledge of shedding rates from PRV-1 infected Atlantic Salmon; and the lack of knowledge of the minimum exposure time and dose required to result in a PRV-1 infection in juvenile and adult Fraser River Sockeye Salmon, at PRV-1 concentrations found in the wild.

Uncertainties in the consequence assessment

The main uncertainties in the likelihood assessment are attributed to the lack of knowledge of minimal infectious doses to infect Sockeye Salmon with PRV-1; the lack of knowledge of the spread of PRV-1 infections in Sockeye Salmon populations, and the lack of laboratory challenge studies with adult Sockeye Salmon.

The characterization of the uncertainty associated with the consequence assessment as reasonably certain for juvenile Fraser River Sockeye Salmon and reasonable uncertainty for adult Fraser River Sockeye Salmon was debated. A minority of participants expressed their assessment that the uncertainties associated with the consequence assessment were one step higher than presented in the risk assessment. This was based on their assessment of the quantity of publications and results, and the appropriateness of using laboratory study results to

estimate the consequences of PRV-1 infection in wild Sockeye Salmon. There was no consensus to change the uncertainty rankings (reasonable uncertainty and high uncertainty).

The uncertainties selected for the consequence assessment were based on the CSAS Policy on the Principle of Consensus in which "consensus means an absence of opposition to the meeting conclusions and advice that are based on scientific data and information and not on external considerations such as the potential impacts of future decisions….In many cases, some of the participants believe that additional data or more thorough analyses could support another conclusion or refine the conclusions and advice; however, they do not oppose the proposed conclusions, as these are supported by the current data and scientific analyses being considered".

The definitions used for assessing the uncertainties associated to the rankings in the likelihood and consequence assessments are:

- High uncertainty: No or insufficient data; and/or available data are of poor quality; and/or very high intrinsic variability; and/or experts' conclusions vary considerably.
- Reasonable uncertainty: Limited, incomplete, or only surrogate data are available; and/or available data can only be reported with significant caveats; and/or significant intrinsic variability; and/or experts and/or models come to different conclusions.
- Reasonable certainty: Available data are abundant, but not comprehensive; and/or available data are robust; and/or low intrinsic variability; and/or experts and/or models mostly agree.
- High certainty: Available data are abundant and comprehensive; and/or robust, peer-reviewed and published; and/or very low intrinsic variability; and/or experts and/or models agree.

CONCLUSIONS

Characterization of Piscine Orthoreovirus (PRV) and Associated Diseases

PRV-1 is ubiquitous and highly prevalent in net-pen farmed Pacific and Atlantic salmon of British Columbia and is also widely distributed in wild Pacific salmon at lower prevalence.

The environmental source(s) and transmission potential of PRV in ocean environments are unknown. Specifically, there are currently no data on environmental shedding (quantity or duration) or the minimum exposure dose (quantity or duration) required to establish an infection in any salmon species.

There is a current lack of understanding for why PRV-1 can show higher virulence in some instances compared to others. Where PRV-1 has been linked to disease in farmed salmon, it is as yet unclear as to whether all host, environment, and viral specific factors of these diseases can manifest in the natural environment in British Columbia.

Infections with PRV-1 in British Columbia generate high-load blood infections in both Atlantic and Sockeye salmon species but have failed to generate notable (moderate to severe) disease following experimental infection. To date, there is no evidence to suggest that PRV-1 causes disease or mortality in Sockeye Salmon.

Piscine Orthoreovirus (PRV-1) Transfer Risk Assessment

With the current state of knowledge, the assessment concluded that PRV-1 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 levels of the uncertainty attributed to the magnitude of consequences ranged from reasonable certainty to reasonable uncertainty. Expert participants came to different conclusions on the applicability and abundance of the data to support uncertainty estimates.

The attribution of the minimal risk was mainly influenced by the potential magnitude of consequences to Fraser River Sockeye Salmon. Despite concluding that it is very likely that one Fraser River Sockeye Salmon would become infected with PRV-1 attributable to Atlantic Salmon farms in the Discovery Islands area, the consequence of such infections to both Fraser River Sockeye Salmon abundance and diversity was assessed as being negligible.

There are sources of uncertainties associated with the determination of the risk to Fraser River Sockeye Salmon due to PRV-1 attributable to Atlantic Salmon farms in the Discovery Islands area. Sources of uncertainties include the lack of knowledge of the shedding rate in Atlantic Salmon infected with PRV-1, PRV-1 survival in the marine environment, and the minimum infectious doses of PRV-1 required to infect Sockeye Salmon. Additionally, there is a lack of knowledge about the persistence of PRV-1 infections in Sockeye Salmon and the spread of infections in migrating Fraser River Sockeye Salmon.

RECOMMENDATIONS

- Actions could be undertaken to reduce key areas of uncertainties and knowledge gaps, for example, determining shedding rates from PRV-1-infected salmon, and assessing prevalence and loads of PRV-1 in Fraser River Sockeye Salmon through surveillance. A number of specific research recommendations have also been identified in the pathogen paper (Polinski and Garver, 2019) and risk assessment (Mimeault et al., 2019).
- Conclusions of this risk assessment should be reviewed as new research findings fill knowledge gaps.
- If the audit program assesses changes in prevalence of lesions that have been related to PRV-1 exposure, audit samples could be used for further testing to determine if genetic make up or virulence of PRV-1 has changed.
- Undertake an assessment of factors influencing risk of importing exotic strains of PRV into BC.

OTHER CONSIDERATIONS

The considerations 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 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 is an area that warrants more study.

- The application of laboratory studies of pathogens to the assessment of risk is influenced by the experimental methods and design, including the need for minimal standards of diagnostic tools.
- This risk assessment is based on current industry size, 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
Boily, France	Fisheries and Oceans Canada
Bruneau, Nathalie	Canadian Food Inspection Agency
Burgetz, Ingrid	Fisheries and Oceans Canada
Farrell, Tony	University of British Columbia
Fuller, Chad	First Nations Fisheries Council of BC
Gagné, Nellie	Fisheries and Oceans Canada
Gardner, Ian	Atlantic Veterinary College UPEI
Garver, Kyle	Fisheries and Oceans Canada
Hewison, Tim	Grieg Seafood
Holt, Kendra	Fisheries and Oceans Canada
Johnson, Stewart	Fisheries and Oceans Canada
Jones, Simon	Fisheries and Oceans Canada
Marty, Gary	BC Animal Health Centre
Miller-Saunders, Kristi	Fisheries and Oceans Canada
Milligan, Barry	Cermaq Canada
Mimeault, Caroline	Fisheries and Oceans Canada
Olivier, Gilles (co-chair)	Fisheries and Oceans Canada
Parsons, Jay	Fisheries and Oceans Canada
Polinski, Mark	Fisheries and Oceans Canada
Powell, Mark	Institute of Marine Research Norway
Rechisky, Erin	Kintama Research
Riddell, Brian	Pacific Salmon Foundation
Rimstad, Espen	Norwegian University of Life Sciences (NMBU)
Rodger,. Hamish	Fish Vet Group
Roth, Myron	BC Ministry of Agriculture
Saksida, Sonja	Veterinary Consultant
Siah, Ahmed	BC Centre for Aquatic Health Sciences
Stephen, Craig (co-chair)	Canadian Wildlife Health Cooperative
Struthers, Alistair	Fisheries and Oceans Canada
Vendramin, Niccolo	Technical University of Denmark
Waddington, Zac	Fisheries and Oceans Canada
Weber, Lily	Fisheries and Oceans Canada
Werring, John	David Suzuki Foundation

The following experts provided written comments but did not attend the meeting:

Name	Affiliation
Meyers, Ted	Alaska Department of Fish and Game
Peeler, Edmund	Center for Environment Fisheries and Aquaculture Science (CEFAS)

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Fisheries and Oceans Canada
200 Kent Street
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Telephone: 613-990-0293
E-Mail: csas-sccs@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

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