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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

C. Mimeault[1], J. Wade[1], M.G.G. Foreman[2], P.C. Chandler[2], P. Aubry[3], K.A. Garver[4], S.C.H. Grant[5], C. Holt[4], S.R.M. Jones[4], S.C. Johnson[4], M. Trudel[6], I.J. Burgetz[1], and G.J. Parsons[1]

[1]Fisheries and Oceans Canada
Aquaculture, Biotechnology and Aquatic Animal Health Science
200 Kent, Ottawa, ON K1A 0E6

[2]Fisheries and Oceans Canada
Institute of Ocean Sciences
9860 West Saanich Road, Sidney, BC V8L 5T5

[3]Canadian Food Inspection Agency
Animal Health Science Division
1400 Merivale, Ottawa, ON K1A 0Y9

[4]Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road, Nanaimo, BC V9T 6N7

[5]Fisheries and Oceans Canada
Fraser River Stock Assessment Program
100 Annacis Parkway, Unit 3, Delta, BC V3M 6A2

[6]Fisheries and Oceans Canada
St. Andrews Biological Station
531 Brandy Cove Road, St. Andrews, NB E5B 2L9

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

An assessment was conducted to determine the extent of the risk to Fraser River Sockeye Salmon due to the potential transfer of Infectious Hematopoietic Necrosis Virus (IHNV) from Atlantic Salmon farms in the Discovery Islands of British Columbia under current fish health management practices.

The risk assessment was conducted in three main steps. First, an assessment of the likelihood that wild fish populations would be infected and become diseased due to IHNV released from Atlantic Salmon farms operating in the Discovery Islands under current fish health management practices (which includes assessments of the likelihood of disease, release, exposure and infection). Second, an assessment of the magnitude of consequences of IHNV attributable to Atlantic Salmon farms on Fraser River Sockeye Salmon (which includes assessments of the magnitude of consequences to abundance and diversity). Third, the combination of the likelihood and consequence assessments in risk matrices to obtain final risk estimates.

IHN outbreaks on Atlantic Salmon farms in the Discovery Islands are very unlikely given the current fish health management practices which include efficient vaccination for IHN. However, if an outbreak were to happen, IHNV would be released into the marine environment as infected farmed Atlantic Salmon shed the virus. In the event that IHNV is released from Atlantic Salmon farms, juvenile Fraser River Sockeye Salmon, a susceptible host, would be very likely to be exposed to the virus during their migration either by swimming into net pens holding farmed Atlantic Salmon or by swimming through IHNV plumes dispersed from the infected farm. However, the estimated maximum waterborne concentrations of IHNV under current fish health management practices would be several orders of magnitude lower than the minimum lethal dose of IHNV for juvenile Sockeye Salmon and infection would therefore be extremely unlikely. Overall, it was concluded that it is extremely unlikely that wild fish populations would be infected and become diseased due to IHNV released from Atlantic Salmon farms operating in the Discovery Islands under current fish health management practices.

There were no data to directly support the potential impact of IHNV on wild Fraser River Sockeye Salmon populations. Consequently, data from IHN epizootics in Sockeye Salmon smolts in Alaska which resulted in 8% mortality were used as a proxy for the potential magnitude of consequence on Fraser River Sockeye Salmon. It was concluded with high uncertainty that the potential magnitude of consequences to the abundance and diversity of Fraser River Sockeye Salmon resulting from IHNV infection attributable to Atlantic Salmon farms would be moderate representing between 5 and 10% reduction in the number of returning adult Fraser River Sockeye Salmon and no loss of Fraser River Sockeye Salmon conservation units.

Overall, the assessment concluded that IHNV attributable to Atlantic Salmon farms in the Discovery Islands poses minimal risk to Fraser River Sockeye Salmon abundance and diversity under the current fish health management practices. This risk assessment includes considerable sources of uncertainties, both due to intrinsic variability and knowledge gaps.

Évaluation du risque pour le saumon rouge du fleuve Fraser que représente le transfert du virus de la nécrose hématopoïétique infectieuse à partir des fermes de saumon atlantique situées dans la région des îles Discovery (Colombie-Britannique)

RÉSUMÉ

Une évaluation a été menée afin de déterminer l'étendue du risque pour le saumon rouge du fleuve Fraser que représente le transfert potentiel du virus de la nécrose hématopoïétique infectieuse (VNHI) à partir des fermes de saumon atlantique situées dans la région des îles Discovery (Colombie-Britannique), compte tenu des pratiques actuelles de gestion de la santé des poissons.

L'évaluation du risque a été réalisée en trois étapes principales. La première étape consistait en l'évaluation de la probabilité que les populations de poissons sauvages soient contaminées et deviennent malades à cause du VNHI provenant des fermes de saumon atlantique dans la région des îles Discovery, compte tenu des pratiques actuelles de gestion de la santé des poissons (y compris les évaluations de la probabilité de maladie, de dissémination, d'exposition et d'infection). La deuxième étape consistait en l'évaluation de l'ampleur des conséquences du VNHI, pour le saumon rouge du fleuve Fraser, qui sont attribuables aux fermes de saumon atlantique (y compris les évaluations de l'ampleur des conséquences sur l'abondance et la diversité). Finalement, la troisième étape consistait en une combinaison des évaluations de la probabilité et des conséquences dans les matrices des risques, afin d'obtenir des estimations définitives du risque.

La probabilité d'une épidémie de nécrose hématopoïétique infectieuse (NHI) dans les fermes de saumon atlantique des îles Discovery est considérée comme très faible compte tenu des pratiques actuelles de gestion de la santé, notamment la vaccination efficace contre la NHI. Toutefois, si une épidémie se produisait, le VNHI serait disséminé dans le milieu marin à mesure que les saumons atlantiques d'élevage infectés excrètent le virus. Dans le cas où le VNHI serait disséminé à partir des fermes de saumon atlantique, les saumons rouges juvéniles du fleuve Fraser, un hôte vulnérable, seraient sans doute exposés au virus pendant leur migration soit en nageant dans les parcs en filets d'élevage de saumons atlantiques ou en nageant dans des panaches de VNHI disséminés à partir des fermes infectées. Toutefois, les concentrations aqueuses maximales estimées de VNHI, compte tenu des pratiques actuelles de gestion de la santé des poissons, seraient de plusieurs ordres de grandeur inférieures à la dose infectieuse létale minimale pour le saumon rouge juvénile et une infection serait très peu probable. Dans l'ensemble, il a été conclu qu'il serait très peu probable que les populations de poissons sauvages soient infectées et tombent malades à la suite de la dissémination du VNHI à partir des fermes de saumon de l'Atlantique des îles Discovery, compte tenu des pratiques actuelles de gestion de la santé des poissons.

On n'a trouvé aucune donnée pour directement appuyer l'impact possible du VNHI sur les populations sauvages de saumon rouge du fleuve Fraser. Par conséquent, les données provenant des épizooties de NHI sur les saumoneaux rouges en Alaska qui ont provoqué une mortalité de 8% ont servi comme taux de mortalité de substitution pour évaluer l'ampleur des répercussions possibles sur le saumon rouge du fleuve Fraser. Ainsi, il a été conclu avec une incertitude élevée que l'ampleur des répercussions possibles sur l'abondance et la diversité du saumon rouge du fleuve Fraser dues à l'infection au VNHI attribuable aux fermes de saumon de l'Atlantique serait modérée, soit une diminution de 5 à 10% du nombre de saumons rouges adultes du fleuve Fraser en montaison, ce qui n'entraînerait pas la disparition des unités de conservation de saumons rouges du fleuve Fraser.

L'évaluation a permis de conclure que le VNHI attribuable aux fermes de saumon de l'Atlantique dans la région des îles Discovery pose un risque minime pour l'abondance et la diversité du saumon rouge du fleuve Fraser compte tenu des pratiques actuelles de gestion de la santé des poissons. Cette évaluation du risque comporte un grand nombre de sources d'incertitude, dues à la fois à la variabilité intrinsèque et au manque de connaissances.

1. INTRODUCTION

Fisheries and Oceans Canada (DFO) has a regulatory role to ensure the protection of the environment while creating the conditions for the development of an economically, socially and environmentally sustainable aquaculture sector. Restoring funding to support federal ocean science programs to protect the health of fish stocks, to monitor contaminants and pollution in the oceans, and to support responsible and sustainable aquaculture industries in Canada has been identified as a top priority of the Minister of Fisheries, Oceans and the Canadian Coast Guard.

It is recognized that there are interactions between aquaculture operations and the environment (Grant and Jones, 2010; Foreman et al., 2015b). One interaction is the risk to wild salmon populations resulting from the potential spread of infectious diseases from Atlantic Salmon (*Salmo salar)* farms in British Columbia (BC) (Cohen, 2012). While several Atlantic Salmon farms are located within the migratory routes of wild salmon species, no risk assessment has been conducted to specifically determine the risk to wild fish populations associated with pathogens released from Atlantic Salmon farms.

DFO Aquaculture Management Division requested formal science advice on the risk of pathogen transfer from Atlantic Salmon farms to wild fish populations in BC. Given the complexity of interactions between pathogens, hosts and the environment, DFO will deliver the science advice through a series of pathogen-specific risk assessments followed by a synthesis.

This document provides the scope, methodology and conclusions of the assessment of the risk to Fraser River Sockeye Salmon (*Onchorhynchus nerka*) from Infectious Hematopoietic Necrosis Virus (IHNV) on Atlantic Salmon (*Salmo salar*) farms in the Discovery Islands in BC. Risk posed to other wild fish populations and related to other fish farms, pathogens, and regions of BC will be determined through subsequent analyses and are consequently not included in this document.

2. OBJECTIVE

This risk assessment was conducted in response to a formal request for science advice from DFO’s Aquaculture Management Division. This assessment aims to determine the incremental risk to Fraser River Sockeye Salmon from IHNV infection attributable to Atlantic Salmon farms located in the Discovery Islands of BC under current farm practices.

3. BACKGROUND

This risk assessment is being conducted under the DFO Aquaculture Science Environmental Risk Assessment Initiative (hereinafter referred to as the Initiative) implemented as a structured approach to provide science-based risk advice to further support sustainable aquaculture in Canada.

To ensure consistency across risk assessments conducted under the Initiative, the Aquaculture Science Environmental Risk Assessment Framework (hereinafter referred to as the Framework) outlines the process and components of each assessment. The Framework is consistent with international and national risk assessment frameworks (GESAMP, 2008; ISO, 2009) and includes the establishment of management protection goals, a problem formulation, a risk assessment and the generation of science advice. The Framework ensures the delivery of systematic, structured, transparent and comprehensive risk assessments. Further details about the Initiative and the Framework are available on the DFO Aquaculture Science Environmental Risk Assessment Initiative webpage.

The process is enhanced by the inclusion of risk communication and a scientific peer-review through DFO's Canadian Science Advisory Secretariat (CSAS) that includes external scientific experts. All risk assessments conducted under the Initiative are science-based, do not include socio-economic considerations and are not cost-benefit or risk-benefit analyses.

3.1. MANAGEMENT PROTECTION GOALS

The management protection goals were determined in collaboration with DFO's Ecosystem and Fisheries Management and Ecosystems and Oceans Sciences sectors and approved by DFO Aquaculture Management.

In accordance with the recommendations pertaining to aquaculture and fish health in the 2012 final report of the Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River (Cohen, 2012), the valued ecosystem component in this risk assessment is the Fraser River Sockeye Salmon and the management protection goals are to preserve the abundance and diversity of the Fraser River Sockeye Salmon.

3.2. PROBLEM FORMULATION

The problem formulation was developed in collaboration with DFO's Ecosystems and Oceans Sciences and Ecosystem and Fisheries Management sectors and has been approved by Aquaculture Management Directorate. It defines the scope of the risk assessment including the identification of the hazards; the development of a conceptual model; the terminology and definitions to rank the likelihood of events, the severity of consequences and uncertainties; and the risk matrices to estimate the overall risk.

3.2.1. Hazard identification

A hazard is a biological, chemical or physical agent with the potential to cause an adverse health effect (OIE, 2010). In this risk assessment, the hazard is IHNV attributable to Atlantic Salmon farms in the Discovery Islands.

IHNV is known to cause an acute systemic, primarily salmonid disease, called Infectious Hematopoietic Necrosis (IHN) (OIE, 2012). IHN is on the list of the World Organisation for Animal Health notifiable diseases (OIE, 2016) and is a reportable disease in Canada. Consequently, all suspected and confirmed cases must be immediately reported to the Canadian Food Inspection Agency (CFIA).

3.2.2. Scope

The scope of the risk assessment is aligned with DFO's mandate to conserve wild fish and to ensure sustainable fisheries, including aquaculture. Recommendations from the Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River (Cohen, 2012) also contributed to defining the scope of this risk assessment, specifically recommendations 18 and 19:

Recommendation 18: "If at any time between now and September 30, 2020, the minister of fisheries and oceans determines that net-pen salmon farms in the Discovery Islands (fish health sub-zone 3-2) pose more than a minimal risk of serious harm to the health of migrating Fraser

River Sockeye Salmon, he or she should promptly order that those salmon farms cease operations" (Cohen, 2012).

Recommendation 19: "On September 30, 2020, the minister of fisheries and oceans should prohibit net-pen salmon farming in the Discovery Islands (fish health sub-zone 3-2) unless he or she is satisfied that such farms pose at most a minimal risk of serious harm to the health of migrating Fraser River Sockeye Salmon. The Minister's decision should summarize the information relied on and include detailed reasons. The decision should be published on the Department of Fisheries and Oceans' Website" (Cohen, 2012).

3.2.2.1. Farmed salmon species

Atlantic Salmon is the most predominant species of fish farmed in the marine environment in BC (DFO, 2011) and is highly susceptible to IHN. Consequently, this risk assessment focuses on the risk attributable to Atlantic Salmon farms and does not include Pacific salmon farms.

3.2.2.2. Region

DFO manages marine salmonid production in BC through aggregated areas called Salmonid Fish Health Zones (hereinafter referred to as Zones). The Discovery Islands (Zone 3-2) is an area located east of Vancouver Island, west of mainland BC, northwest of the Strait of Georgia and southeast of Johnstone Strait (Figure 1).

This risk assessment focuses on Atlantic Salmon farms located in Zone 3-2 and three farms located in Zone 3-3 adjacent to the northwest of Zone 3-2. These additional three farms were included due to their proximity to Zone 3-2 and potential oceanographic connectivity. For the purposes of this risk assessment, Atlantic Salmon farms in the Discovery Islands therefore refer to the ones located in Zone 3-2 and the three located in Zone 3-3 (Table 1).

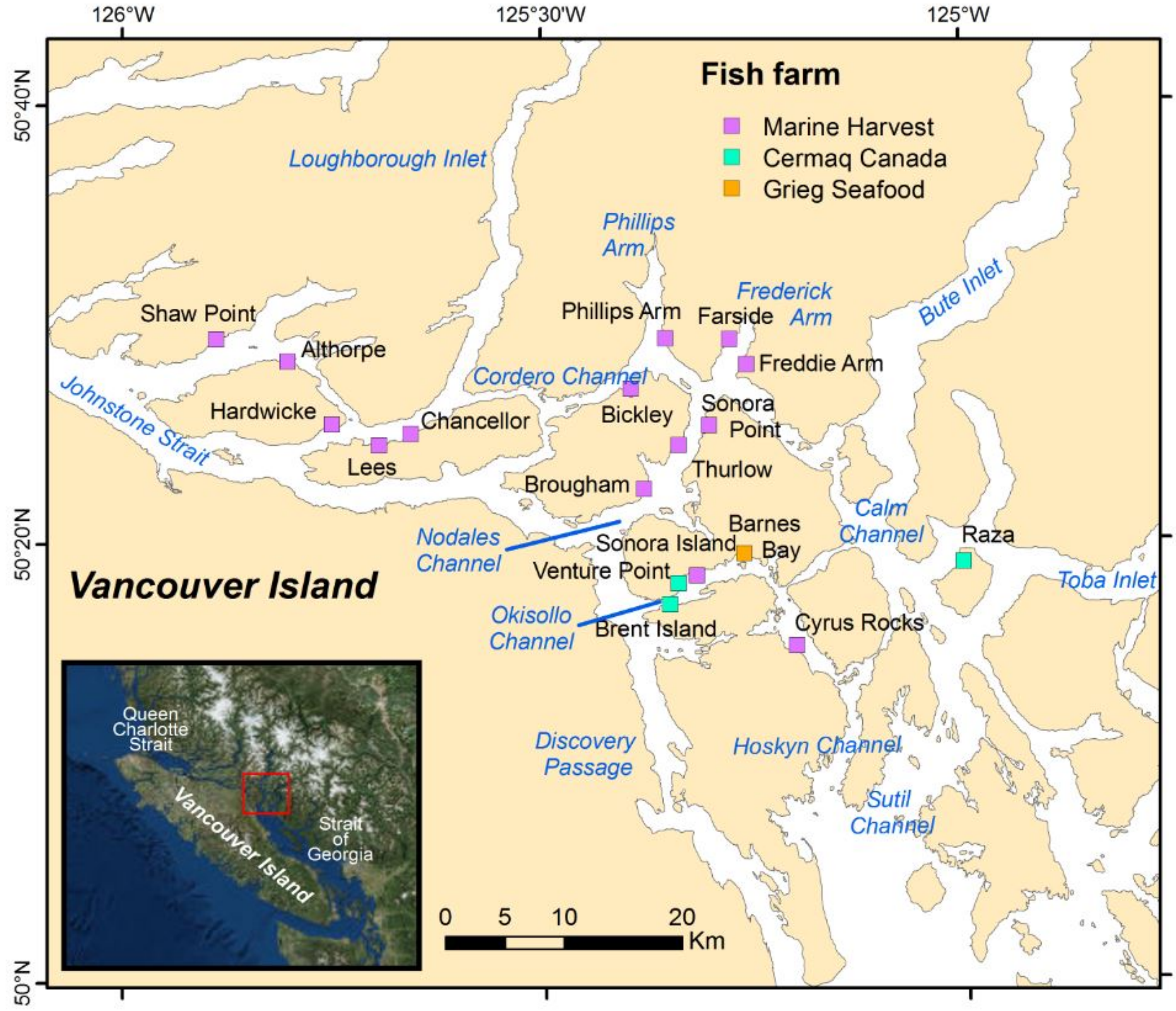

Figure 1. Locations of Atlantic Salmon farms in the Discovery Islands (Zone 3-2 and three farms in Zone 3-3) included in this risk assessment. Symbol size for fish farms is not to scale. Different colours represent different companies operating the farms as identified in the legend. The insert illustrates the location of the Discovery Islands in BC.

3.2.2.3. Current management practices

This assessment aimed to determine the risk under 2016 (hereinafter referred to as current) farm management practices in the Discovery Islands. All current fish health management practices on Atlantic Salmon farms were considered in this risk assessment including regulatory requirements and additional voluntary industry practices. Refer to Wade (2017) for a review of the current fish health practices on Atlantic Salmon farms in BC.

3.2.2.4. List of farms

All farms located in the Discovery Islands with a valid Atlantic Salmon licence as of January 2016 were considered in this risk assessment. However, as farms can hold a valid licence without producing Atlantic Salmon, only farms active at least once since December 2010 were included. DFO aquaculture management considers a farm to be active once three net pens have been stocked for a minimum of 30 days (Wade, 2017).

As of January 2016, there were 23 valid Atlantic Salmon aquaculture licenses in the Discovery Islands of which 18 had produced Atlantic Salmon at least once since December 2010, 15 in Zone 3-2 and three in Zone 3-3. A total of 18 Atlantic Salmon farms were therefore included in this risk assessment (Table 1).

Table 1. List of the 18 active Atlantic Salmon farms included in the risk assessment.

Company	Farm	Salmonid Fish Health Zone
Cermaq Canada	Brent Island	3-2
	Raza	3-2
	Venture	3-2
Grieg Seafood	Barnes	3-2
Marine Harvest Canada	Althorpe	3-3
	Bickley	3-2
	Brougham	3-2
	Chancellor	3-2
	Cyrus Rocks	3-2
	Farside	3-2
	Freddie Arm	3-2
	Hardwicke	3-3
	Lees	3-2
	Phillips Arm	3-2
	Shaw Point	3-3
	Sonora Point	3-2
	Sonora/Okisollo	3-2
	Thurlow	3-2

3.2.3. Risk question

What is the risk to Fraser River Sockeye Salmon abundance and diversity due to IHNV transfer from Atlantic Salmon farms located in the Discovery Islands under the current farm practices? Given that IHNV is endemic in BC, this assessment aims to determine the incremental risk to Fraser River Sockeye Salmon attributable to farmed Atlantic Salmon infected with IHNV.

3.2.4. Methodology

Experts in fields of Pacific salmon ecology, oceanography, fish health, IHNV, fish farm management and risk assessment collaborated on this risk assessment which follows a qualitative approach in which the output of the likelihood of an event and the magnitude of consequences are expressed in qualitative terms. The methodology is adapted from the DFO Guidelines for Assessing the Biological Risk of Aquatic Invasive Species in Canada (Mandrak et al., 2012), the World Organisation for Animal Health (OIE) Import Risk Analysis (OIE, 2010), recommendations for risk assessments in coastal aquaculture (GESAMP, 2008) and the Food and Agriculture Organization guidelines on understanding and applying risk analysis in aquaculture (FAO, 2008).

3.2.4.1. Sources of information

The information used to inform this risk assessment was summarized in the following four stand-alone documents describing the current state of knowledge based on literature reviews, data analysis and consultation with experts:

- "Oceanography and environmental conditions in the Discovery Islands in British Columbia" (Chandler et al., 2017)
- "Health management practices on Atlantic Salmon farms in British Columbia" (Wade, 2017)
- "Characterization of Infectious Hematopoietic Necrosis Virus (IHNV)" (Garver and Wade, 2017)
- "Summary of Fraser River Sockeye Salmon (*Oncorhynchus nerka*) ecology to inform pathogen transfer risk assessments in the Discovery Islands, BC" (Grant et al., in review)

3.2.4.2. Conceptual model

This paper assesses (i) the likelihood of wild fish populations to become infected and diseased by IHNV attributable to Atlantic Salmon farms in the Discovery Islands (likelihood assessment); (ii) the impact of IHNV transmission on the abundance and diversity of Fraser River Sockeye Salmon (consequence assessment); and (iii) the risk to Fraser River Sockeye Salmon abundance and diversity due to IHNV transfer from Atlantic Salmon farms located in the Discovery Islands under current farm practices. Figure 2 illustrates the conceptual model used for this risk assessment.

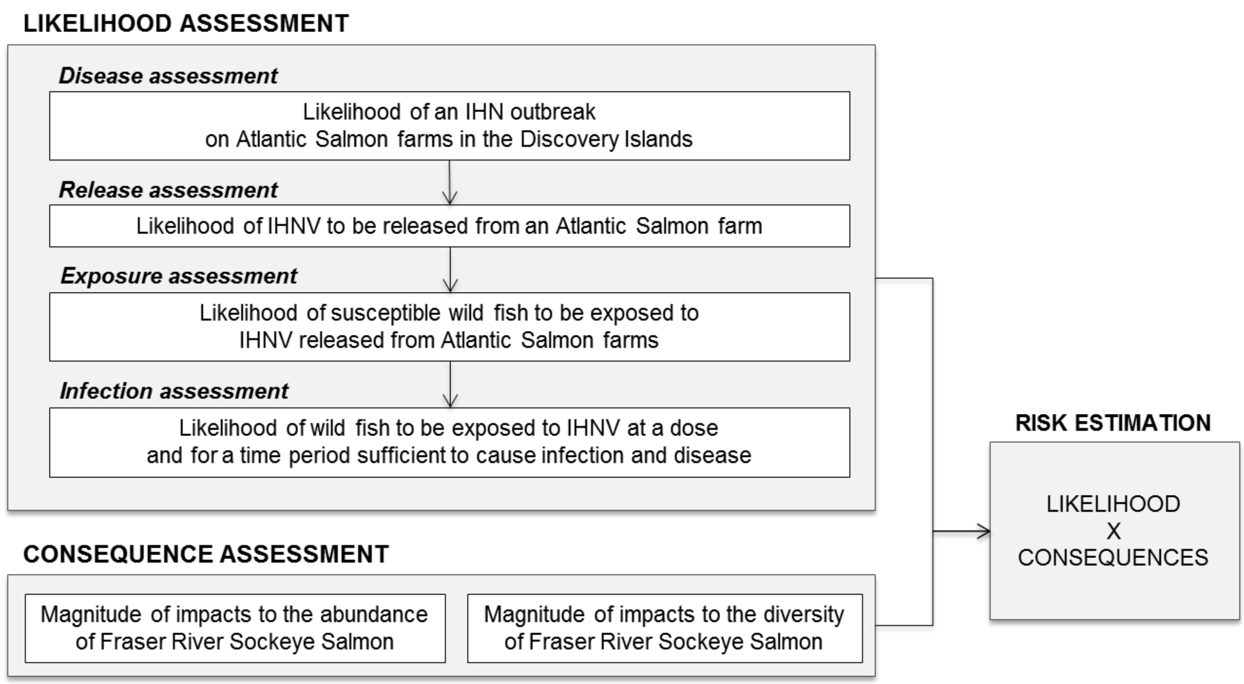

Figure 2. Conceptual model for the pathogen transfer risk assessment to Fraser River Sockeye Salmon from IHNV attributable to Atlantic Salmon farms located in the Discovery Islands, BC.

The likelihood assessment included four consecutive steps: disease assessment, release assessment, exposure assessment and infection assessment. The rankings of each assessment were combined to determine the overall likelihood of wild fish populations to become infected and diseased by IHNV attributable to Atlantic Salmon farms in the Discovery Islands. IHNV is endemic to BC and evidence suggests that wild Pacific salmon are the reservoir and farmed Atlantic Salmon are spillover hosts (Garver and Wade, 2017). However, as this assessment aims to determine the risk attributable to the transfer of IHNV from Atlantic Salmon farms in the Discovery Islands to wild fish populations, the disease assessment aims to determine the likelihood of an IHN outbreak on Atlantic Salmon farms in the Discovery Islands irrespective of the source of infection on the farms. The consequence assessment determines the potential magnitude of impact of IHNV infection attributable to Atlantic Salmon farms on the abundance and diversity of Fraser River Sockeye Salmon.

All steps of the likelihood and consequences assessments were ranked according to the categories and definitions included in the terminology section (3.2.4.4). The risk estimations were based on the integration of the results of the likelihood and consequence assessments using the risk matrices (refer to section 3.2.4.6).

3.2.4.3. 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 can be reduced with additional data or expert opinion (Vose, 2008).

Uncertainty can have important implications for decision making, therefore, to ensure transparency and accurate interpretation of the conclusions, the degree of uncertainty associated with each likelihood and consequence ranking is reported.

3.2.4.4. Terminology

The categories and definitions used to rank likelihood (Table 2), consequences to abundance (Table 3), consequences to diversity (Table 4), uncertainty for data and information (Table 5) and uncertainty for fish health management (Table 6) were determined prior to the commencement of the risk assessment.

Definitions of likelihoods and uncertainties categories were adapted from previous risk assessments (Cudmore et al., 2012; Mandrak et al., 2012; DFO, 2013c). Definitions of consequence categories were informed by DFO science and fisheries management. In particular, consequences to abundance with 25% and 50% decline (major and severe categories) are aligned with biological benchmarks for status assessments under the Wild Salmon Policy (Holt et al., 2009; Grant et al., 2011). Consequences on diversity are aligned with the level of diversity described by Conservation Units under Canada’s Wild Salmon Policy.

Table 2. Categories and definitions used to describe the likelihood of an event over a period of a year.

Categories	Definitions
Extremely unlikely	Event has little to no chance to occur
Very unlikely	Event is very unlikely to occur
Unlikely	Event is unlikely but might occur
Likely	Event is likely to occur
Very likely	Event is very likely to occur
Expected	Event is expected to occur

Table 3. Categories and definitions used to describe the potential consequences to the abundance of Fraser River Sockeye Salmon.

Categories	Definitions
Negligible	0 to 1% reduction in the number of returning Fraser River Sockeye Salmon
Minor	> 1 to 5% reduction in the number of returning Fraser River Sockeye Salmon
Moderate	> 5 to 10% reduction in the number of returning Fraser River Sockeye Salmon
Major	> 10 to 25% reduction in the number of returning Fraser River Sockeye Salmon
Severe	> 25 to 50% reduction in the number of returning Fraser River Sockeye Salmon
Extreme	> 50% reduction in the number of returning Fraser River Sockeye Salmon

Table 4. Categories and definitions used to describe the potential consequences to the diversity of Fraser River Sockeye Salmon.

Categories	Definitions
Negligible	No change in abundance over a generation in conservations units
Minor	Minor reduction in abundance in some conservation units that would not result in the loss of a Fraser River Sockeye Salmon conservation unit
Moderate	Moderate reduction in abundance in some conservation units that would not result in the loss of a Fraser River Sockeye Salmon conservation unit
Major	Major reduction in abundance in most conservation units that would not result in the loss of a Fraser River Sockeye Salmon conservation unit
Severe	Reduction in abundance that would result in the loss of a Fraser River Sockeye Salmon conservation unit
Extreme	Reduction in abundance that would result in the loss of more than one Fraser River Sockeye Salmon conservation unit

Table 5. Categories and definitions used to describe the level of uncertainty associated with data and information.

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

Table 6. Categories and definitions used to describe the level of uncertainty associated with fish health management. "Some" and "most" are respectively defined as less and more than 50% of relevant data.

Categories	Definitions
High uncertainty	• No information collected through farm management practices, as specified in Salmonid Health Management Plans, is available • Discrepancy between information/data obtained through farms and farm audits for all farms • Voluntary farm practice(s)
Reasonable uncertainty	• Some information collected through farm management practices, as specified in Salmonid Health Management Plans, is available • Discrepancy between information/data obtained through farms and farm audits for most farms • Voluntary company practice(s)
Reasonable certainty	• Most information collected through farm management practices, as specified in Salmonid Health Management Plans, is available • Corroboration between information/data obtained through farms and farm audits for most farms • Voluntary industry-wide practice(s) agreed through a Memorandum of Understanding
High certainty	• All information collected through farm management practices, as specified in Salmonid Health Management Plans, is available • Corroboration between information/data obtained through farms and farm audits for all farms • Mandatory practice(s) required under legislation

3.2.4.5. Combination rules

The combination of likelihoods and uncertainties differs if events are dependent or independent. An event is dependent when its outcome is affected by another event. For example, infection can only happen if exposure took place, consequently infection is dependent on exposure. Events are independent when the outcome of one event does not affect the outcome of other event(s); for example, a pathogen can be released into the environment via different unrelated pathways.

Likelihoods are combined as per accepted methodologies in qualitative risk assessments adopting the lowest value (e.g., low) for dependent events and the highest value (e.g., high) for independent events (Cox, 2008; Gale et al., 2010; Cudmore et al., 2012). However, when events are independent but not mutually exclusive, i.e., could occur concurrently, the adoption of the highest likelihood might underestimate the overall likelihood.

Methodology for combining qualitative uncertainty rankings in risk assessments is not as clearly defined as for combining likelihoods. Some authors report uncertainty for every step without combination (Peeler and Thrush, 2009; Jones et al., 2015), others adopt the highest uncertainty (Mandrak et al., 2012) while finally others adopt the highest uncertainty associated with the lowest likelihood for dependent events (Cudmore et al., 2012). Table 7 details the combination rules used in this risk assessment.

Table 7. Combination rules for likelihood and uncertainty rankings and risk determination.

Step	Combination rule	Combination rule with tied likelihoods
Independent events	Adopt the highest likelihood and its corresponding uncertainty	Adopt the highest uncertainty of the tied likelihoods
Dependent events	Adopt the lowest likelihood and its corresponding uncertainty	
Risk	Determined based on the risk matrix; uncertainties are not combined	

3.2.4.6. Risk estimation

Risk matrices are widely used in qualitative risk assessments to integrate and communicate the results of likelihood and consequence assessments (Cudmore et al., 2012; Mandrak et al., 2012; Canadian Food Inspection Agency, 2013).

Two risk matrices were developed in collaboration with DFO's Ecosystems and Oceans Sciences and Ecosystem and Fisheries Management sectors to categorize the risk estimates for the abundance (Figure 3) and diversity (Figure 4) of Fraser River Sockeye Salmon. They are aligned with relevant scale of consequences for fisheries management and policy purposes, existing policy and current management risk tolerance relevant to the risk assessments.

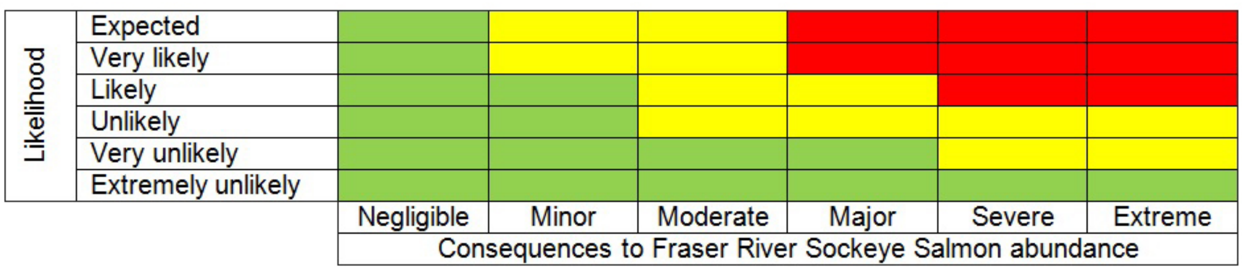

Figure 3. Risk matrix for combining the results of the likelihood and consequence to Fraser River Sockeye Salmon abundance assessments. Green, yellow and red, respectively, represent minimal, moderate and high risk.

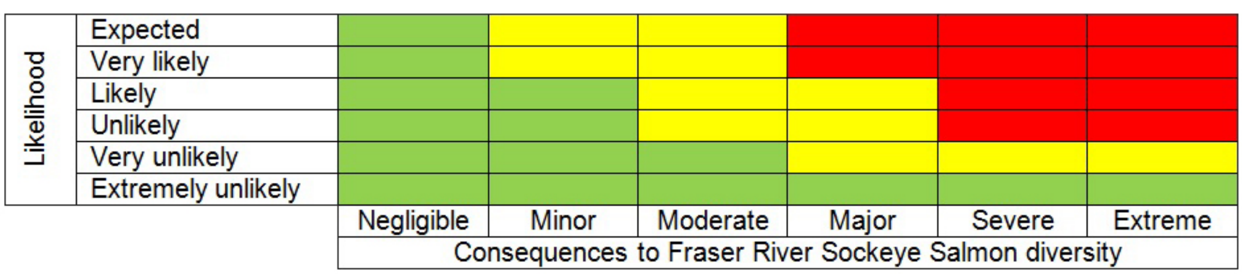

Figure 4. Risk matrix for combining the outputs of the likelihood and consequence to Fraser River Sockeye Salmon diversity assessments. Green, yellow and red, respectively, represent minimal, moderate and high risk.

3.2.4.7. Rankings

Rankings for each step of the risk assessment are the result of meetings between experts in the fields of Pacific salmon ecology, oceanography, fish health management, IHNV and risk assessment. Once consensus was reached, all steps were combined according to the combination rules (Table 7) and risk estimations were determined based on risk matrices (Figure 3 and Figure 4).

3.3. HAZARD CHARACTERIZATION

The hazard characterization includes a brief description of IHN pathology, hosts, susceptibility, distribution, prevalence and transmission; more details are provided in Garver and Wade (2017).

3.3.1. Pathology

IHN is a disease, caused by the IHNV, that has led to significant mortality in both wild and cultured salmon and trout populations (Bootland and Leong, 1999). Signs of IHN include darkening of the skin, pale gills, bulging eyes, distended abdomen and areas of pinpoint bleeding internally and externally (OIE, 2012; Canadian Food Inspection Agency, 2016). Behavioural signs include lethargy interspersed with bouts of frenzied, and abnormal activity (OIE, 2012; Canadian Food Inspection Agency, 2016).

3.3.2. Hosts and susceptibility

Natural infections and controlled laboratory exposure studies indicate that IHNV has a broad host range. Although primarily identified in salmonids, IHNV has also been found in non-salmonids and invertebrates (reviewed in Garver and Wade (2017)). Infection can cause disease in some hosts and may be transient in others.

Atlantic Salmon is one of the most susceptible species to IHNV (Garver and Wade, 2017). Several cases of IHNV infection and disease have occurred in marine reared Atlantic Salmon in western North America (Mulcahy and Wood, 1986; St-Hilaire et al., 2002; Saksida, 2006).

Sockeye Salmon, Rainbow Trout/steelhead (*O. mykiss*) and Chinook Salmon (*O. tshawytscha*) are considered highly susceptible to IHN (reviewed in Garver and Wade (2017)). Coho Salmon (*O. kisutch*) and Pink Salmon (*O. gorbuscha*) can be infected by IHNV but are considered least susceptible to IHN based on the absence of reports of natural outbreaks and low to no mortality in experimental studies (reviewed in Garver and Wade (2017)). Other salmonids in which IHNV infection has been reported include Chum Salmon (*O. keta*), Brook Trout (*Salvelinus fontinalis*), Brown Trout (*S. trutta*) and Lake Trout (*S. namycush*) (reviewed in Garver and Wade (2017)).

Few non-salmonids such as Pacific Herring (*Clupea pallasii*) (n=1), Shiner Perch (*Cymatogaster aggregata*) (n=1) and Tubesnout (*Aulorhynchus flavidus*) (n=2) captured in BC have tested positive for IHNV but did not show clinical signs of disease (Kent et al., 1998). Based on the scientific literature, IHNV can infect several non-salmonid fish species; however, the infection appears to be transient and whether such infections could result in alternative or reservoir hosts for IHNV remains unknown (Garver and Wade, 2017).

IHNV has also been detected in mayflies (*Callibaetis* spp.) (Shors and Winston, 1989), leeches (*Piscicola salmositica*) (Mulcahy et al., 1990), and ectoparasitic copepods (*Salmincola* sp. and *Lepeophtheirus salmonis*) (Mulcahy et al., 1990) without confirmation of virus replication (Garver and Wade, 2017). The available data suggest that invertebrates may harbour the virus for only brief periods of time, during which they may serve as mechanical vectors (Garver and Wade, 2017).

In addition to differences in IHN susceptibility among species, variability in susceptibility also exists at the stock level as documented in Chinook Salmon (Wertheimer and Winton, 1982) and Sockeye Salmon (Garver and Wade, 2017) and also in life stage, age, and/or size of the host upon exposure to the virus (LaPatra et al., 1990). Natural IHNV associated mortality has been documented in fry and juveniles Pacific salmon while neither disease nor epizootics have been reported in returning adult Pacific salmon that have tested positive for IHNV (Garver and Wade, 2017). Decreasing IHN susceptibility with increasing age has been documented through laboratory studies exposing Rainbow Trout and Sockeye Salmon (reviewed in Garver and Wade (2017)).

3.3.3. Distribution

IHNV is endemic to the western coast of North America from Alaska to California (Garver and Wade, 2017).

3.3.4. Prevalence in wild Sockeye Salmon populations

Annual prevalence of IHNV in spawning adult Sockeye Salmon in BC is highly variable within and among stocks (Garver and Wade, 2017). For example, between 1987 and 2015, prevalence of IHNV in spawning adults varied from 0 to 50% (average of 9%) in Weaver Creek and from 0 to 62% (average of 11%) in Nadina River (Garver and Wade, 2017) .

Prevalence of IHNV in juvenile Fraser River Sockeye Salmon between 2010 and 2015 varied from 0 to 10.5% during their out-migration through the Strait of Georgia and Discovery Islands (Garver and Wade, 2017).

3.3.5. Transmission

The primary mode of IHNV transmission is horizontal within and among wild salmon populations. Atlantic Salmon can become infected through cohabitation with IHNV infected fish (Traxler et al., 1993) or simply through exposure to virus contaminated water (Garver et al., 2013; Kurath et al., 2016). The waterborne virus infects hosts through the gills, skin, fin bases, oral region and the oesophagus/cardiac region (reviewed in Bootland and Leong (1999)). The onset and progression of IHN is highly dependent on the exposure dose (Garver and Wade, 2017).

There is indirect evidence of egg associated transmission of IHNV to developing embryos (Garver and Wade, 2017). This mode of transmission can be mitigated in hatcheries by properly disinfecting the eggs.

Analyses of IHN outbreaks on Atlantic Salmon farms concluded that IHNV can spread within and among farms (St-Hilaire et al., 2002; Saksida, 2006). Additionally, results from hydrodynamic ocean circulation models estimating potential infective connectivity among farms suggest that IHN diseased farms have the potential to expose neighboring unvaccinated farms to an infectious dose of virus through water current dispersion (Foreman et al., 2015b).

3.4. ATLANTIC SALMON PRODUCTION IN THE DISCOVERY ISLANDS

DFO has the primary responsibility for the regulation and management of aquaculture in BC since December 2010 through the *Pacific Aquaculture Regulations* developed under the *Fisheries Act*.

3.4.1. Farm dimensions

Atlantic Salmon in the Discovery Islands are reared in net pens, typically consisting of an array of 10 to 18, 24 m x 24 m, 30 m x 30 m or 36 m x 36 m cages (Wade, 2017). Based on data provided by DFO Aquaculture Management in April 2016, the average surface area of containment arrays on Atlantic Salmon farms in the Discovery Islands was estimated to be 10,194 m^2 and the average depth of net pens was calculated to be of 19.1 m from which the average volume was calculated to be 194,705 m^3.

3.4.2. Production on active Atlantic Salmon farms

Based on data provided by DFO Aquaculture Management, since December 2010, the average duration of an Atlantic Salmon production cycle in the Discovery Islands is 17 months, ranging from 11 to 23 based on complete production cycles (n=18). Cycles initiated before December 2010 or incomplete in February 2016 were not included.

Between 2010 and 2016, the total number of active farms (Figure 5A), total biomass (Figure 5B) and total number of Atlantic Salmon (Figure 5C) in the Discovery Islands varied within and among years. This variation is attributed to fish being harvested year round and/or being transferred, with appropriate permitting, into to the Discovery Islands after first being stocked elsewhere as smolts. Smolts are not stocked directly in the Discovery Islands due to the risk of infection from *Kudoa* sp., a parasite of marine fishes (Wade, 2017).

Of the 18 sites in production from December 2010 to February 2016, there was an average of eight active Atlantic Salmon farms in any given month. At any time between January 2013 and February 2016, there was an average of 11,000 tonnes of fish or 3.36 million fish in production. Atlantic Salmon farms in operation between January 2013 and February 2016 had on average 517,000 ± 54,000 fish/farm. Data prior to January 2013 were not available.

Farm production data including total number of fish on the farm, fish biomass and number of active farms were analysed by month to identify any seasonal variation in production (Figure 5). One-way ANOVA did not detect any significant statistical differences among months (alpha=0.05) in the number of active farms (p=0.956), biomass (p=0.980), or number of Atlantic Salmon (p=0.955) suggesting no seasonal pattern in Atlantic Salmon production in the Discovery Islands.

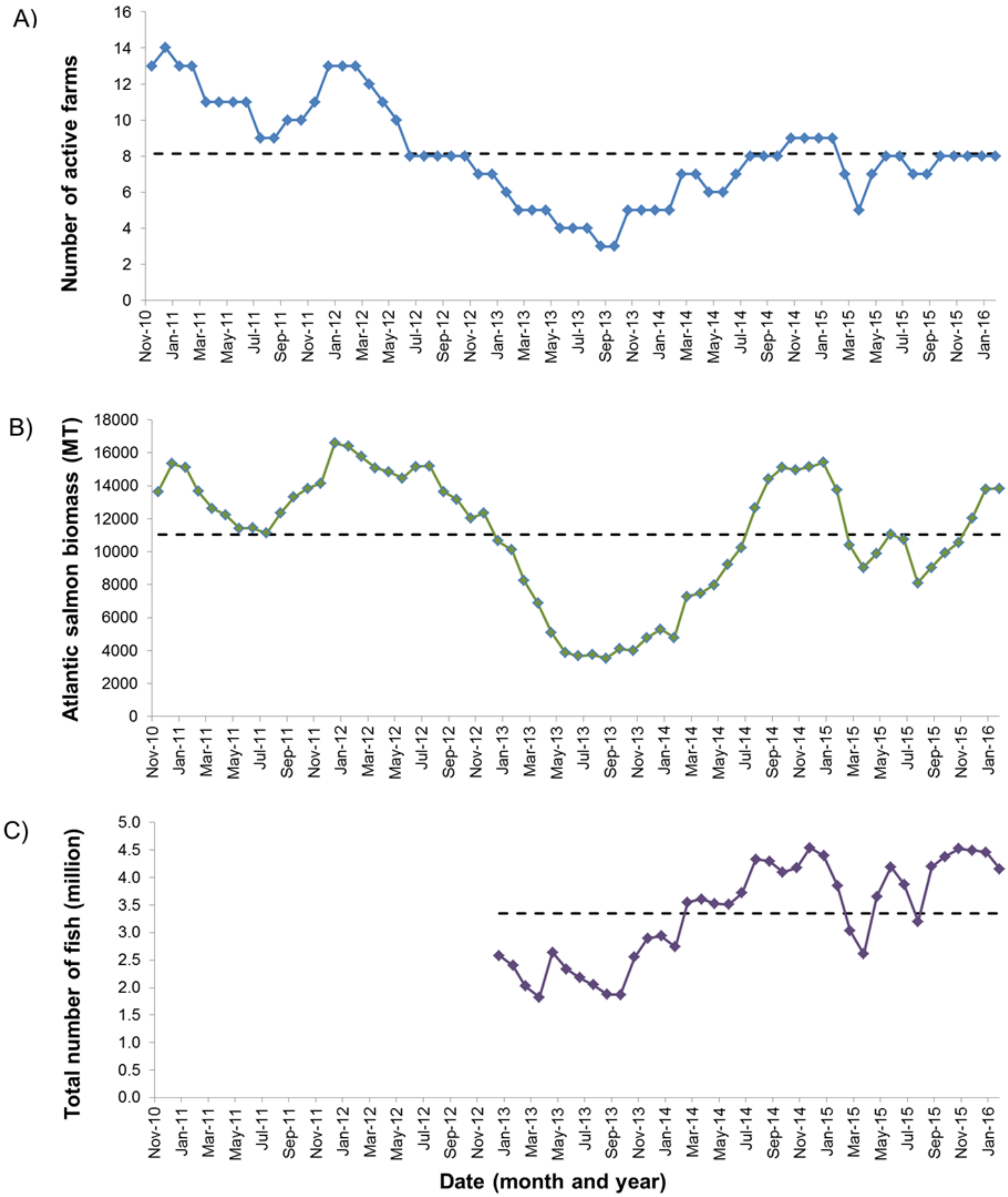

Figure 5. Summary of Atlantic Salmon production in the Discovery Islands. Panels A and B, respectively, represent the number of active farms holding Atlantic Salmon by month and the total biomass (metric tonnes) of Atlantic Salmon held by month between December 2010 and February 2016. Panel C represents the total number of fish in net pens in this region between January 2013 and February 2016 (earlier data are not available). Dashed lines represent average values. Data from Fisheries and Oceans Canada.

4. LIKELIHOOD ASSESSMENT

The likelihood assessment consists of determining the likelihood that Atlantic Salmon farms located in the Discovery Islands would release IHNV into an environment accessible to wild fish populations and expose them to a dose and for a period of time sufficient to cause infection and disease. It includes a disease assessment, a release assessment, an exposure assessment and an infection assessment.

4.1. DISEASE ASSESSMENT

The disease assessment consists of determining the likelihood, in any given year, of an IHN outbreak on Atlantic Salmon farms in the Discovery Islands under the current fish health management practices.

4.1.1. Question

In a given year, what is the likelihood of an IHN outbreak on Atlantic Salmon farms in the Discovery Islands under the current fish health management practices?

4.1.2. Considerations

Relevant considerations include the endemism of IHNV in BC, historical IHN prevalence on Atlantic Salmon farms in BC, aquaculture regulatory requirements, industry practices and IHN vaccine efficacy.

4.1.2.1. IHNV is endemic to BC

IHNV occurs naturally in the waters of western North America with highly variable prevalence within and among Sockeye Salmon populations in BC (Garver and Wade, 2017) (refer to sections 3.3.3 and 3.3.4).

Given that IHNV is endemic to BC, and based on evidence of prevalence in some juvenile Sockeye Salmon prior to migration through the Discovery Islands (Garver and Wade, 2017), Sockeye Salmon juveniles can be exposed to IHNV prior to reaching Atlantic Salmon farms located in the Discovery Islands. It has been suggested that juvenile Sockeye Salmon could be a potential source of IHNV to farmed Atlantic Salmon held in net pens (Garver and Wade, 2017).

4.1.2.2. IHN on Atlantic Salmon farms in BC (outbreak statistics)

IHN outbreaks and epizootics have occurred in marine Atlantic Salmon farms in BC (St-Hilaire et al., 2001a; Saksida, 2006; Garver and Wade, 2017). In all cases, fish were unvaccinated against IHN disease. Current industry practices include vaccination of all smolts against IHN (Wade, 2017). Refer to Garver and Wade (2017) for further details about the specifics of each outbreak and to Wade (2017) for more details on current fish health management practices.

4.1.2.2.1. The 1992-1996 epizootic

In 1992, IHNV was reported for the first time in Atlantic Salmon from net pens in BC (Armstrong et al., 1993). The first infection occurred in July at a farm located in the Discovery Islands just east of Campbell River (Garver and Wade, 2017). The epizootic lasted for five years ultimately infecting 13 farms within 20 km of the suspected index case on which mortality ranged between

18 and 78% (St-Hilaire et al., 2002). Depopulation of infected fish was not a requirement of licence or a standard industry practice at the time.

The spatial and temporal distribution of infected cases, their duration, the genetic similarity between isolates collected from different farms, and the effectiveness of an area management plan that resulted in a sharp decrease in incidence of disease, all support the hypothesis of a single index case followed by farm to farm spread of disease during these years (St-Hilaire et al., 2002).

4.1.2.2.2. The 2001-2003 epizootic

In 2001, IHNV was confirmed in farmed Atlantic Salmon (Saksida, 2006). The epizootic lasted for three years ultimately encompassing 13 farms in the Discovery Islands and spreading to four other areas affecting a total of 36 farms operated by five different companies during which cumulative mortality averaged 58% (Saksida, 2006). Evidence points towards two separate introductions of the virus, each followed by farm to farm transmission (Saksida, 2006). The first index case occurred in the Discovery Islands in August 2001, and the second one off the west coast of Vancouver Island in March 2002. Depopulation of infected fish was not a requirement of licence or a standard industry practice at the time.

Temporal and spatial analyses of outbreaks within this epizootic suggest that spread most likely occurred via natural waterborne transmission for farms located in close proximity to an infected farm. Transmission to regions outside of the Discovery Islands most likely occurred through moving fish from one site to another, through the movement of personnel and equipment between sites and the practice of pumping water through well boats during transport of fish in areas positive for IHNV or which were harvesting IHNV positive fish.

4.1.2.2.3. The 2012 outbreaks

In 2012, IHNV was confirmed on three Atlantic Salmon farms: Dixon and Millar farms off the West Coast of Vancouver Island (one in May and one in August) and Culloden farm on the Sunshine Coast (in August). All fish were depopulated from infected farms between 4 to 14 days after confirmation of positive samples for IHNV (Garver and Wade, 2017).

The IHN outbreak periods were defined as ten days prior to the date on which samples that first tested positive for IHNV were collected until complete farm depopulation. The average percent daily mortality during the outbreaks were consequently 0.21% on Dixon farm (April 29 to May 22, 2012: 23 days), 0.04% on Millar farm (July 15 to August 15, 2012: 31 days) and 0.18% on Culloden farm (July 21 to August 9, 2012: 19 days). Comparison of outbreak durations and average mortalities on different farms should however be done with caution as they depend on surveillance protocols and period of time between confirmation and depopulation. Due to the physical separation and/or temporal nature of the three detections of IHNV on Atlantic Salmon farms in BC outside of the Discovery Islands in 2012, it is believed that each occurrence represents a separate introduction from a wild source rather than farm to farm spread (Garver and Wade, 2017).

Despite the 2012 IHN outbreaks on Atlantic Salmon farms in BC, none occurred in the Discovery Islands during that year (Garver and Wade, 2017) where all Atlantic Salmon farms had been vaccinated against IHN disease.

4.1.2.3. Regulatory requirements

4.1.2.3.1. Licensing requirements

Fisheries and Oceans Canada is responsible for issuing aquaculture licenses for marine finfish, shellfish and freshwater operations in BC. Farms operating in BC require a Finfish Aquaculture Licence under the *Pacific Aquaculture Regulations*. Licence holders are authorized to conduct aquaculture activities by complying with the *Fisheries Act*, related regulations and licence conditions which include the requirement for a Salmonid Health Management Plan (SHMP) and accompanying proprietary Standard Operating Procedures (SOPs) (DFO, 2016b).

The SHMP outlines the health concepts and required elements associated with a finfish aquaculture licence (Wade, 2017), while accompanying SOPs detail the procedures to address specific concepts of the SHMP such as biosecurity, fish handling and fish health (DFO, 2015; Wade, 2017).

In BC, SOPs are submitted to Pacific Region DFO Aquaculture Management Division for review and response upon submission of a new licence application. Once a licence has been granted, the licence holder must annually submit all amendments to the SOPs, or indicate no changes (Wade, 2017). In the event of a suspected reportable disease or outbreak of a reportable disease such as IHN, companies are required to report to CFIA. Details of the above process, SHMP and SOPs are described in Wade (2017).

4.1.2.3.2. Fish transfer and movement controls

Live fish are transferred between land-based hatcheries and marine grow-out sites as well as between marine grow-out sites (Wade, 2017). Such transfers are regulated through the BC Introduction and Transfers Committee and through the CFIA under the National Aquatic Animal Health Program (NAAHP) (Wade, 2017).

Since September 2015, any movement of live fish into or within BC to a fish-rearing facility requires a licence from the BC Introduction and Transfers Committee, a joint federal-provincial committee comprised of members from the DFO, the BC Ministry of Environment, and the BC Ministry of Forests, Lands & Natural Resource Operations (DFO, 2016a). The BC Introduction and Transfers Committee is responsible for reviewing transfers that could affect wild or cultured fish to maintain their healthy productive populations (DFO, 2016a). Each application to transfer live fish is reviewed for effects on the incidence, distribution and/or impact of pathogens and parasites on native species.

Authorizations to move aquatic animals under the NAAHP are subject to relevant import or domestic program requirements (DFO, 2013b). A CFIA-issued import permit is required under the NAAHP to import species susceptible to diseases of concern. More information on the import program is available on the CFIA Aquatic Animal Import webpage. For domestic movements, the CFIA has assigned to each applicable province/territory or part of a province/territory, as well as the territorial sea and contiguous zone of Canada a specific disease status for reportable diseases that occur in Canada. Movements from an area of lower health status to an area of higher health status require a CFIA domestic movement permit. More information on the domestic movement program is available on the CFIA Aquatic Animal Domestic Movements webpage.

Additionally, as a licence condition, growers are required to have a SOP which addresses the movement of fish between facilities which includes the requirement to have the appropriate permits in place before transferring fish in an effort to minimize stress, transmission of pathogens or possible escape (Wade, 2017).

4.1.2.3.3. DFO's audit program

Licensed marine salmon farms in BC are audited by DFO's BC Aquaculture Regulatory Program (BCARP). Wade (2017) provides a description of the audit program, the audit checklist and audit deficiencies. Briefly, the audit program consists of three main activities: (i) monitoring of activities and review of health-related records at marine farms using a compliance inspection; (ii) collection of samples from recently dead fish; and (iii) comparison of DFO audit results to reports submitted to DFO (Wade, 2017).

All samples collected during audits are analyzed by accredited diagnostic services laboratories using test methods which conform to international standards (Wade, 2017). From 2002 to 2016, a total of 240 Atlantic Salmon farm audits were conducted in the Discovery Islands from which 1,382 fish were tested for IHNV. Of the farms tested in the Discovery Islands, one was reported positive for IHNV in October 2002 (Wade, 2017).

Audits are conducted using an inspection checklist which includes over 65 questions about biosecurity; feed, nutrition and medication; water quality monitoring; fish health; sea lice; fish handling, euthanasia and welfare; and disease outbreak and kill contingency plan (Wade, 2017). Identified deficiencies are categorised and publicly reported on DFO's Aquaculture Pacific Region website.

From 2011 to 2015, 465 audits of Atlantic Salmon farms were conducted in BC, most of which (59%) reported no deficiencies (Wade, 2017). When deficiencies were identified, an average of 1.7 deficiencies per audit were reported (Wade, 2017). The most reported deficiencies pertain to sea lice protocols and records (27%) which are most often a transcriptional error between paper copies of records and electronic files. The next most frequent deficiency related to carcass retrieval protocol or record (18%), is most often a failure to create an adequate barrier between dead fish and equipment or adequate disinfection. The next two most frequent deficiencies pertain to mooring signage (15%) and transfer records (15%) (Wade, 2017). For a detailed list of reported DFO audit deficiencies in Atlantic Salmon farms and a copy of the inspection checklist refer to Wade (2017).

4.1.2.4. Industry practices

4.1.2.4.1. IHNV testing by the industry

Diagnostic testing is conducted according to each company's SOPs and/or upon instruction by the company veterinarian or other person responsible for the major fish health decisions. All companies have in-house criteria (e.g., mortality levels, unusual behaviour, etc.) which trigger site visits (Wade, 2017). All industry-driven diagnostic testing is voluntary and informs management decisions within the company, hence the level of testing varies by company (Wade, 2017).

Between 2011 and 2015 inclusively, Grieg Seafood, Marine Harvest Canada and Cermaq Canada collectively conducted 4,060 cell culture and 11,084 polymerase chain reaction (PCR) tests for IHNV in BC (Wade, 2017). These numbers do not include any broodstock or pre-transfer smolt testing. A total of 135 tests confirmed the presence of IHNV on three unvaccinated farms (Grieg Seafood and Cermaq Canada) located outside of the Discovery Islands in 2012, which corresponds to the known IHN outbreaks (refer to section 4.1.2.2) (Wade, 2017).

4.1.2.4.2. Viral Management Plan

Beginning in 2011, Marine Harvest Canada, Grieg Seafood and Cermaq Canada in collaboration with the BC Salmon Farmers' Association (BCSFA) developed and agreed upon a Salmon Farming Industry Viral Disease Management Plan (Viral Management Plan) which outlines procedures and cooperation between farms and companies to minimize the spread of disease and in the event of an outbreak to minimize spread (Wade, 2017). The Viral Management Plan is an initiative driven by the industry and is not a condition of licence. It is reviewed, updated and approved by all participating members each year. Refer to Wade (2017) for thorough description of the Viral Management Plan.

4.1.2.4.3. Vaccination against IHN in the Discovery Islands

Vaccination of farmed Atlantic Salmon is not a requirement of licence (Wade, 2017). Since 2011, in accordance with the Viral Management Plan, viral vaccines have been used in what the industry considered "high risk" areas (Wade, 2017) which includes the Discovery Islands. Since 2015, all companies have vaccinated Atlantic Salmon against IHNV in all BC production areas (Wade, 2017). Consequently, all Atlantic Salmon reared in the Discovery Islands are currently vaccinated against IHNV with the APEX-IHN® vaccine (Wade, 2017).

4.1.2.4.4. Syndromic surveillance

Syndromic information in this context refers to any data or information that can aid in the early detection of illness or disease, or in the production and health management of stocks. Information such as biosecurity protocols, facility inspections, animal import requirements and disease monitoring programs can provide different types of syndromic information (Gustafson et al., 2010). Examples of syndromic information collected by salmon farmers include water parameters (dissolved oxygen, salinity, and temperature), causes of mortality, food consumption, stressful events (e.g., storms, toxic phytoplankton and predator attacks), routine necropsies and pathogen screening data (Wade, 2017).

4.1.2.4.5. Third party certifications

Some Atlantic Salmon farm companies in BC are certified through the Best Aquaculture Practices (BAP) and the Aquaculture Stewardship Council (ASC). These third party certification programs review salmon farm practices and procedures and determine if they are in compliance to specific standards (Wade, 2017).

All Marine Harvest Canada, Cermaq Canada and Grieg Seafood marine Atlantic Salmon farms located in the Discovery Islands are currently BAP certified. Additionally, two of Cermaq Canada's marine sites have pending ASC approval.

Several fish health related standards must be met in order to maintain certification under these programs (Wade, 2017). Of relevance to this risk assessment are the requirements for the use of vaccines and other fish health requirements. In order for a farm to be certified under ASC, fish must be vaccinated for diseases known to present a significant risk in the region and for which there are effective vaccines (ASC, 2012). BAP certification require that smolts brought into the farm be free of notifiable diseases and parasites and be vaccinated against diseases for which effective vaccines are available.

4.1.2.5. IHN vaccine efficacy

The APEX-IHN® vaccine is the first licensed vaccine designed to protect salmonids against IHN (Novartis, 2012). The vaccine is produced by Elanco Canada Limited (formerly Novartis Animal Health Canada) and administered through a single intramuscular injection.

Based upon manufacturer quality control and assurance procedures (Novartis, 2012), the APEX-IHN® vaccine must have a minimum vaccine efficacy of 67% (Appendix A). In Atlantic Salmon, the vaccine efficacy was calculated to be 65% (Salonius et al., 2007) and 95% (Long et al., 2017) based on reported mortality rates. Refer to Appendix A for more details on the above calculations.

Despite no formal field evaluation of the vaccine efficacy, over 60 million doses of APEX-IHN® have been administered to Atlantic Salmon in BC since its licensure, and to date there has been no detection of IHNV in an APEX-IHN® vaccinated farmed Atlantic Salmon (Garver and Wade, 2017). Whether vaccinated Atlantic Salmon have been exposed to IHNV is unknown but could have happened in 2014 as IHNV-infected juvenile Sockeye Salmon were caught in the Strait of Georgia and Discovery Islands (Garver and Wade, 2017) but farms were not infected.

In a production setting, Atlantic Salmon are vaccinated in the hatcheries as fish reach minimum size requirements for the particular vaccine. Vaccination can therefore occur over a six to seven month period. To ensure that vaccines do not expire, they are ordered in small batches with multiple orders made each year. This practice decreases the likelihood that an entire year class would be affected if a batch of vaccine lost efficacy (Wade, 2017).

4.1.3. Assumptions

The ranking of the likelihood of an IHN outbreak on Atlantic Salmon farms in the Discovery Islands under the current fish health management practices was made under the following assumptions:

- current management practices are followed and will be maintained, including vaccination of all Atlantic Salmon against IHN;
- fish transferred to net pens are free of IHN;
- the 1992-1996 IHN epizootic was initiated by a single index case, the 2001-2003 IHN epizootic was initiated by two index cases while the 2012 outbreaks had three independent index cases; and
- all infected fish are depopulated within 14 days upon confirmation of positive samples and approval of CFIA.

4.1.4. Likelihood of disease

The following factors contribute to the likelihood of an IHN outbreak in Atlantic Salmon farms in the Discovery Islands:

- Atlantic Salmon are highly susceptible to IHNV infection and IHN (Garver et al., 2013);
- IHNV is endemic to BC and Atlantic Salmon farms are located within the natural geographic distribution of the virus (Garver and Wade, 2017);
- Juvenile Sockeye Salmon can get infected with IHNV prior to migrating through the Discovery Islands and could act as a potential source of IHNV to farmed Atlantic Salmon (Garver and Wade, 2017);

- IHN epizootics occurred on marine Atlantic Salmon farms in the Discovery Islands from 1992 to 1996 (St-Hilaire et al., 2002) and from 2001 to 2003 (Saksida, 2006); and
- IHN outbreaks occurred on three Atlantic Salmon farms that had not been vaccinated against IHN in BC in 2012 (Garver and Wade, 2017).

The following factors limit the likelihood of an IHN outbreak in Atlantic Salmon farms in the Discovery Islands:

- All operating Atlantic Salmon farms in the Discovery Islands hold a valid Finfish Aquaculture Licence under the Pacific Aquaculture Regulations which require a SHMP and accompanying proprietary SOPs to ensure good health conditions for cultured fish (DFO, 2016b);
- Fish health professionals are present on farms monitoring fish health, collecting and utilizing syndromic information;
- Only two IHN index cases occurred on Atlantic Salmon farms in the Discovery Islands over the last 25 years; both index cases occurred under fish health management practices different than the current ones;
- There have been no IHN outbreaks on Atlantic Salmon farms in the Discovery Islands since 2003;
- Current fish health management practices include movement controls and timely depopulation of IHNV infected fish;
- All operating Atlantic Salmon farms in the Discovery Islands conduct additional voluntary fish health management practices including syndromic surveillance, industry-driven IHNV testing and all practices described in the Viral Management Plan;
- Since 2011, all Atlantic Salmon reared in the Discovery Islands are vaccinated against IHNV with the APEX-IHN® vaccine (Wade, 2017); and
- Despite no formal field evaluation of the vaccine efficacy, to date, there has been no detection of IHNV in an APEX-IHN® vaccinated farmed Atlantic Salmon (Wade, 2017).

It was concluded that over the period of one year the likelihood of an IHN outbreak on Atlantic Salmon farms in the Discovery Islands under the current fish health management practices is **very unlikely** due to the low prevalence of IHN over the last 25 years, the implementation of effective biosecurity measures, the use of an effective vaccine against IHN and the presence of fish health professionals on Atlantic Salmon farms.

This conclusion was made with **reasonable certainty** given the low levels of operational deficiencies that could affect fish health on Atlantic Salmon farms in the Discovery Islands; the adoption and implementation of the Viral Management Plan by all companies operating in the Discovery Islands; and the BAP certification of all Atlantic Salmon farms in the Discovery Islands providing confidence that vaccination for IHNV is occurring.

4.2. RELEASE ASSESSMENT

The release assessment consists of determining the likelihood of IHNV to be released from Atlantic Salmon farms operating in the Discovery Islands into an environment accessible to wild populations of Fraser River Sockeye Salmon and other susceptible fish. The release assessment assumes that IHN is present on farms.

Likelihood of IHNV release from Atlantic Salmon farms was determined through three different release pathways: farmed Atlantic Salmon; mechanical vectors (e.g., personnel, visitors and wildlife); and fomites (e.g., farm equipment and vessels).

4.2.1. Question

Assuming that IHN is present on an Atlantic Salmon farm in the Discovery Islands, what is the likelihood of IHNV to be released from this farm into an environment accessible to wild fish populations under the current fish health management practices?

4.2.2. Considerations

Relevant considerations include Atlantic Salmon marine rearing methods in the Discovery Islands, IHNV shedding mechanisms and fish health management practices.

4.2.2.1. Atlantic Salmon rearing

In the Discovery Islands, Atlantic Salmon are cultured in net pens permitting exposure of farmed fish to pathogens in the marine environment (Johansen et al., 2011; Saksida, 2014; Jones et al., 2015) and allowing pathogens present on farms to be released into the environment.

4.2.2.2. Virus shedding

IHNV infected fish shed the virus through urine, sexual fluids and mucus (OIE, 2012). Once infected with IHNV, Atlantic Salmon with IHN shed increasingly higher quantities of virus into surrounding water with the progression of the disease (Garver et al., 2013). Under laboratory conditions, peak shedding rates averaging 3.2 $\times 10^{7}$ pfu per fish per hour were observed in Atlantic Salmon smolts (average weight of 122 g) one to two days prior to death when fish were displaying visible signs of IHN (Garver et al., 2013).

4.2.2.3. Fish health management practices

Analyses of the 1992 and 2001 IHN epizootics concluded that farming practices likely contributed to the secondary spread of IHNV between farms (St-Hilaire et al., 2002; Saksida, 2006). However, fish health management practices have changed significantly since those conclusions were made. In 2012, despite three IHN outbreaks in BC, no evidence of secondary spread from infected farms was reported suggesting that current farm practices were effective at minimizing IHNV release and spread through early detection of infection, removal of dead fish and complete farm depopulation within 4 to 14 days after confirmation of the positive samples.

Fish health management practices, described in the disease assessment, are also relevant to the release assessment. As a condition of licence under the Pacific Aquaculture Regulations, marine farms operating in BC must submit a SHMP and accompanying SOPs for approval. The SHMP requires that appropriate measures are in place to ensure biosecurity is maintained, that fish health and disease monitoring procedures are in place and that appropriate emergency measures are in place in case of a disease outbreak (DFO, 2015).

Fish health management practices of most relevance to the release assessment include the collection and utilization of syndromic information for the promotion of fish health and early detection of disease; the biosecurity measures outlined in industry SOPs required as a condition of licence and audited by DFO; the industry Viral Management Plan which stipulates that all infected fish will be depopulated within 14 days of positive confirmation of the index case and upon approval by CFIA; biosecurity measures (SOPs, Viral Management Plan and CFIA restrictions) to mitigate the transmission of IHNV through mechanical vectors or fomites; and the industry Viral Management Plan which stipulates that positive sites will be fallowed for a minimum of three months or one month after release from quarantine, whichever is longer, upon approval by CFIA (Wade, 2017).

CFIA conducted an epidemiological evaluation of the surveillance activities of the BC farmed salmon industry and concluded that no additional surveillance was necessary for the early detection of clinical signs of IHN in unvaccinated populations (Canadian Food Inspection Agency, 2014).

4.2.3. Assumptions

The rankings of the likelihood of IHNV to be released from an IHN diseased farm into an environment accessible to wild fish populations under the current fish health management practices were made under the following assumptions:

- fish will be depopulated within 14 days upon confirmation; and
- industry enacts the Viral Management Plan protocols upon initial suspicion of IHNV on a farm.

4.2.4. Likelihood of release

The likelihood of release was determined through three different release pathways from Atlantic Salmon farms: (1) farmed Atlantic Salmon; (2) mechanical vectors; and (3) fomites.

4.2.4.1. Release through farmed Atlantic Salmon

The following factors contribute to the likelihood that Atlantic Salmon will release IHNV from an IHN positive Atlantic Salmon farm to an environment accessible to wild fish populations:

- Atlantic Salmon showing clinical signs of IHN shed the virus into their surrounding environment (Garver et al., 2013); and
- Atlantic Salmon in the Discovery Islands are reared in net pens allowing viruses to be released from the farms to the surrounding environment.

It was concluded that the likelihood for IHNV to be released from an IHN positive Atlantic Salmon farm through Atlantic Salmon shedding the virus is **expected** under current farm practices given the mode of transmission of the virus and Atlantic Salmon rearing method in the marine environment in the Discovery Islands.

This conclusion was made with **high certainty** given the published peer-reviewed evidence of IHNV shedding rates in IHN diseased Atlantic Salmon.

4.2.4.2. Release through mechanical vectors

The following factor contributes to the likelihood that IHNV will be released from an IHN positive Atlantic Salmon farm to an environment accessible to wild fish through mechanical vectors:

- Analyses of the 1992 and 2001 IHN epizootics concluded that farming practices have likely contributed to the secondary spread of IHNV between farms (St-Hilaire et al., 2002; Saksida, 2006).

The following factors limit the likelihood that IHNV will be released from an IHN positive Atlantic Salmon farm to an environment accessible to wild fish through mechanical vectors:

- Protocols are in place for handling and storing dead fish; for labeling, cleaning, disinfecting and storing gear used to handle dead fish and; all companies use Virkon® Aquatic, a broad spectrum surface disinfectant, applied in accordance with manufacturer's recommendations (Wade, 2017);
- Protocols are in place to restrict visitors who must obtain permission prior to arriving on site (Wade, 2017);
- Protocols are in place to control on-site visitors through the use of signage, footbaths and site specific protective clothing (Wade, 2017);
- Protocols are in place to minimize predator and wildlife access (Wade, 2017);
- While it is possible that invertebrates species may serve as mechanical vectors, studies suggest that they harbour the virus for only brief periods of time and virus replication has not been confirmed (Garver and Wade, 2017); and
- Low levels of operational deficiencies on Atlantic Salmon farms audited by DFO.

It was concluded that the release of IHNV through mechanical vectors is not a significant concern under current farm practices. Consequently, the likelihood for IHNV to be released from an IHN positive Atlantic Salmon farm through mechanical vectors is **very unlikely** under current farm practices mainly due to the implementation of effective biocontainment measures related to personnel, visitors and wildlife.

This conclusion was made with **high certainty** given the biosecurity measures in place and the low levels of operational deficiencies that could affect fish health on Atlantic Salmon farms in the Discovery Islands.

4.2.4.3. Release through fomites

The following factor contributes to the likelihood that IHNV will be released from an IHN positive Atlantic Salmon farm to an environment accessible to wild fish through fomites:

- Analyses of the 1992 and 2001 IHN epizootics concluded that farming practices have likely contributed to the secondary spread of IHNV between farms (St-Hilaire et al., 2002; Saksida, 2006).

The following factors limit the likelihood that IHNV will be released from an IHN positive Atlantic Salmon farm to an environment accessible to wild fish through fomites:

- Protocols are in place for net washing procedures, not sharing equipment when possible, cleaning and disinfecting equipment after use and dry storing in proper locations (Wade, 2017);
- Protocols are in place for cleaning, disinfecting and transferring large and submerged equipment among sites (Wade, 2017);
- Positive sites remain fallow for a minimum of three months or one month after release from quarantine, whichever is longer (Wade, 2017);
- Biosecurity measures are in place to control vessel movement (Wade, 2017);
- In the event of a confirmed disease status, boat traffic to and from the farm is not authorized without CFIA approval and equipment from the affected area has to be kept separate from equipment from other areas as per the Viral Management Plan (Wade, 2017); and
- Low levels of operational deficiencies on Atlantic Salmon farms audited by DFO.

It was concluded that the release of IHNV through fomites is not a significant concern under current farm practices. Consequently, the likelihood for IHNV to be released from an IHN positive Atlantic Salmon farm through fomites is **very unlikely** under current farm practices mainly given the implementation of effective biocontainment measures related to equipment and control vessel movement.

This conclusion was made with **high certainty** due to the biosecurity measures in place and the low levels of operational deficiencies that could affect fish health on Atlantic Salmon farms in the Discovery Islands.

4.2.4.4. Overall likelihood of release

The overall likelihood for IHNV to be released from an IHN positive Atlantic Salmon farm in the Discovery Islands was obtained by adopting the highest likelihood of all three release pathways and the corresponding uncertainty (refer to section 3.2.4.5).

Consequently, it was concluded with **high certainty** that the likelihood for IHNV to be released from an IHN positive Atlantic Salmon farm in the Discovery Islands is **expected**.

4.3. EXPOSURE ASSESSMENT

The exposure assessment consists of determining the spatial and temporal concurrence of the released pathogen and susceptible species (Taranger et al., 2014). In the context of this risk assessment, it consists of determining the likelihood that a susceptible wild fish would be exposed to IHNV released from Atlantic Salmon farms operating in the Discovery Islands. The exposure assessment assumes that IHNV has been released from farms.

Likelihood of exposure was determined for three exposure groups (juvenile Fraser River Sockeye Salmon, adult Fraser River Sockeye Salmon and other IHN susceptible fish species) and through two exposure routes (in net pens and in the IHNV plume dispersed from infected farms). Other susceptible fish species were included as an exposure group to account for potential ecological consequences that could impact Fraser River Sockeye Salmon populations through prey, predator or competitor interactions but were not included as an exposure route, as they were considered negligible in the context of this risk assessment.

4.3.1. Question

Assuming that IHNV has been released from Atlantic Salmon farms operating in the Discovery Islands, what is the likelihood that a susceptible fish would be exposed to IHNV?

4.3.2. Considerations

Relevant considerations include the timing and duration of IHN outbreaks in Atlantic Salmon farms, IHNV survival in the environment, water currents in the Discovery Islands, relative farm size and volume, migration routes and timing of all three exposure groups through the Discovery Islands.

4.3.2.1. Timing of IHN outbreaks on Atlantic Salmon farms

It is difficult to identify any seasonality in IHN outbreaks based on the 1992-1997 and 2001-2003 epizootics given that few movement controls were in place and there was no requirement to depopulate infected fish. Consequently, infection spread within and among farms and infections persisted year round. IHNV index cases, rather than IHNV prevalence, are therefore considered to be more informative of the time of the year during which IHN outbreaks have occurred.

Historically, the IHN index cases in BC occurred in March (in 2002 on the West Coast of Vancouver Island), in May (in 2012 on the West Coast of Vancouver Island), in July (in 1992 in the Discovery Islands) and in August (in 2001 in the Discovery Islands and in 2012 on the Sunshine Coast) (Garver and Wade, 2017).

4.3.2.2. IHNV survival in the environment

The environmental stability of IHNV is affected by water salinity, temperature, organic load, microbial content, and exposure to ultraviolet light (Garver and Wade, 2017). IHNV is inactivated within days in naturally occurring river and ocean waters and within minutes if further subjected to sunlight (Garver et al., 2013). Consequently higher concentrations of waterborne IHNV are likely to accumulate during the winter months when water temperatures and UV light intensity are significantly less than those observed during spring and summer months (Garver et al., 2013).

Based on hydrodynamic modelling simulations, Foreman et al. (2015a) reported exponentially-decaying IHNV survival rates and complete virus inactivation after eight days in the Discovery Islands region.

4.3.2.3. Relative farm size and volume

The relative surface area and relative volume of active Atlantic Salmon farms to the region of the Discovery Islands can be used as initial crude approximations of the likelihood for wild fish to encounter an Atlantic Salmon farm in the Discovery Islands region.

The average calculated volume of net pens on Atlantic Salmon farms in the Discovery Islands is 194,705 m^3. Given 18 active farms in the area, the total surface area and volume occupied by Atlantic Salmon farms in the Discovery Islands are approximately 183,492 m^2 (0.183 km^2) and 3,504,697 m^3 (3.5 km^3), respectively. The sea surface area of the Discovery Islands region, as defined in Foreman et al. (2015a) with a slight westward extension to include all farms in this risk assessment, is approximately 2,542 km^2 with an average depth of 173 m, resulting in an approximated volume of 439,766 km^3. Atlantic Salmon farms operating in the Discovery Islands therefore occupy approximately 0.007% of the sea surface area and 0.0008% of the volume of the Discovery Islands region.

However, as the Discovery Islands region is a complex network of islands, narrow channels and deep fjords, a more realistic approach for estimating the likelihood of encounters should take into account farm versus channel cross-sectional areas. To this end, Figure 6 illustrates cross sections of the narrowest and widest channels in which Atlantic Salmon farms are located to visually depict the potential for wild fish swimming along-channel to randomly encounter two particular farms in the Discovery Islands.

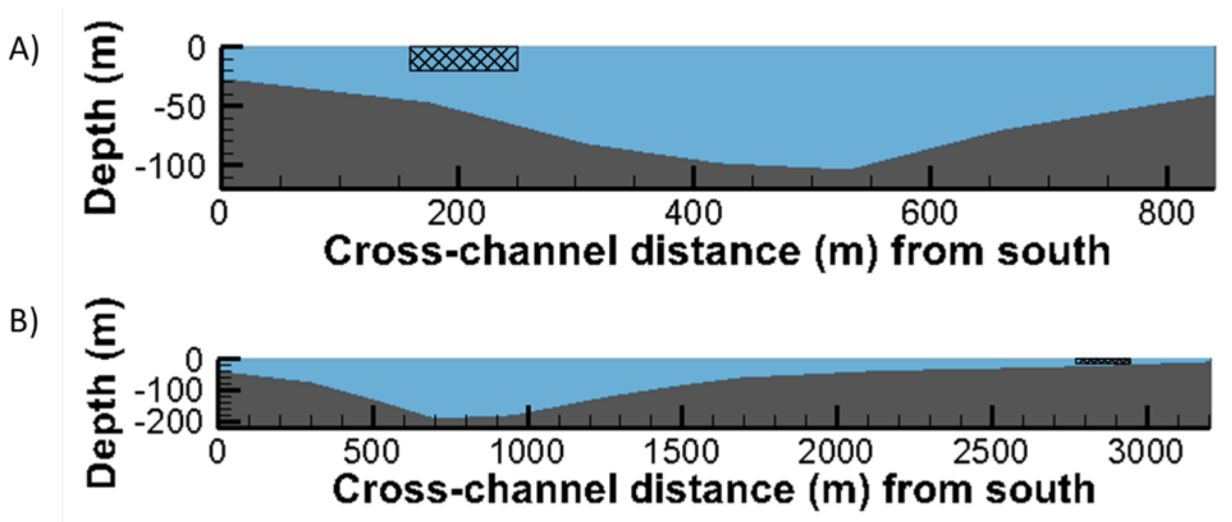

Figure 6. Cross sections of channels at Brent (A) and Shaw (B) farms located in respectively the narrowest and widest channel in which Atlantic Salmon farms are located in the Discovery Islands. Cross-hatched boxes show the cross-channel projection of the net-pens of the farms depicted at scale, i.e., what fish swimming along-channel could encounter. Note the difference in the ranges on the axes to maintain constant ratio (one:one) between the x and y axes in each cross section.

4.3.2.4. Water currents in the Discovery Islands

The Discovery Islands region is characterized by fjord-like geography with many deep, steep-sided channels and tall, steep-sided mountains. Johnstone Strait and Discovery Passage are the primary waterways between the Strait of Georgia to the south and Queen Charlotte Strait to the north. Atlantic Salmon farms included in this risk assessment are sited along the other interconnecting channels (Figure 1).

IHNV introduced into the marine environment in the Discovery Islands region will be transported horizontally and mixed vertically due to the currents in the region. The strength and direction of the currents is due to three main forces: the tides, the winds, and the freshwater flow from rivers.

The region is influenced by tides from the south and the north, but as they peak at different times, strong current flows (up to 8 m/s) throughout the water column can be generated during a 12 hour (semidiurnal) cycle. The ebb and flood tides may not result in much net transport causing waterborne particles to be retained in some areas.

The wind pattern follows the orientation of the channels and varies significantly by location. The wind stress on the surface of the water will influence the transport of particles in the surface layer, and will also influence whether particles are mixed deeper into the water column and, in the case of IHNV, away from the UV in sunlight that causes virus decay. Wind events vary at a time scale of a few days, but winds also vary on seasonal time scales with the winter months generally stormier (Chandler et al., 2017).

The runoff of freshwater from rivers generates a low salinity surface current that flows towards the sea, and a returning deeper current that brings seawater up-channel. In the Discovery Islands there is a clear annual signal to this flow due to the large contribution of snowmelt from April to July. Extreme rainfall events, which can occur at any time of the year, can provide peaks in flow lasting about a week.

There is no ongoing observational program to measure the spatial and temporal complexity of the water circulation in the Discovery Islands so this information has been generated using the Finite-Volume Community Ocean Model (FVCOM), a widely-used numerical hydrodynamic model (Foreman et al., 2015a and 2015b). The model output provides hourly three dimensional fields of currents, temperature and salinity at a varying horizontal resolution from tens to hundreds of meters and at 21 depth levels. Two periods have been simulated, April and July 2010, and these have been demonstrated to be representative of spring and summer conditions (Chandler et al., 2017).

4.3.2.5. Waterborne dispersal of IHNV

Waterborne dispersal of IHNV has been implicated in the spread of the disease between fish farms (Saksida, 2006) and modeled IHNV dispersal from IHN diseased farms in the Discovery Islands suggests temporal and spatial variations in the viral plumes (Foreman et al., 2015a).

Modeled estimates of IHNV concentrations in surface waters (top 20 m) showed IHNV plumes extending beyond the farms and sometimes covering the entire width of channels (Foreman et al., 2015a; Foreman et al., 2015b).

4.3.2.6. Juvenile Fraser River Sockeye Salmon in the Discovery Islands

Fraser River Sockeye Salmon have two key anadromous life histories: lake-type and river-type. For both life-history types, Fraser River Sockeye Salmon adults spawn from mid-summer to late-autumn in streams, rivers and lakes. Eggs incubate over the winter and fry emerge from the gravel in early spring. Most lake-type Sockeye Salmon rear in a nursery lake for one year before migrating to the ocean while river-type Sockeye Salmon migrate to the ocean shortly after they emerge from the gravel (Burgner, 1991). Most lake-type smolts from the Fraser River watershed begin their downstream migration to the Strait of Georgia in the early spring with timing varying by stock and year. In contrast, river-type Fraser River Sockeye Salmon smolts migrate downstream to the Strait of Georgia shortly after gravel emergence.

Field studies have demonstrated that juvenile Fraser River Sockeye Salmon can be found in the channels of the Discovery Islands during their northward migration (Levings and Kotyk, 1983; Groot and Cooke, 1987; Johnson, 2016). Most (85.7%) juvenile Sockeye Salmon in the Strait of Georgia (1997-2005) were primarily caught between 0 and 15 m depth (Beamish et al., 2007). The remaining Sockeye Salmon were captured at depths of 15 to 30 m (12%), 30 to 45 m (2.25%), with few surveys fishing, and consequently catching few fish deeper than 45 m (Beamish et al., 2007).

Information on the timing of juvenile Fraser River Sockeye Salmon migration through the Discovery Islands is scarce. Based on available data, juvenile Fraser River Sockeye Salmon are present in the Discovery Islands from mid-May to mid-July with a peak migration in early-to-mid June (Neville et al., 2013; Johnson, 2016; Neville et al., 2016). There is currently no precise estimate of the migration timing of river-type Harrison Sockeye Salmon through the Discovery Islands. Refer to Grant et al. (in review) for a more detailed review of the current state of knowledge of juvenile Fraser River Sockeye Salmon migration through the Discovery Islands.

4.3.2.7. Adult Fraser River Sockeye Salmon in the Discovery Islands

Once in the ocean, Fraser River Sockeye Salmon feed, grow and mature for up to four years before returning to freshwater to begin the upstream migration to their natal streams where they spawn and die (Burgner, 1991). Current knowledge about the migration routes and time of return of adult Fraser River Sockeye Salmon is primarily based on information and data collected to inform fisheries management.

Fraser River Sockeye Salmon return to the Fraser River either through Johnstone Strait, referred to as the northern route, or through the Strait of Juan de Fuca, called the southern route. The proportion of fish that return through the northern route instead of the southern route has been termed the northern diversion rate, or simply diversion rate (DFO, 2016c). From 1980 to 2015, an average of 52% of adults returned through the northern route with significant variations among years, ranging from a minimum of 10% in 2008 and a maximum of 96% in 2014 (Grant et al., in review).

The Fraser River Sockeye Salmon fishery is managed as groups termed management groups. Early Stuart and Early Summer management groups contribute relatively few fish to the total abundance of Fraser River Sockeye Salmon while the Late and Summer management groups are consistently the major contributors. Between 1980 and 2014, there was an average 9.6 million returning Fraser River Sockeye Salmon of which 3, 7, 54 and 36% were respectively from the Early Stuart, Early Summer, Summer and Late management groups (summarized in Grant et al. (in review)).

Most Fraser River Sockeye Salmon return to spawn mid-summer to late-autumn (Pestal et al., 2012) arriving at Mission, close to the mouth of the Fraser River, as early as July and as late as mid-October (Grant et al., in review). Based on Pacific Salmon Commission test fishery data and an estimated traveling speed of 43 km/day (Grant et al., in review), the period over which returning adult Fraser River Sockeye Salmon can be found in the Discovery Islands was estimated to range from late-June to early-October (Grant et al., in review).

4.3.2.8. Other fish species in the Discovery Islands

Other IHN susceptible fish species are included in this risk assessment to address potential ecological consequences that could indirectly impact Fraser River Sockeye Salmon populations through prey-predator or competitor relationships.

Chinook, Chum, Coho and Pink Salmon have all been reported in the nearshore area of Nanaimo from March to July 1975 and during surveys in June and July of 2013 and 2014 in the Discovery Islands when Sockeye Salmon juveniles were present (summarized in Grant et al. (in review)).

Adult Sockeye Salmon and Pink Salmon are the two species annually reported with the highest catch-per-unit-effort since 2000 in the lower Johnstone Strait during the Pacific Salmon Commission in-season Sockeye Salmon test fisheries conducted approximately from mid-July to early September (reviewed in Grant et al. (in review)). Chum Salmon are also occasionally caught while Chinook Salmon, Coho Salmon and steelhead are rarely caught (Grant et al., in review).

Pacific Herring were often caught with Sockeye Salmon in surveys including in the nearshore area of Nanaimo from March to July 1975, April to July 1976 and 1977, in the Strait of Georgia in May and June 1976, and in the Hecate Strait in July and August (Schmidt et al., 1978; Schmidt et al., 1979b, a; Shaw et al., 1983). They were the predominant species caught during DFO trawl surveys in the Discovery Islands in June and July of 2013 and 2014 (summarized in Grant et al. (in review)).

As a condition of licence, Atlantic Salmon farm operators are required to report to DFO any incidental catches during harvests and fish transfers. Between 2011 and 2015, several species of finfish were reported as incidental catches on farms in the Discovery Islands providing evidence of their occurrence in the area and on farms. Salmonid species reported in incidental catches included Chinook, Chum, Coho, and Pink Salmon (Table 8).

Table 8. Total reported incidental catches by quarter of wild finfish from farms in the Discovery Islands (2011 to 2015). Numbers before the parentheses represent the total number of fish caught and the number in parentheses represent the number of harvest or transfer events during which incidental catches were reported. Data assembled from [DFO Public Reporting on Aquaculture - Incidental Catch]() (website accessed in March 2016).

Species name	January to March	April to June	July to September	October to December	Total
Buffalo Sculpin (*Enophrys bison*)	-	-	1 (1)	-	1 (1)
Cabezon (*Scorpaenichthys marmoratus*)	-	1 (1)	-	-	1 (1)
Chinook Salmon (*O. tshawytscha*)	1 (1)	-	-	1 (1)	2 (2)
Chum Salmon (*O. keta*)	28 (1)	-	-	-	28 (1)
Coho Salmon (*O. kisutch*)	3 (1)	-	-	-	3 (1)
Greenling (*Hexagrammos decagrammus*)	-	-	-	3 (2)	3 (2)
Lingcod (*Ophiodon elongatus*)	1 (1)	-	-	-	1 (1)
Pacific Cod (*Gadus macrocephalus*)	62 (4)	5,497 (4)	12 (2)	167 (2)	5,738 (12)
Pacific Herring (*Clupea pallasii*)	3,580 (8)	1,243 (6)	432 (7)	142 (6)	5,397 (27)
Pacific Spiny Dogfish (*Squalus acanthias*)	5 (1)	-	-	-	5 (1)
Pacific Tomcod (*Gadus californicus*)	17 (1)	34 (1)	1 (1)	-	52 (3)
Perch (Perca spp.)	-	44 (1)	-	3 (1)	47 (2)
Pile Perch (*Rhacochilus vacca*)	-	18 (1)	-	-	18 (1)
Pink Salmon (*Oncorhynchus gorbuscha*)	5 (2)	1 (1)	17 (1)	1 (1)	24 (5)
Pipefish (*Syngnathus griseolineatus*)	-	-	7 (1)	-	7 (1)
Ratfish (*Hydrolagus colliei*)	-	7 (1)	-	-	7 (1)
Sablefish (*Anoplopoma fimbria*)	3 (1)	43 (1)	-	-	46 (2)
Salmon (Oncorhynchus spp.)	-	-	-	1 (1)	1 (1)
Sculpin (Cottidae spp.)	-	19 (1)	-	-	19 (1)
Walleye Pollock (*Theragra chalcogramma*)	-	-	8 (2)	-	8 (2)
TOTAL	3,705 (21)	6,907 (18)	478 (15)	318 (14)	11,408 (68)

4.3.3. Assumptions

The rankings of the likelihood that a susceptible fish would be exposed to IHNV released from an infected Atlantic Salmon farm operating in the Discovery Islands under the current management practices were made under the following assumptions:

- in the Discovery Islands, IHN outbreaks on Atlantic Salmon farms are likely to occur in July and August;
- wild Sockeye Salmon and Sockeye Salmon produced through enhancement are not differentiated for the purpose of this risk assessment;
- lake-type juvenile Fraser River Sockeye Salmon can be present in the Discovery Islands from at least mid-May to mid-July;
- adult Fraser River Sockeye Salmon can be present in the Discovery Islands from at least late-June to early-October; and

- waterborne transmission is the main exposure pathway of wild susceptible fish species to IHNV released from Atlantic Salmon farms during an IHN outbreak.

4.3.4. Likelihood of exposure

The following factors contribute to the likelihood of all three exposure groups being exposed to IHNV released from an IHN-positive Atlantic Salmon farm in the Discovery Islands:

- IHNV can survive in seawater (Garver et al., 2013);
- IHNV infection can spread beyond infected farms (St-Hilaire et al., 2002; Saksida, 2006); and
- Hydrodynamic simulations suggest that IHNV released from Atlantic Salmon farms can disperse beyond the farms and cover the entire width of a channel (Foreman et al., 2015a).

The following factors limit the likelihood of all three exposure groups being exposed to IHNV released from an IHN-positive Atlantic Salmon farm in the Discovery Islands:

- IHNV is rapidly inactivated in seawater (Garver et al., 2013);
- Atlantic Salmon farms are not found in all channels of the Discovery Islands; and
- Atlantic Salmon farms occupy a relatively small surface area and volume of the Discovery Islands region.

In addition to the above, other factors specifically affect the likelihood of juvenile Fraser River Sockeye Salmon, adult Fraser River Sockeye Salmon or other IHN susceptible fish species. Consequently, the likelihoods of exposure were ranked for each combination of exposure group and exposure route.

4.3.4.1. Exposure of juvenile Fraser River Sockeye Salmon

The Discovery Islands are a complex network of channels and islands offering several potential migratory paths for juvenile Sockeye Salmon with and without Atlantic Salmon farms. The details of the migration of juvenile Fraser River Sockeye Salmon through the Discovery Islands are unknown (Grant et al., in review); fish have, however, been found in many different channels in the area.

There is spatial and some temporal overlap between the time of the year during which IHNV is most likely to occur on Atlantic Salmon farms located in the Discovery Islands (July and August) and the migration period of lake-type juvenile Fraser River Sockeye Salmon through the Discovery Islands (mid-May to mid-July) (Table 9). There is insufficient data about river-type Fraser River Sockeye Salmon to determine if they overlap temporally with the period during which an IHN outbreak is most likely to occur in the Discovery Islands. Consequently, this risk assessment focuses on the lake-type Fraser River Sockeye Salmon.

Table 9. Overview of months with reported IHN index cases on Atlantic Salmon farms and Fraser River Sockeye Salmon migration through the Discovery Islands (DIs). IHN index cases are represented for both BC and Discovery Islands. Migration of juvenile lake-type and returning adult Fraser River Sockeye Salmon are presented separately.

	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct
IHN index cases on Atlantic Salmon farms in BC								
IHN index cases on Atlantic Salmon farms in the DIs								
Lake-type juvenile Fraser River Sockeye Salmon out-migrating through the DIs								
Returning adult Fraser River Sockeye Salmon migrating through the DIs								

The following factors contribute to the likelihood of juvenile Fraser River Sockeye Salmon to be exposed to IHNV in net pens or plumes released from an IHN-positive Atlantic Salmon farm in the Discovery Islands:

- Millions of juvenile Fraser River Sockeye Salmon migrate through the Discovery Islands every year; and
- Juvenile Fraser River Sockeye Salmon overlap temporally with the IHNV index case reported in July in the Discovery Islands.

4.3.4.1.1. In net pens

It was concluded that the likelihood that at least one juvenile Fraser River Sockeye Salmon would encounter and swim through an infected Atlantic Salmon net pen in the Discovery Islands is **likely** given the temporal and spatial overlap of juvenile Fraser River Sockeye Salmon and reported IHNV index cases in Atlantic Salmon farms in the Discovery Islands.

This conclusion was made with **reasonable uncertainty** given the lack of information regarding the interaction of juvenile Sockeye Salmon and Atlantic Salmon farms.

4.3.4.1.2. In plumes

It was concluded that the likelihood that at least one juvenile Fraser River Sockeye Salmon would encounter and swim through the dispersed viral plume of an infected Atlantic Salmon farm in the Discovery Islands is **very likely** given the temporal and extended spatial overlap (through potential dispersal) of juvenile Fraser River Sockeye Salmon and reported IHNV index cases in Atlantic Salmon farms in the Discovery Islands.

This conclusion was made with **reasonable certainty** given the corroboration of the spread of IHNV among farms in epidemiological analyses and the results from hydrodynamic simulations.

4.3.4.2. Exposure of adult Fraser River Sockeye Salmon

Despite the high intrinsic variability in diversion rates of returning Fraser River Sockeye Salmon, every year some returning adult Sockeye Salmon use the northern route and swim through the Discovery Islands to reach the Fraser River, but the specific routes used within the Discovery Islands region are unknown.

There is spatial and temporal overlap between the time of the year during which IHNV is most likely to occur on Atlantic Salmon farms located in the Discovery Islands (July to August) and the estimated migration period of adult Fraser River Sockeye Salmon through the Discovery Islands (late-June to early-October) (Table 9).

The following factors contribute to the likelihood of adult Fraser River Sockeye Salmon being exposed to IHNV on or released from an IHN-positive Atlantic Salmon farm in the Discovery Islands:

- On average, 52% of returning adult Fraser River Sockeye Salmon (average of 9.6 million fish) migrate through the Discovery Islands every year; and
- Adult Fraser River Sockeye Salmon overlap temporally with IHNV index cases in the Discovery Islands in July and August.

The following factors limit the likelihood of adult Fraser River Sockeye Salmon to be exposed to IHNV in the net pen of an IHN-positive Atlantic Salmon farm in the Discovery Islands:

- Adult Sockeye Salmon are not expected to fit through the net mesh of and Atlantic Salmon farm; and
- There is no evidence of adult Sockeye Salmon in Atlantic Salmon net pens.

4.3.4.2.1. In net pens

It was concluded that the likelihood that at least one adult Fraser River Sockeye Salmon would first encounter and then swim through an infected Atlantic Salmon net pen in the Discovery Islands is **extremely unlikely** given the expected size of returning adult Sockeye Salmon relative to the net mesh size and the lack of evidence of adult Sockeye Salmon in Atlantic Salmon cages.

This conclusion is made with **reasonable certainty** given the extensive data of adult Sockeye Salmon size.

4.3.4.2.2. In plumes

It was concluded that the likelihood that at least one adult Fraser River Sockeye Salmon would encounter and swim through the dispersed viral plume of an infected Atlantic Salmon farm in the Discovery Islands is **very likely** given the temporal and extended spatial overlap (through potential dispersal) of juvenile Fraser River Sockeye Salmon and reported IHNV index cases in Atlantic Salmon farms in the Discovery Islands.

This conclusion was made with **reasonable certainty** given the corroboration of the spread of IHNV among farms in epidemiological analyses and the results from hydrodynamic simulations.

4.3.4.3. Exposure of other IHN susceptible fish species

Other susceptible fish species are considered to take into account potential ecological consequences that could impact Fraser River Sockeye Salmon populations through prey, predator or competitor interactions.

Coho Salmon and Pink Salmon are not considered further in this risk assessment as there are no reports of natural outbreaks and experimental exposures showed low to no mortality (reviewed in Garver and Wade (2017)). Pacific Herring is also not considered further despite its high abundance in the Discovery Islands at some times of the year (Grant et al., in review), as the only reported case of positive IHNV in Pacific Herring could not be confirmed and attempts to directly infect the species in laboratory exposure studies revealed a lack of susceptibility to IHNV (Hart et al., 2011).

Chinook Salmon and Chum Salmon are the two wild fish species, other than Sockeye Salmon, of most relevance to this risk assessment given that both species are known to occur in the Discovery Islands (Grant et al., in review), have been reported in incidental catches on Atlantic Salmon farms (Grant et al., in review), and have experienced epizootics (Garver and Wade, 2017).

Both juvenile Chinook and Chum Salmon have been reported in catches during DFO's trawl surveys in the Discovery Islands in June and July 2013, 2014. Adult Chinook and Chum Salmon are reported in the Discovery Islands during the Pacific Salmon Commission's test fishery between mid-July and early September from 2000 to 2015 (Grant et al., in review). The likelihood of Chinook Salmon and Chum Salmon being exposed to IHNV released from an infected Atlantic Salmon farm is conducted for both species and all life stages together.

The following factors contribute to the likelihood of Chinook and Chum Salmon to be exposed to IHNV on or released from an IHN-positive Atlantic Salmon farm in the Discovery Islands:

- Juvenile Chinook and Chum Salmon are present in the Discovery Islands region in June and July; and
- Adult Chinook and Chum Salmon are present in the Discovery Islands region between mid-July and early September; and
- IHNV index cases have occurred in the Discovery Islands region in July and August.

It was therefore concluded that Chinook and Chum Salmon can be found in the Discovery Islands during the time when IHNV index cases on Atlantic Salmon farms have been reported.

4.3.4.3.1. In net pens

The following factor contributes to the likelihood of Chinook and Chum Salmon to be exposed to IHNV in the net pen of an IHN-positive Atlantic Salmon farm in the Discovery Islands:

- Presence of Chinook and Chum Salmon in incidental catches on Atlantic Salmon farms (quarters 1 and 4).

It was concluded that the likelihood that at least one Chinook or Chum Salmon would encounter and swim through an infected Atlantic Salmon net pen in the Discovery Islands is **likely** given the temporal and spatial overlap of Chinook and Chum Salmon and reported IHNV index cases in Atlantic Salmon farms in the Discovery Islands.

This conclusion was made with **reasonable certainty** given the evidence of Chinook and Chum Salmon in incidental catches on Atlantic Salmon farms.

4.3.4.3.2. In plumes

It was concluded that the likelihood that at least one Chinook or Chum Salmon would encounter and swim through the dispersed viral plume of an infected Atlantic Salmon farm in the Discovery Islands is **very likely** given the temporal and extended spatial overlap (through potential dispersal) of Chinook and Chum Salmon juvenile and reported IHNV index cases in Atlantic Salmon farms in the Discovery Islands.

This conclusion was made with **reasonable certainty** given the corroboration of the spread of IHNV among farms in epidemiological analyses and the results from hydrodynamic simulations.

4.4. INFECTION ASSESSMENT

The infection assessment consists of determining the likelihood that susceptible wild fish are exposed to IHNV at a dose and for a period of time sufficient to cause infection and disease. The infection assessment assumes that susceptible fish have been exposed to IHNV released from farms.

Likelihood of infection was determined separately for the three exposure groups and two exposure routes.

4.4.1. Question

Assuming that susceptible wild fish have been exposed to IHNV released from Atlantic Salmon farms in the Discovery Islands, what is the likelihood that they are exposed to a dose and for a period of time sufficient to cause infection and disease?

4.4.2. Considerations

Relevant considerations include the oceanographic and environmental conditions in the Discovery Islands, maximum estimated waterborne concentrations of IHNV in net pen(s) on an diseased farm and in the dispersion plumes, estimated duration of exposure, minimum lethal dose of IHNV and the endemism of IHNV in BC.

4.4.2.1. Oceanographic and environmental conditions

Water properties of relevance to the survival of IHNV in the marine environment include water temperature, salinity, the presence of marine biota, and exposure to UV radiation.

Water temperatures in the Discovery Islands vary both seasonally and regionally with recorded temperatures ranging between 3 and 24°C (Chandler et al., 2017). Average monthly water temperature in the top 15 m of Atlantic Salmon farms in the Discovery Islands ranges from 7.6 ± 2.3°C to 11.5 ± 3.3°C (Chandler et al., 2017). Water temperature during the 2003-2006 IHN outbreaks ranged between 7 and 14 °C (Saksida, 2006). Water temperatures in the Discovery Islands are suitable for IHNV survival.

Water salinity in the Discovery Islands varies considerably by season (due to river runoff of snowmelt), by depth (due to the estuarine circulation), and by location (as some narrow channels are extremely well mixed vertically) ranging from close to zero to 32. Average monthly salinity in the top 15 m of Atlantic Salmon farms in the Discovery Islands ranges from 28.9 ± 7.3 to 29.9 ± 8.7 and there is no evidence to suggest that salinities in this range affect the survivability of IHNV.

Solar radiation data collected at a network of weather stations in the Discovery Islands provide a measure of the exposure of the surface waters to UV-A and UV-B radiation. Field observations in the Discovery Islands have also measured the attenuation of UV as it penetrates the water column and reveal that the effect of UV radiation is reduced by about 50% within the top two meters (Chandler et al., 2017). Combined with laboratory studies that demonstrate that viral particles are inactivated by ambient UV radiation levels, estimates have been made on the inactivation of IHNV as a function of time and depth (Garver et al., 2013). Model simulations suggest relatively greater inactivation of IHNV in July (attributable to greater incident solar radiation and less cloud cover than in April), and a build-up of IHNV concentrations in the early morning after several hours of no incident UV radiation.

The influence of marine biota on the inactivation of IHNV has been demonstrated in laboratory studies (Garver et al., 2013). However, it is unclear as to the identity of the biota responsible for inactivating IHNV and if this biota varies in space and time throughout the Discovery Islands. Model simulations have used a decay rate of 4.18 per day, derived from controlled laboratory experiments (Foreman et al., 2015a). Additional model simulations have been carried out using lower decay rates and show that model results are not overly sensitive to this parameter. However, it is recognized that a reduced decay rate can increase the dispersion of pathogen and the risk of infection.

4.4.2.2. Estimated maximum IHNV concentration in net pens

The IHNV concentration in net pens during an IHN outbreak can be estimated based on the number of infected fish, the viral shedding rate, shedding duration and the farm volume which can be represented as follows:

$$IHNV\ concentration = \frac{Maximum\ number\ of\ infected\ fish\ x\ \ Shedding\ rate\ x\ Time\ period}{Volume\ of\ farm\ net\ pens}$$

Rationales for the estimation of the number of infected fish, the viral shedding rate, the volume of farm net pens and the IHNV concentrations in net pens are provided below.

4.4.2.2.1. Maximum number of infected fish

Epidemiological models have been used for decades to simulate the dynamics of infectious diseases in human and animal populations (Murray, 2009). The spread of IHNV infection within an Atlantic Salmon farm was simulated using a deterministic compartmental susceptible, exposed, infectious, recovered (SEIR) model (Anderson and May, 1979; Hethcote, 2000) to provide an estimation of the maximum number of fish that could be infected on a farm under a given set of conditions (refer to Appendix B for more details on the model and assumptions and implementation through the R package EpiModel (Jenness et al., 2016)).

As current management practices include depopulation of infected fish (Wade, 2017), the maximum number of infected fish on an Atlantic Salmon farm would occur on the day that infected fish would be depopulated, hence a maximum of 14 days after the confirmation of an IHN outbreak. However, assuming that all Atlantic Salmon on farms are vaccinated against IHNV with a vaccine efficacy of 95%, results from the model show that there would be no spread of the infection within the farmed Atlantic Salmon, i.e., the number of IHNV infected fish would not increase after initial infection regardless of the number of initially infected fish. Consequently, no IHN outbreak is expected on an Atlantic Salmon farm with 100% vaccine coverage and an IHN vaccine having 95% efficacy and the maximum number of infected fish would then be the number of initially infected fish.

The number of initially infected fish on an Atlantic Salmon farm diagnosed with IHNV is not known. Most epidemiological models assume a single initially infected animal. However, given that millions of wild salmon migrate through the Discovery Islands region and that IHNV prevalence in wild Sockeye Salmon is highly variable, it is reasonable to assume that more than one Atlantic Salmon can get exposed to an IHNV infectious dose. Assuming that 100 Atlantic Salmon were initially exposed to the minimum lethal dose of IHNV, in a vaccinated population with 100% vaccine coverage and a minimum of 95% vaccine efficacy, five of the exposed Atlantic Salmon would be susceptible and potentially become infected.

4.4.2.2.2. Shedding rates

Although virus shedding from IHNV infected Atlantic Salmon can occur before the onset of visible signs of disease, Atlantic Salmon that appear asymptomatic and remain free of IHN are not a significant source of virus (Garver et al., 2013). Based on IHNV shedding rate profiles reported by Garver et al. (2013), a peak shedding rate (3.2×10^7 pfu per fish per hour) for 40% of the infected fish and half-peak shedding rate (1.6×10^7 pfu/fish/hour) for the remaining 60% of infected fish was assumed to calculate IHNV concentrations in net pens.

4.4.2.2.3. Volume of net pens on a farm

The average volume of net pens on an Atlantic Salmon farm in the Discovery Islands was calculated to be 194,705 m^3. Refer to section 3.4.1 for more details.

4.4.2.2.4. IHNV concentrations in net pens

The maximum IHNV concentration on a farm on which all Atlantic Salmon are vaccinated against IHNV with a vaccine efficacy of 95% was estimated to be 1.4×10^4 pfu/m^3 based on five infected fish (two at peak shedding rate and three at half-peak shedding rate). As this estimation did not account for dispersion and viral decay, concentrations of waterborne IHNV were estimated after 24 hours of continuous shedding.

Caution should be applied in the interpretation of the above estimation as it assumes that (i) all fish are equally susceptible regardless of size or condition, (ii) a high shedding rate, (iii) no dispersion from the farms due to water currents and (iv) no decay of the virus.

4.4.2.3. Estimated IHNV concentration in plumes during IHN outbreaks

IHNV dispersion from marine salmon farms in the Discovery Islands was modeled using ocean circulation and IHNV dispersion, inactivation and re-infection models (Foreman et al., 2012; Foreman et al., 2015a).

Appendix C details all assumptions and input parameters for the IHNV dispersal model. Briefly, the model assumes that all 18 farms were infected and releasing IHNV particles simultaneously. Although this is not a realistic assumption, such an approach was taken to determine the maximum waterborne IHNV concentrations in the event of overlap between dispersal plumes coming from more than one farm. Given that an IHNV infection is not expected to spread in a farmed Atlantic Salmon population vaccinated against IHNV with 95% efficacy, the estimated shedding rate on the first day of infection was used to calculate the scale-up concentration factor for each particle released as part of the particle tracking model simulations.

IHNV dispersal was simulated for two months (April and July 2010) and the maximum waterborne concentration was estimated by counting the number of active particles over specific volumes. Table 10 shows the maximum concentrations (pfu) over all times and four volume choices of 3D disk that arise from all possible combinations of the simultaneous release of IHNV from 18 vaccinated farms. Plumes from different farms rarely overlapped and when they did a maximum of 5% of the modeled concentration at a particular point could be attributed to one or more farms other than the closest one (Table 10).

The highest estimated concentration of 8.69×10^2 pfu/m^3 arose after 14 days of continuous release in April from the combined modeled dispersion from the Farside and Freddie Arm farms. For all months and volumes, the maximum concentration arose within a few hundred meters of the primary contributing farm. In instances when this maximum concentration arose from more than one farm, most of the viral particles originated from a single farm. For example, in April at the 5 to 10 m depth range, Bickley contributed 99.99% of the estimated 7.83×10^2 pfu/m^3 found 300m north of Bickley with the remaining relatively small contributions coming from the Philips and Farside farms.

In July, the maximum IHNV concentration in the 0-5 m depth range (8.07×10^2 pfu/m^3) attributable to simultaneous IHNV infections on all 18 Atlantic Salmon farms in the Discovery

Islands was estimated to arise after 430 hours (over 17 days) of continuous shedding (Table 10, row 6). This maximum concentration was estimated to be approximately 500 m southeast of the Shaw farm. The corresponding maximum 0-5 m depth concentraton in April (5.71 x 10^2 pfu/m^3) occurred after 11 hours, approximately 300 m south of the Shaw farm. Note that in both months slightly larger concentrations were estimated at depth, namely 10-15 m in July (Table 10, row 8) and 15-20 m in April (Table 10, row 5).

Table 10. Modeled concentrations of IHNV (pfu/m^3) arising when all 18 Atlantic Salmon farms operating in the Discovery Islands are simultaneously releasing virus, and assuming all Atlantic Salmon are vaccinated with 95% efficacy. All concentrations are modeled maxima except for row 2 which was included to represent an area where multiple farms are located close to each other. Concentrations were computed over various depth ranges but always in a 100 m radius around the nodes. Hour denotes the time of maximum concentration computed from 0000 GMT on the 6th day of the month while the following value in brackets is the hour within the day of that maximum. Location is the geographical location where the viral particles were observed to produce this maximum concentration.

Row	Month	Depth range	Maximum [IHNV] (pfu/m^3)	Approximate location	Hour (GMT)	Contributing farm(s) and % contribution
1	April	0 – 5 m	5.71 x 10^2	300 m south of Shaw	11 (11)	Shaw (100%)
2	April	0 – 5 m	3.59 x 10^2	300 m northeast of Brent	322 (10)	Brent (99.98%) Venture (0.01%) Sonora (0.01%)
3	April	5 – 10 m	7.83 x 10^2	300 m north of Bickley	232 (16)	Bickley (99.99%) Phillips Arm (0.01%) Farside (0%)
4	April	10 – 15 m	6.84 x 10^2	300 m northwest of Bickley	303 (15)	Bickley (100%)
5	April	15 – 20 m	8.69 x 10^2	500 m northwest of Farside	355 (19)	Farside (100%) Freddie Arm (0%)
6	July	0 – 5 m	8.07 x 10^2	500 m southeast of Shaw	430 (12)	Shaw (100%)
7	July	5 – 10 m	6.31 x 10^2	200 m northwest of Lees	21 (21)	Lees (95.1%) Chancellor (4.9%)
8	July	10 – 15 m	8.61 x 10^2	300 m northwest of Bickley	431 (23)	Bickley (100%)
9	July	15 – 20 m	6.23 x 10^2	135 m northwest of Brent	342 (6)	Brent (99.97%) Venture (0.03%)

Concentrations reported in Table 10 take into account currents arising from tides, winds, freshwater discharge, heat flux, and viral decay due to UV light exposure and biota in the water. The model assumes that all 18 active Atlantic Salmon farms are simultaneously infected and releasing IHNV, which though an extremely unrealistic scenario that has never been observed could be considered a worst case scenario. Figure 7 shows the distribution of the modeled particles at the times of maximum concentration in April and July, respectively at the scale of the Discovery Islands region.

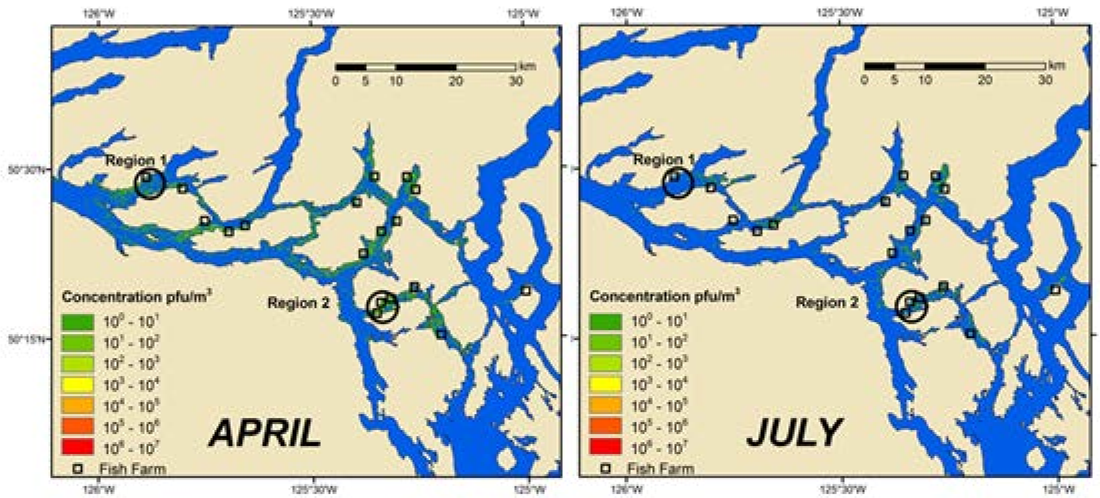

Figure 7. The modeled distribution and concentration of virus particles in the upper five meters over 17 days of continuous shedding corresponding to the time of maximum concentrations in April (left) and July (right). Note that the scale of this figure (showing the entire Discovery Islands region) is insufficient to clearly see the results. Larger scale maps of Regions 1 and 2 are shown in Figure 8 and Figure 9.

Figure 8 shows the modeled IHNV distribution for the expected maximum concentrations in the upper five meters in April and July originating from the Shaw Point farm (Region 1 in Figure 7, Table 10rows 1 and 6). The simulations demonstrate variations in the expected concentrations and plumes orginating from the same farm at different times of the year. The expected maximum concentrations at this farm are slightly lower in April (5.71×10^2 pfu/m^3) than in July (8.07×10^2 pfu/m^3) but with a larger dispersion plume in July compared to April. This is mostly due to the more energetic hydrodynamic environment in July.

Figure 9 focuses on a region of the Discovery Islands in which three fish farms (Brent, Venture and Sonora) are in relatively close proximity (Region 2 in Figure 7). The time periods chosen relate to the highest estimated concentration of IHNV in the area if all three farms were infected. Results for the modeled simultaneous release of virus particles from all fish farms at one time suggest that there is limited overlap (maximum of 5%) of the IHNV plumes from different farms that contribute to the maximum estimated IHNV concentration (Table 10).

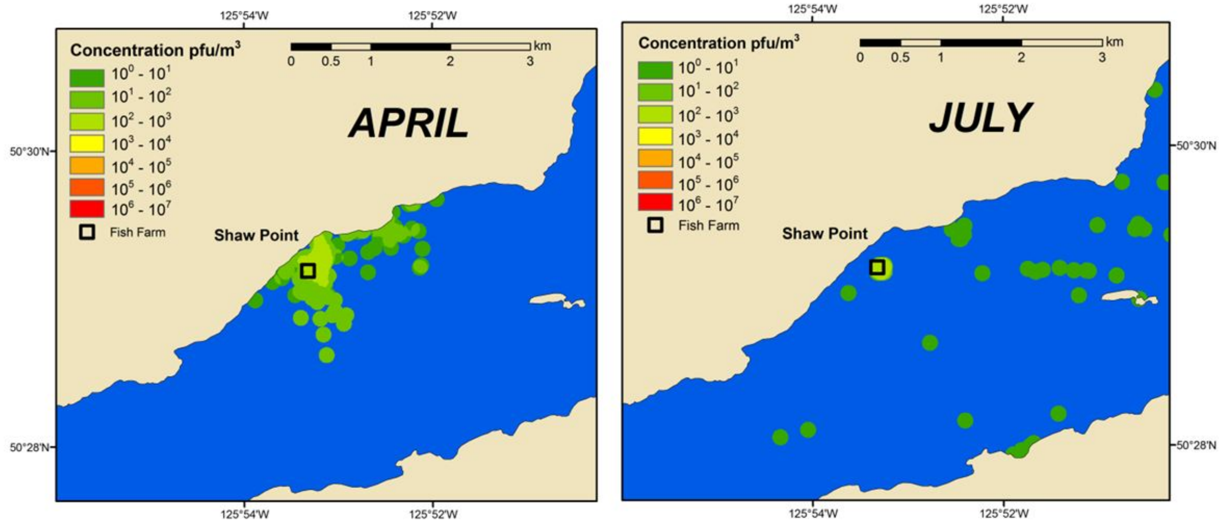

Figure 8. Modeled distribution and concentrations of IHNV particles in the upper five meters around the Shaw Point farm under current fish health practices including vaccination against IHN with a 95% vaccine efficacy. The area represents a zoom-in of Region 1 identified on Figure 7. For April, the time of maximum concentration occurs after 11 hours of continuous shedding corresponding to row 1 of Table 10. For July, the time of maximum concentration occurs after 430 hours of continuous shedding corresponding to row 6 of Table 10.

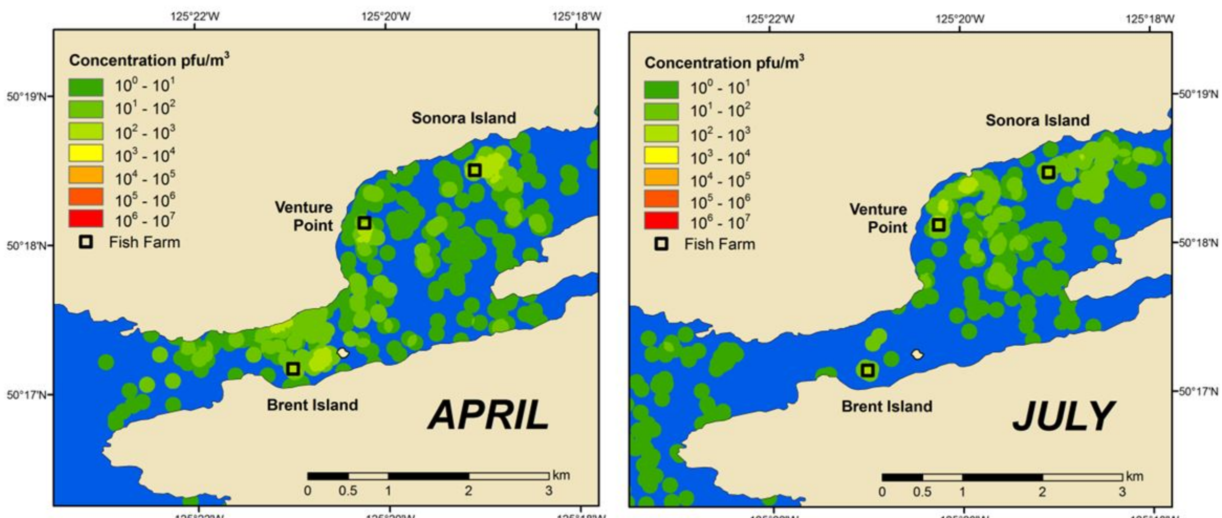

Figure 9. Modeled distribution and concentration of IHNV particles in the upper five meters around Sonora Island, Venture Point and Brent Island farms under current fish health practices including vaccination against IHN with a 95% vaccine efficacy. The area represents a zoom-in of Region 2 identified on Figure 7. For April, the time of maximum concentration occurs after 322 hours of continuous shedding corresponding to row 2 of Table 10. For July, the time of maximum concentration occurs after 342 hours of continuous shedding corresponding to row 9 of Table 10.

4.4.2.4. Estimated duration of exposure

The potential duration that a susceptible fish species is exposed to IHNV released from an Atlantic Salmon farm in the Discovery Islands depends on (i) the duration of IHN outbreaks and (ii) on the residence time of susceptible fish species in the Discovery Islands region, and more specifically in proximity to farms.

4.4.2.4.1. Duration of IHN outbreaks

IHN outbreaks on a given farm lasted 20 to 22 weeks during the 1992-1997 and 2001-2003 events (St-Hilaire et al., 2002; Saksida, 2006). However, in recent years there have been significant changes in farm health management both as a requirement of licence and voluntary industry practices.

Most significantly, fish health management practices have improved to mitigate disease occurrence. Fish health practices such as routine disease testing, examination and classification of dead fish and movement controls are in place. In addition, syndromic surveillance contributes to the early detection of events and signs of diseases (Wade, 2017). Finally, in the event of an outbreak, the industry has in place a communication and technical plan outlined in the Viral Management Plan which includes an agreement to depopulate within 14 days of confirmation of an infected site with the oversight of CFIA.

The efficacy of the above practices was demonstrated in 2012 when three sites independently tested positive for IHNV in BC. Fish were depopulated from the infected farms within four to 14 days from confirmation of positive sample. No other sites tested positive, suggesting that these measures contributed to disease containment.

The 2012 IHN outbreaks occurred on unvaccinated Atlantic Salmon farms located outside the Discovery Islands. The outbreak period was defined as ten days prior to the date on which samples that first tested positive for IHNV were collected until complete farm depopulation. Consequently, IHN outbreaks lasted respectively 23, 31 and 19 days at the Dixon, Millar and Culloden farms (Garver and Wade, 2017).

4.4.2.4.2. Residence time of susceptible species in the Discovery Islands

The average time that each Fraser River Sockeye Salmon spends in the Discovery Islands is unknown. Based on an average swimming speed ranging from 10 to 30 km/day for juveniles (Welch et al., 2009; Clark et al., 2016) and 43 km/day for adults (Quinn, 1987), residence time in the Discovery Islands was estimated to be 5 to 14 days for juveniles and three days for returning adults (Grant et al., in review). However, most Atlantic Salmon farms are located over approximately 75 km of the estimated 140 km length of the Discovery Islands area. Consequently, assuming a constant migration speed and unidirectional movement, juveniles could encounter farms over 3 to 8 days and returning adults over two days on their migration through the Discovery Islands.

In general, Chinook Salmon appear to remain on the shelf near their river of origin until their second year at sea, when they migrate northward (Trudel et al., 2009; Tucker et al., 2011, 2012). Welch et al. (2011) reported an almost three times lower average marine migration swimming speed for juvenile Chinook Salmon (0.33 body length per second, n=5) than Sockeye Salmon (0.95 body length per second, n=128). However, the average time that Chinook Salmon and Chum Salmon actually spend in the Discovery Islands is currently unknown.

There are no data to determine if juvenile Sockeye Salmon are attracted to farms. Juvenile Sockeye Salmon behaviour around salmon farms is also unknown. For instance, salmon farms may provide a shelter to juvenile Sockeye Salmon from currents flowing against their direction of migration. Nevertheless, given that Sockeye Salmon are swimming close to their theoretical optimal swimming speed, they are unlikely to remain in any specific area of the Discovery Islands/Johnstone Strait for long, especially given the low growth conditions observed in this area (Ferriss et al., 2014; McKinnell et al., 2014; Journey, 2015). Consequently, the time juvenile Sockeye Salmon could spend on or in close proximity of farms in the Discovery Islands remains unknown.

4.4.2.5. Minimum lethal dose

Laboratories studies conducted in seawater determined that the lowest concentration of IHNV necessary to cause mortality (minimum lethal dose) in Atlantic Salmon is 10^7 pfu/m^3 (10 pfu/mL) for a one hour exposure period (Garver et al., 2013).

Sockeye Salmon are less susceptible than Atlantic Salmon when exposed to IHNV (Traxler et al., 1993) requiring a 10- to 100-fold higher virus dose than Atlantic Salmon at a similar life stage to result in mortality (Long et al., 2017). Consequently, the minimum lethal dose of IHNV for juvenile Sockeye Salmon is estimated to vary between 10^8 to 10^9 pfu/m^3 (100 to 1000 pfu/mL) for a one hour exposure period (Garver and Wade, 2017).

The minimum lethal dose of IHNV in other Pacific salmon species is unknown.

4.4.2.6. IHN is endemic to BC

As previously stated, IHNV occurs naturally in the waters of western North America (Garver and Wade, 2017) and consequently, Sockeye Salmon juveniles have been shown in some cases to be exposed to IHNV prior to a potential exposure from Atlantic Salmon farms.

It is generally accepted that fish surviving exposure to IHNV mount a protective immunological response, often accompanied by measurable IHNV specific neutralizing antibodies in the plasma (Amend and Smith, 1974). The concentration and duration of exposure to IHNV that stimulates this protective response is likely variable and dependent upon interactions among the host, virus and environment.

4.4.3. Assumptions

The rankings of the likelihood of IHN susceptible wild fish to be exposed to a dose and for a period of time sufficient to cause infection and disease under the current fish health management practices were made under the following assumptions:

- IHNV particles are almost completely inactivated eight days after being released in the environment (Foreman et al., 2015a);
- exposure to a minimum concentration of IHNV of 10^8 pfu/m^3 for an hour or more is required to infect and cause IHN in juvenile Sockeye Salmon;
- the minimum lethal dose for adult Sockeye Salmon is higher than that of juvenile Sockeye Salmon (i.e., 10^8 pfu/m^3 for an hour);
- although considered an overestimation, the duration of exposure is equivalent to the estimated time Sockeye Salmon spend migrating through the Discovery Islands where Atlantic Salmon farms are located (i.e., 3 to 8 days for juveniles and 2 days for adults);
- farmed Atlantic Salmon are vaccinated against IHNV with a vaccine having 95% efficacy (refer to Appendices E and F for other vaccine efficacy rates);

- in a vaccinated farmed population, the proportion of susceptible individuals is directly related to the vaccine failure rates;
- 40% of infected Atlantic Salmon shed IHNV at peak shedding rate (3.2×10^7 pfu/fish/hour) and 60% at half this rate (1.6×10^7 pfu/fish/hour) regardless of age and size;
- all infected farmed Atlantic Salmon are depopulated within 14 days upon confirmation of positive samples and approval of CFIA; and
- all juvenile Fraser River Sockeye Salmon entering the Discovery Islands are assumed to be naïve, i.e., have not been exposed to IHNV, even though this represents an unrealistic scenario.

4.4.4. Likelihood of infection

The following factor contributes to the likelihood that susceptible wild fish would be exposed to IHNV at a dose and for a period of time sufficient to cause infection and disease:

- Water temperature and salinity in the vicinity of Atlantic Salmon farms are suitable for IHNV survival.

The following factors limit the likelihood that susceptible wild fish would be exposed to IHNV at a dose and for a period of time sufficient to cause infection and disease:

- The estimated maximum waterborne IHNV concentrations of IHNV in net pens is approximately 7,000 times lower than the minimum one-hour lethal dose of IHNV for juvenile Sockeye Salmon;
- The estimated maximum waterborne concentrations of IHNV in dispersed plumes from infected Atlantic Salmon farms is approximately 100,000 times lower than the minimum one-hour lethal dose of IHNV for juvenile Sockeye Salmon, even in the extremely unrealistic scenario of simultaneous IHNV releases on all active farms;
- Voluntary fish health management practices include measures for early detection of infection and depopulation of infected fish within 14 days of confirmation of positive samples and approval of CFIA.

4.4.4.1. Infection of juvenile Fraser River Sockeye Salmon

This assessment considers the likelihood that juvenile Fraser River Sockeye Salmon are exposed to IHNV at a dose and for a period of time sufficient to cause infection and disease. It assumes that juvenile Fraser River Sockeye Salmon have only been exposed to IHNV released from infected farms.

4.4.4.1.1. In net pens

It was concluded that the likelihood for juvenile Fraser River Sockeye Salmon to be exposed to IHNV in Atlantic Salmon net pens in the Discovery Islands at a dose and for a period of time sufficient to cause infection and disease is **extremely unlikely** given that the estimated maximum waterborne IHNV concentrations of IHNV in net pens is approximately 7,000 times lower than the minimum one-hour lethal dose of IHNV for juvenile Sockeye Salmon.

This conclusion was, however, made with **reasonable uncertainty** given the limited data to estimate the waterborne IHNV concentrations in net pens as well as the incomplete knowledge of the time juvenile Sockeye Salmon spend in net pens and the outcome of a prolonged exposure of juvenile Sockeye Salmon to sublethal doses.

4.4.4.1.2. In plumes

It was concluded that the likelihood for juvenile Fraser River Sockeye Salmon to be exposed to IHNV in plumes dispersed from Atlantic Salmon farms in the Discovery Islands at a dose and for a period of time sufficient to cause infection and disease is **extremely unlikely** given that the estimated maximum waterborne concentrations of IHNV in dispersed plumes from infected Atlantic Salmon farms is approximately 100,000 times lower than the minimum one-hour lethal dose of IHNV for juvenile Sockeye Salmon.

This conclusion was, however, made with **reasonable uncertainty** given the limited data and requirement to use modeling to estimate the waterborne IHNV concentrations in plumes, as well as the incomplete knowledge of the time juvenile Sockeye Salmon spend in plumes and the outcome of a prolonged exposure of juvenile Sockeye Salmon to sublethal doses.

4.4.4.2. Infection of adult Fraser River Sockeye Salmon

The following factors limit the likelihood that adult Sockeye Salmon would be exposed to IHNV at a dose and for a period of time sufficient to cause infection and disease:

- Pacific salmon species, including Sockeye Salmon, have been reported to become refractory to IHN with increasing size and life stage (Garver and Wade, 2017).
- IHNV is commonly found in spawning adult Sockeye Salmon but is not associated with IHN (Meyers et al., 2003).

4.4.4.2.1. In net pens

It was concluded that the likelihood for adult Fraser River Sockeye Salmon to be exposed to IHNV in Atlantic Salmon net pens in the Discovery Islands at a dose and for a period of time sufficient to cause infection and disease is **extremely unlikely** given that Pacific salmon species, including Sockeye Salmon, have been reported to become refractory to IHN with increasing size and life stage and that the estimated maximum waterborne IHNV concentrations of IHNV in net pens are not even sufficient to infect and cause disease in juveniles Sockeye Salmon and thus even less likely to infect adult.

This conclusion was made with **reasonable certainty** given abundant data about the refractory nature of Sockeye Salmon to IHN with increasing size and life stage.

4.4.4.2.2. In plumes

It is concluded that the likelihood for adult Fraser River Sockeye Salmon to be exposed to IHNV in plumes dispersed from Atlantic Salmon farms in the Discovery Islands at a dose and for a period of time sufficient to cause infection and disease is **extremely unlikely** given that Pacific salmon species, including Sockeye Salmon, have been reported to become refractory to IHN with increasing size and life stage and that the estimated maximum waterborne IHNV concentrations of IHNV in plumes are not sufficient to infect and cause disease in juveniles Sockeye Salmon.

This conclusion was made with **reasonable certainty** given abundant data about the refractory nature of Sockeye Salmon to IHN with increasing size and life stage.

4.4.4.3. Infection of other IHN susceptible fish species

The following factors limit the likelihood that Chinook or Chum Salmon would be exposed to IHNV at a dose and for a period of time sufficient to cause infection and disease:

- Chinook and Chum Salmon are less susceptible to IHNV than Atlantic and Sockeye Salmon (Garver and Wade, 2017); and
- Pacific salmon species have been reported to become refractory to IHN with increasing size and life stage (reviewed in Garver and Wade (2017)).

4.4.4.3.1. In net pens

It was concluded that the likelihood for Chinook and Chum Salmon to be exposed to IHNV in Atlantic Salmon net pens in the Discovery Islands at a dose and for a period of time sufficient to cause infection and disease is **extremely unlikely** given that Chinook and Chum Salmon are less susceptible to IHNV than Atlantic and Sockeye Salmon, that Pacific salmon species have been reported to become refractory to IHN with increasing size and life stage and that the estimated maximum waterborne IHNV concentrations of IHNV in net pens are not even sufficient to infect and cause disease in juveniles Sockeye Salmon.

This conclusion was made with **reasonable certainty** given abundant data about the relative susceptibility of Chinook and Chum Salmon, as well as increasing size and older life stages, to IHN disease.

4.4.4.3.2. In plumes

It was concluded that the likelihood for Chinook and Chum Salmon to be exposed to IHNV in plumes dispersed from Atlantic Salmon farms in the Discovery Islands at a dose and for a period of time sufficient to cause infection and disease is **extremely unlikely** given that Chinook and Chum Salmon are less susceptible to IHNV than Atlantic and Sockeye Salmon, that Pacific salmon species have been reported to become refractory to IHN with increasing size and life stage and that the estimated maximum waterborne IHNV concentrations of IHNV in plumes are not even sufficient to infect and cause disease in juveniles Sockeye Salmon.

This conclusion was made with **reasonable certainty** given abundant data about the relative susceptibility of Chinook and Chum Salmon, as well as increasing size and older life stages, to IHN disease.

4.5. OVERALL LIKELIHOOD ASSESSMENT

The estimated likelihoods and uncertainties (Table 11) were combined as per the combination rules (see section 3.2.4.5). The combined likelihood for the release assessment was determined by adopting the highest likelihood ranking among the release pathways. As the release pathways are not mutually exclusive and could occur concurrently, the combined likelihood could be an underestimation of the likelihood of IHNV being released from an IHNV-infected farm.

The overall likelihood was determined sequentially. First, for each route in a given exposure group, the lowest likelihood ranking among the disease, release, exposure and infection assessments was adopted. Second, for each exposure group, the highest likelihood ranking between the exposure routes was adopted. Finally, the highest likelihood ranking among the exposure groups was adopted to determine the overall likelihood. Uncertainties were combined as described in section 3.2.4.5.

It was concluded with **reasonable uncertainty** that the likelihood that Atlantic Salmon farms in the Discovery Islands release IHNV into an environment and subsequently expose susceptible wild fish populations to a dose and for a period of time sufficient to cause infection and disease is **extremely unlikely**.

Table 11. Likelihood and uncertainty rankings for each step of the likelihood assessment under current fish health management practices. Estimates are reported in white cells and likelihood combination results are reported in coloured cells.

Disease assessment	**Likelihood of disease**	Very unlikely *Reasonable certainty*					
Release assessment	**Release pathways**	**Farmed Atlantic Salmon**		**Mechanical vectors**		**Fomites**	
	Likelihood of release	Expected *High certainty*		Very unlikely *High certainty*		Very unlikely *High certainty*	
	Combined likelihood of release	Expected *High certainty*					
Exposure and infection assessments	**Exposure group**	**Juvenile Fraser River Sockeye Salmon**		**Adult Fraser River Sockeye Salmon**		**Other IHN susceptible fish**	
	Exposure route	**In net pens**	**In plumes**	**In net pens**	**In plumes**	**In net pens**	**In plumes**
	Likelihood of exposure	Likely *Reasonable uncertainty*	Very likely *Reasonable certainty*	Extremely unlikely *Reasonable certainty*	Very likely *Reasonable certainty*	Likely *Reasonable certainty*	Very likely *Reasonable certainty*
	Likelihood of infection	Extremely unlikely *Reasonable uncertainty*	Extremely unlikely *Reasonable uncertainty*	Extremely unlikely *Reasonable certainty*	Extremely unlikely *Reasonable certainty*	Extremely unlikely *Reasonable certainty*	Extremely unlikely *Reasonable certainty*
Combined likelihoods for each exposure route in a given exposure group		Extremely unlikely *Reasonable uncertainty*	Extremely unlikely *Reasonable uncertainty*	Extremely unlikely *Reasonable certainty*	Extremely unlikely *Reasonable certainty*	Extremely unlikely *Reasonable certainty*	Extremely unlikely *Reasonable certainty*
Combined likelihoods for each exposure group		Extremely unlikely *Reasonable uncertainty*		Extremely unlikely *Reasonable certainty*		Extremely unlikely *Reasonable certainty*	
Overall likelihood of disease, release, exposure and infection		Extremely unlikely *Reasonable uncertainty*					

5. CONSEQUENCE ASSESSMENT

The consequence assessment consists of determining the potential magnitude of impact of IHNV infection attributable to Atlantic Salmon farms on the abundance and diversity of Fraser River Sockeye Salmon. The consequence assessment assumes that wild fish have been exposed to IHNV released from an infected Atlantic Salmon farm at a dose and for a period of time sufficient to cause infection.

5.1. QUESTIONS

The consequence assessment aims to answer the following two questions:

- Assuming that wild fish have been exposed to IHNV released from infected Atlantic Salmon farms at a dose and for a period of time sufficient to cause infection, what is the potential magnitude of impact on the number of returning adult Fraser River Sockeye Salmon?
- Assuming that wild fish have been exposed to IHNV released from infected Atlantic Salmon farms at a dose and for a period of time sufficient to cause infection, what is the potential magnitude of impact on the diversity of Fraser River Sockeye Salmon?

5.2. CONSIDERATIONS

Relevant considerations include IHN prevalence and corresponding Sockeye Salmon mortality, stock specific susceptibility of Fraser River Sockeye Salmon to IHN, sublethal impacts of IHNV infection in Sockeye Salmon, status of Fraser River Sockeye Salmon conservation units, and Fraser River Sockeye Salmon marine survival.

5.2.1. IHN prevalence and mortality in Sockeye Salmon populations

There are few references documenting the prevalence and distribution of mortalities during IHN epizootics in Sockeye Salmon populations in the wild and available information is limited to impact resulting from exposure in freshwater. Two studies describe the impact in pre-smolt (Williams and Amend, 1976; Traxler and Rankin, 1989) and one study reports the impact in 1.5 year old out-migrating smolts (Burke and Grischkowsky, 1984). To this date, there are no studies reporting the impact of IHN on Sockeye Salmon populations in the wild resulting from exposure in a marine environment.

The first documented epizootic of IHN under natural conditions occurred in pre-smolt Sockeye Salmon at Chilko Lake, BC during the spring of 1973 (Williams and Amend, 1976). An estimated 31.4 million fry were produced during that year compared to a predicted 55.1 million based on previous years (1952 to 1971). However, the effect of IHN on this population was predominantly observed on egg-to-fry survival and had no apparent effect on the fry during the lacustrine stage of the life cycle (Williams and Amend, 1976).

The egg-to-fry stage was also the most impacted life stage in an IHN epizootic in Sockeye Salmon in the Weaver Creek spawning channel in 1987 (Traxler and Rankin, 1989). The prevalence of IHN virus in Sockeye Salmon fry was highest during the early part of the fry migration from the spawning channel and resulted in an estimated loss of 8.3 million of the 16.8 million fry migrating from the channel (Traxler and Rankin, 1989).

IHN epizootics occurred in 1.5-year-old Sockeye Salmon smolts in Alaska in two consecutive years (1980 and 1981) (Burke and Grischkowsky, 1984). In both years, mortality was observed in a portion of out-migrating Sockeye Salmon smolts from Hidden Lake. In 1980, mortality reached 8% in the last 29% of the out-migrants, and in 1981, mortality reached 2.5% in the last 26% of the out-migrants. Based on tissue culture assays, the authors concluded that mortalities were due to IHN (Burke and Grischkowsky, 1984).

Mortalities due to IHN resulting from exposure to IHNV in seawater under laboratory conditions have been reported. Exposure of 25 Sockeye Salmon post-smolts to IHNV through cohabitation with infected Atlantic Salmon undergoing acute IHN resulted in 4% mortality (1 out of 25) after 37 days post-exposure (Traxler et al., 1993). More recently, Sockeye Salmon smolts cohabitating in seawater with infected Atlantic Salmon under laboratory conditions for 50 days resulted in a maximum cumulative percent mortality of 12.5% (Long et al., 2017).

To date, no natural IHN mortality events have been observed in the marine environment and adult life stages of Sockeye Salmon. Table 12 summarizes studies reporting impacts of IHN to older life stages in the wild and/or laboratory studies conducted in seawater.

Table 12. Summary of most relevant studies to this risk assessment on IHN mortality in Sockeye Salmon smolts exposed to IHNV. NA: not applicable.

Source	Description	Mortality	Days to first observed mortality
Burke and Grischkowsky (1984)	Natural IHN epizootic in freshwater in 1.5-year-old Sockeye Salmon out migrating smolts in Alaska in 1980. Mortality rate reached 8% in 29% of 81,942 total out-migrants.	8%	≈ 19
	Natural IHN epizootic in freshwater in 1.5 year-old Sockeye Salmon out migrating smolts in Alaska in 1981. Mortality rate reached 2.5% in 26% of 161,522 total out-migrants.	2.5%	≈ 15
Traxler et al. (1993)	Transmission of IHN to sockeye and Atlantic Salmon smolts by cohabitation with acutely injected Atlantic Salmon under laboratory conditions. 1/25 Sockeye Salmon died 37 days post-exposure.	4.0%	37
	Bath challenge of Sockeye Salmon in a sea water bath of 8.98×10^3 pfu/mL (8.98×10^9 pfu/m^3). None of the 20 fish died after three hours.	0%	NA
Long et al. (2017)	Forty (40) Sockeye Salmon smolts cohabitating with acutely infected Atlantic Salmon in sea water under laboratory conditions resulted in a maximum cumulative percent mortality of 12.5% (5/40).	12.5%	19

5.2.2. Stock-specific susceptibility

Susceptibility to IHNV is also known to vary within a species (Garver and Wade, 2017). For instance, Chinook Salmon from a genetically-defined stock (defined as a unit of assessment for management purposes) from Washington were more susceptible to IHNV than Chinook Salmon stocks from Alaska (Wertheimer and Winton, 1982) and Sockeye Salmon from Pitt River exhibited higher susceptibility to IHNV than Sockeye Salmon the Upper Columbia River (Garver and Wade, 2017). Although it is recognized that there can be stock specific differences in susceptibility between watersheds given strong homing behaviour and genetic variability among watersheds (Holtby and Ciruna, 2007), it is uncertain to what extent Fraser River Sockeye Salmon stocks exhibit this variability.

5.2.3. Sublethal impact of IHNV infections

It is recognized that there can be both sublethal and cumulative effects of exposure to pathogens. There is no reason to believe that this is different for exposure to IHNV. However, the current state of knowledge is not sufficient to quantify sublethal effects due to IHNV infection.

Documented sublethal effects due to IHNV infection are limited. Scoliosis has been observed in Sockeye Salmon fry surviving IHNV infection (Meyers et al., 2008; Müller et al., 2015); however, it is unknown as to whether this effect is observed in smolts or juveniles exposed to IHNV. Although sublethal effects of IHNV infection may impact body condition (e.g., scoliosis in fry) and body condition of salmon is thought to be correlated with susceptibility to predation (Miller et al. 2014, Tucker et al. 2016), sublethal impacts of IHNV infection on predation have not been studied and remains uncertain.

Additionally, although the majority of fry surviving an infectious exposure of IHNV in freshwater are able to clear infection and mount a protective immune response to subsequent IHNV exposure (Garver and Wade, 2017), a small proportion of exposed fish develop persistent subclinical infections. Asymptomatic persistent infections have been observed in sockeye and Chinook Salmon fry exposed to IHNV under controlled laboratory conditions (St-Hilaire et al., 2001b; Müller et al., 2015; Hernandez et al., 2016). Transcriptional profiling of subclinically infected Sockeye Salmon fry demonstrated a unique brain transcriptome profile which suggested an ongoing adaptive immune response, yet IHNV carriers remained uncompromised in mounting efficient innate antiviral responses when exposed to a viral mimic (Müller et al., 2015).

It remains unknown if marine phase Sockeye Salmon develop persistent subclinical infections after IHNV exposure in the marine environment. Furthermore it is unknown whether sublethal exposure of marine phase Sockeye Salmon to IHNV would result in elevated resistance to further infection with IHNV and/or other viruses or elevated susceptibility to other pathogens. Consequently, the impact at the population level resulting from an exposure to a concentration lower than the minimum lethal dose is unknown.

5.2.4. Fraser River Sockeye Salmon ecology

5.2.4.1. Cyclic dominance

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

5.2.4.2. Conservation units

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

The Wild Salmon Policy defines three zones of biological status (Red, Amber and Green) (DFO, 2005). The status of each Fraser River Sockeye Salmon CU has been determined through a Canadian Science Advisory Secretariat workshop during which relevant metrics for each CU were integrated to generate a final status assessment (DFO, 2013a; Grant and Pestal, 2013). Two main factors can change the biological status of a CU: a change in biology and a management intervention. For example, if spawner abundance decreases, a lower status is attributed (e.g., amber to red) and the extent of management intervention for conservation purposes increases (DFO, 2005).

Out of the 24 Fraser River Sockeye Salmon CU's, seven are in the Red status zone and four are in the Red/Amber zone, which are poor status zones (Grant and Pestal, 2013). The factors that contribute to the designation of each of these CU's vary, although these CU's generally have low abundances, and also may have experienced recent declines in abundance and productivity (Grant and Pestal, 2013). Since CU's with low abundances are at higher risk of extirpation (Holt et al., 2009; Holt and Bradford, 2011), factors that decrease survival in these CU's in particular will further increase their risk of extirpation and possibly reduce effectiveness of recovery actions.

5.2.5. Sockeye Salmon marine survival

Adult returns of Fraser River Sockeye Salmon exhibit high inter-annual variability ranging from 1.5 to 28.2 million, with an average of 9.6 million between 1980 and 2014 (Grant et al., in review).

Sockeye Salmon CUs from the Chilko system and Cultus Lake are the only two Fraser River Sockeye Salmon CUs for which marine survival data are available. For both CUs, smolt-to-adult marine survival estimates include freshwater survival from the time the fish leave their respective rearing lakes.

Chilko Lake Sockeye Salmon dominate total returns particularly in recent years and thus its marine survival time series is considered an indicator of marine survival for Fraser River Sockeye Salmon as an aggregate. The average (geometric) Chilko Lake Sockeye Salmon marine survival from the outlet of Chilko Lake to returning adult is 6.9% over the whole time series (1951-2013 ocean entry years) and 4.3% in recent years (1992-2013 ocean entry years). Maximum survival calculated for Chilko Lake Sockeye Salmon is 25.1% in ocean entry year 1988 and the minimum is 0.4% in ocean entry year 2007.

Although marine survival rates are not available for other Fraser River CUs, Peterman and Dorner (2012) show that trends in productivity (including overall survival and fecundity) are correlated among most lake-type Fraser River Sockeye Salmon.

5.3. ASSUMPTIONS

Estimates of the magnitude of impact of an IHNV infection attributable to Atlantic Salmon farms operating in the Discovery Islands on the abundance and diversity of Fraser River Sockeye Salmon were made under the following assumptions:

- the entire CU is exposed to IHNV;
- all fish infected with IHNV die of IHN; and
- there is no correlation between IHN mortality and marine mortality from other sources in Sockeye Salmon, i.e., the marine mortality rate is the same in IHN infected and non-infected fish.

5.4. MAGNITUDE OF CONSEQUENCES

The potential magnitude of consequences on both abundance and diversity of Fraser River Sockeye Salmon resulting from the exposure and infection of juvenile Fraser River Sockeye Salmon, adult Fraser River Sockeye Salmon or other IHN susceptible fish species were determined separately.

5.4.1. Juvenile Fraser River Sockeye Salmon

Although laboratory exposures of post-smolt Sockeye Salmon have been conducted, mortality rates associated with natural IHNV epizootics were used to more closely reflect field conditions rather than a laboratory setting. Consequently, IHN mortality data (Table 12) of most relevance to determine the consequence of exposure to an infectious dose of IHNV in Sockeye Salmon are those reported by Burke and Grischkowsky (1984) in Alaska.

It can be demonstrated that the percent reduction in the number of returning Fraser River Sockeye Salmon is equivalent to the product of IHN prevalence (proportion of the population that is infected) and IHN case fatality rate (proportion of the infected fish that die) (refer to Appendix D for more details). However, no data are available to separately estimate the prevalence and case fatality rate in exposed Fraser River Sockeye Salmon. Although it is possible that surviving fish may also be diseased and have reduced (or improved) fitness, there is no quantitative evidence to support this hypothesis. It is therefore reasonable to assume that the mortality rates observed in the Alaska outbreaks (Burke and Grischkowsky, 1984) represent both the prevalence and case fatality rate in fish exposed to IHNV at a dose and for a duration sufficient to cause infection and disease (i.e., all fish that are infected die of IHN). Therefore, the consequence on abundance, defined as the percent reduction in the number of returning Fraser River Sockeye Salmon (Table 3), is equal to the observed IHN mortality rate, assuming that there is no correlation between IHN mortality and marine survival from other sources in Fraser River Sockeye Salmon.

To interpret the study by Burke and Grischkowsky (1984), it was necessary to estimate the proportion of the population that had been exposed to an infectious dose of IHNV. The time elapsed between exposure to IHNV and the first mortality in laboratory studies varies with dose and life stage: it can be as long as 19 days for smolt and fry (Traxler et al., 1993; Müller et al., 2015; Long et al., 2017) and as short as seven days in fry exposed to high doses (Garver and Wade, 2017). In the Alaska outbreaks, the mortalities were first observed approximately 19 days (1980) and 15 days (1981) after the beginning of the migration (Burke and Mulcahy, 1983) which is consistent with time to first mortality reported by Long et al. (2017) under laboratory conditions. It is therefore considered reasonable to assume that the entire population of out-migrating smolts was exposed to an infectious dose of IHNV at the beginning of the migration. Assuming that all the mortalities observed in the epizootics in Alaska were due to IHN, the mean reduction in the number of returning Fraser River Sockeye Salmon resulting from an IHNV infection at the smolt stage could reach 8%.

5.4.1.1. Abundance

It was concluded that the magnitude of potential consequences to the abundance of Fraser River Sockeye Salmon resulting from an IHNV infection in juvenile Fraser River Sockeye Salmon attributable to Atlantic Salmon farms would be **moderate** given that mortality reached 8% in a Sockeye Salmon population exposed to a lethal dose (Burke and Grischkowsky, 1984).

This conclusion was made with **high uncertainty** given the lack of data on the IHN mortality in wild Sockeye Salmon exposed to IHNV in seawater and the high reliance on proxy data and information. Although the natural IHNV epizootics (Burke and Grischkowsky, 1984) were considered to be the most informative for this risk assessment, interpretation of the results was limited as it was not possible to determine if fish may have died in the lake prior to outmigration and if fish that had migrated past the counting station had then died from IHN due to direct and indirect effects. Furthermore, given the lack of detailed information about the migration route of juvenile Fraser River Sockeye Salmon and their interaction with farms in the Discovery Islands, the entire population was assumed to be exposed to a lethal dose which is considered an overestimation given the multiple potential migration routes through the Discovery Islands.

5.4.1.2. Diversity

The potential magnitudes of consequences of IHN in cyclic stocks were considered separately for the weak and dominant cycle lines. The weak cycle years do not drive production for the CU and the loss of weak cycles could be re-populated from age-classes from other larger cycles in the future. However, this may not be the case for reductions in the dominant cycle line. Given an IHN mortality rate of 8% (Burke and Grischkowsky, 1984), it would represent a moderate consequence for strongly cyclic stocks, regardless of whether IHN impacted a dominant or a non-dominant cycle line.

The potential magnitudes of consequences of IHN in non-cyclic stocks would not be expected to differ among years. Consequently, non-cyclic CUs, even one with a poor status (i.e., identified as a Red or Red/Amber), would have to be impacted by IHN at least three or four years in a row to be at risk of extirpation given that returning Fraser River Sockeye Salmon are predominantly four-year-old fish and an IHNV infection on a single year would not affect the three other cycle years. Even if mortality for one cycle line increases due to IHN, the remaining three cycle lines would not be affected and could contribute in future years to the one cycle line affected by IHNV contributions from their different age classes. Consequently, the average abundance across the four cycle years used in the assessment of status would experience a moderate impact, given that abundances on three other cycle years would not be affected.

It was concluded that the magnitude of potential consequences to the diversity of Fraser River Sockeye Salmon resulting from an IHNV infection in juvenile Fraser River Sockeye Salmon attributable to Atlantic Salmon farms would be **moderate** based on the above and the reported mortality in Burke and Grischkowsky (1984).

This conclusion was made with **high uncertainty** given the lack of data on the IHN mortality rates in wild Sockeye Salmon exposed to IHNV in seawater, the high reliance on proxy data and expert opinion and on the possibility that IHN would occur in a cyclic vs non-cyclic stock, and in a weak or dominant cycle.

5.4.2. Adult Fraser River Sockeye Salmon

It was concluded that the magnitude of potential consequences to the abundance or diversity of Fraser River Sockeye Salmon resulting from an IHNV infection in adult Fraser River Sockeye Salmon attributable to Atlantic Salmon farms is **negligible** given that despite evidence of IHNV in adult Sockeye Salmon in seawater (Traxler et al., 1997), no natural IHNV mortality events have been observed in the adult life stages of Sockeye Salmon (Garver and Wade, 2017) as adult Sockeye Salmon appear to be refractory to IHN (Garver and Wade, 2017).

This conclusion was made with **reasonable certainty** given available data demonstrating that adult Sockeye Salmon become refractory to IHN with increasing size and time.

5.4.3. Other IHN susceptible fish species

It was concluded that the magnitude of potential consequences to abundance and diversity of Fraser River Sockeye Salmon resulting from an IHNV infection in Chinook and Chum Salmon would be **negligible** given that Chinook and Chum Salmon are considered to be more refractory to IHNV infection than Sockeye Salmon (Follett et al., 1987). Furthermore, Pacific salmon species, including Chinook and Chum Salmon, become refractory to IHN disease with increasing age (Garver and Wade, 2017) and no IHN disease or epizootics have been reported in adult Chinook and Chum Salmon that have tested positive for IHNV (Garver and Wade, 2017).

This conclusion was made with **high uncertainty** given the lack of empirical data concerning the ability of IHNV infected Chinook and Chum Salmon to be a source of virus for Sockeye Salmon.

5.5. OVERALL CONSEQUENCE ASSESSMENT

Potential consequences of IHNV infection attributable to Atlantic Salmon farms to the abundance and diversity of Fraser River Sockeye Salmon in juvenile Fraser River Sockeye Salmon, adult Fraser River Sockeye Salmon or other IHN susceptible species were considered separately.

Juvenile Fraser River Sockeye Salmon were concluded to be the only exposure group through which potential consequences to the abundance and diversity of Fraser River Sockeye Salmon could arise as a result of IHNV infection attributable to Atlantic Salmon farms.

5.5.1. Abundance

It was concluded with **high uncertainty** that the potential magnitude of consequences to the abundance of Fraser River Sockeye Salmon resulting from IHNV infection attributable to Atlantic Salmon farms would be **moderate**.

5.5.2. Diversity

It was concluded with **high uncertainty** that the potential magnitude of consequences to the diversity of Fraser River Sockeye Salmon resulting from IHNV infection attributable to Atlantic Salmon farms would be **moderate**.

6. RISK ESTIMATION

The risk to both the abundance and diversity of Fraser River Sockeye Salmon were estimated based on the results from the likelihood and consequence assessments and using the risk matrices (Figure 3 and Figure 4) included in the problem formulation (Section 3.2.4.6).

6.1. ABUNDANCE

The risk to the abundance of Fraser River Sockeye Salmon was estimated based on the matrix combining the results of the likelihood assessment and the results of the consequence to the abundance assessment (Figure 3).

It was concluded that, under the current fish health management practices, the risk to the abundance of Fraser River Sockeye Salmon as a result of IHNV infection attributable to Atlantic Salmon farms operating in the Discovery Islands is **minimal**.

6.2. DIVERSITY

The risk to the diversity of Fraser River Sockeye Salmon was estimated based on the risk matrix combining the results of the likelihood assessment and the results of the consequence to the diversity assessment (Figure 4).

It was concluded that, under the current fish health management practices, the risk to the diversity of Fraser River Sockeye Salmon as a result of IHNV infection attributable to Atlantic Salmon farms operating in the Discovery Islands is **minimal**.

7. SOURCES OF UNCERTAINTIES

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

7.1. UNCERTAINTIES IN THE LIKELIHOOD ASSESSMENT

Uncertainties associated with the rankings in the likelihood assessment were generally lower in the first steps (disease and release assessment) and higher in the last steps (exposure and infection assessments).

The reasonable certainty associated with the disease assessment resulted from the low levels of operational deficiencies that could affect fish health on Atlantic Salmon farms in the Discovery Islands; the adoption and implementation of the Viral Management Plan by all companies operating in the Discovery Islands; and the BAP certification of all Atlantic Salmon farms in the Discovery Islands providing confidence that vaccination for IHNV is being implemented. However, the voluntary nature of some key fish health management practices prevented the attribution of a high certainty for the disease assessment.

The high certainty associated with the release assessment resulted from available peer-reviewed and published data on shedding of IHNV by disease Atlantic Salmon.

The reasonable uncertainty attributed to the exposure of juvenile Fraser River Sockeye Salmon in net pens results from the lack of knowledge of the precise residence time of juvenile Fraser River Sockeye Salmon in the Discovery Islands and the proportion that interact with Atlantic Salmon farms.

The reasonable uncertainty attributed to the infection of juvenile Fraser River Sockeye Salmon results from the need to model the estimated infection pressure and the lack of knowledge of the impact of exposure to waterborne IHNV at concentrations lower than the minimal one-hour lethal dose. Uncertainty also remains in the variability observed in disease progression during the 2012 IHN outbreaks in BC.

7.2. UNCERTAINTIES IN THE CONSEQUENCE ASSESSMENT

The high uncertainties in the consequence assessments for both abundance and diversity result from the absence of data on IHN mortality in wild Sockeye Salmon exposed to IHNV in seawater and the high reliance on proxy data and information; the lack of data to estimate the proportion of the population that would be exposed to IHNV released from Atlantic Salmon farms in the event of an IHN outbreak; the lack of knowledge of potential sublethal and cumulative effects of exposure to IHNV; and the intrinsic complexity, high variability and lack of data regarding Sockeye Salmon marine survival.

There are also additional uncertainties related to the natural environmental variability, including climate change, which influence several parameters including viral survival and dispersion in seawater, as well as salmon migration patterns and timing.

8. CONCLUSIONS

The assessment concluded that IHNV attributable to Atlantic Salmon farms operating in the Discovery Islands poses minimal risk to Fraser River Sockeye Salmon abundance and diversity under the current fish health management practices which includes vaccination against IHN and timely depopulation of infected fish.

Two main factors influenced the attribution of the minimal risk. First, it is reasonably certain that IHN outbreaks on Atlantic Salmon farms in the Discovery Islands are very unlikely to occur under current health management practices. Second, even assuming an IHNV infection and disease did occur on an Atlantic Salmon farm, the maximum waterborne concentrations of IHNV in the net pens and surrounding the infected farm are estimated to remain below the one-hour minimum lethal dose for juvenile Sockeye Salmon given the timely depopulation of an infected farm, the high efficacy of the APEX-IHN® vaccine and resulting small number of susceptible fish on farms.

There are considerable sources of uncertainties, due to intrinsic variability and knowledge gaps, associated with the determination of the risk to Fraser River Sockeye Salmon due to IHNV transfer from Atlantic Salmon farms in the Discovery Islands. Those uncertainties include the voluntary nature of key fish health management practices such as vaccination and knowledge gaps related to several considerations including the residence time of susceptible species on and near Atlantic Salmon farms in the Discovery Islands; the actual waterborne concentrations of IHNV during an outbreak; the sublethal effects of exposure to IHNV at concentrations lower than the one-hour minimum lethal dose; the impacts of IHNV exposure in seawater in juvenile and adult Sockeye Salmon; the complexity of Sockeye Salmon marine survival; and the potential cumulative effects on Sockeye Salmon.

The highest uncertainties in the risk assessment are attributed to the consequence assessment in which mitigation is not possible. Consequently, measures to maintain minimal risk from IHNV transfer from Atlantic Salmon farms to Fraser River Sockeye Salmon should focus on maintaining or reducing the likelihoods of disease, release, exposure and infection.

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10. APPENDIXES

10.1. APPENDIX A: APEX-IHN® VACCINE EFFICACY IN ATLANTIC SALMON

The efficacy of the APEX-IHN® vaccine in Atlantic Salmon was estimated based on the mortality rates reported in Salonius et al. (2007), Novartis (2012) and Long et al. (2017). Vaccine efficacies were calculated based on the mortality rate (MR) in unvaccinated fish and vaccinated fish (Orenstein et al., 1985).

$$Vaccine\ efficacy(\%) = \frac{MR\ unvaccinated\ fish - \ MR\ vaccinated\ fish}{MR\ unvaccinated\ fish} \times 100$$

Salonius et al. (2007) reported that 17 months after vaccination with the APEX-IHN® vaccine, Atlantic Salmon maintained a protective advantage in response to a challenge with live virus. Mortality among virus exposed fish reached approximately 76% in the control group and approximately 27% in the vaccinated group, which represents a 64.5% vaccine efficacy and can be denoted as follows:

$$Vaccine\ efficacy(\%) = \frac{76 - 27}{76} \times 100 = 64\%$$

Novartis (2012) reported ranges of mortality rates from their *in vivo* consistency testing of each batch of vaccine ensuring that at least 60-98% of the unvaccinated fish die and no more than 20% of the vaccinated fish die during an immersion challenge. Consequently, a worst-case approach was used in which it was assumed that 60% of the unvaccinated fish and 20% of the vaccinated fish died during the challenge, which represents a 66.7% vaccine efficacy and can be denoted as follows:

$$Vaccine\ efficacy(\%) = \frac{60 - 20}{60} \times 100 = 67\%$$

Long et al. (2017) conducted cohabitation trials with unvaccinated IHN-infected Atlantic Salmon. Average mortality rates reached 80% in cohabitating unvaccinated Atlantic Salmon and 4% in cohabitating vaccinated Atlantic Salmon, which represents a vaccine efficacy of 95% and can be denoted as follows:

$$Vaccine\ efficacy(\%) = \frac{80 - 4}{80} \times 100 = 95\%$$

10.2. APPENDIX B: MODELING THE NUMBER OF INFECTED FISH ON AN ATLANTIC SALMON FARM

10.2.1. The Susceptible, Exposure, Infected and Recovered (SEIR) model

A compartmental Susceptible, Exposed, Infected and Recovered (SEIR) model (Anderson and May, 1979; Hethcote, 2000) was used to estimate the number of IHNV-infected fish on the day of depopulation (14 days after confirmation of IHN) on an Atlantic Salmon farm using the EpiModel package in the R software environment (Jenness et al., 2016; R Core Team, 2016).

Briefly, susceptible fish (S) can become infected at rate λ, first being exposed and infected (E) before becoming infectious (I) and finally removed (R). Removed animals are those that recover and become immune, or die from the disease. Effectively vaccinated fish go directly to the removed compartment. The infection rate is estimated based on the following four basic parameters in the model:

- The initial reproductive number (R_0) is the average number of individuals that one infectious fish would infect over its entire period of infectiousness, if all the fish in the population were susceptible. The R_0 for IHN in Atlantic Salmon is not known. For Rainbow Trout exposed to IHNV (M genogroup) in the laboratory, R_0 has been estimated at 2.57 (Ögüt, 2001). Given the high IHN susceptibility of Atlantic Salmon, an R_0 of five was used in the model.
- The exposed state (`e.dur`) is the period during which the fish are exposed and become infected but have yet to reach significant virus shedding rates. Its duration was estimated at eight days, which is the number of days to detectable viral shedding in a laboratory population of Atlantic Salmon after a one hour immersion exposure to IHNV at a dose of 4.6×10^3 pfu/mL (Garver et al., 2013).
- The duration of the infectious state (`i.dur`) is the period that starts when the fish shed significant levels of virus, until they recover and stop shedding, or die. It was estimated at ten days based on the duration of shedding in fish that succumbed to IHN mortality following an immersion challenge (Garver et al., 2013).
- The case fatality rate (`cfr`) is the proportion of infected fish that die. A worst-case approach was used and the 58% average cumulative mortality rate reported for the

2001-2003 outbreaks in Atlantic Salmon farms in British Columbia (Saksida, 2006) was used.

Other assumptions:

- The average number of fish on a farm is 517,000 and it is a closed population, i.e., no additions or deaths other that those caused by IHN are considered.
- The number of susceptible fish in an unvaccinated population is the number of fish on the farm and the number of susceptible fish in a vaccinated population is calculated by multiplying the number of fish on farm by the vaccine failure rate (1 minus vaccine efficacy).
- The initial number of infected fish on a farm is unknown and most epidemiological models assume a single initially infected animal. However, IHN infection on Atlantic Salmon farms in the Discovery Islands is likely to be the result of exposure to IHNV-infected wild salmon and given that millions of wild Sockeye Salmon migrate through the Discovery Islands with IHNV prevalence ranging from 0 to 11% in juvenile Sockeye Salmon and 0 to 62% in adults spawning in the Fraser River watershed, it is not unreasonable to assume more than one initially infected fish. An arbitrary number of 100 initially exposed fish in an unvaccinated population was therefore assumed. The number of initially infected fish in a vaccinated population is calculated by multiplying the number of initially infected fish in an unvaccinated population by the vaccine failure rate (1 minus vaccine efficacy).
- Companies have their own mortality threshold level for an automatic site visit by either the company veterinarian or Fish Health Management Team. These levels vary from 0.02 to 0.05% mortality/day depending on life stage and environmental conditions (Wade, 2017). In this assessment, it was assumed that the outbreak is detected when 0.03% mortality/day is reached and confirmed five days later accounting for one to two days from mortality threshold to site visit and sampling and three days for laboratory confirmation. It is noted that outbreaks would likely be recognized before mortality rates were elevated as mortalities are examined and staff have been trained to identify clinical signs of disease.
- The infected population is depopulated 14 days following the confirmation of detection of positive samples.

10.2.2. Model output

The output of the model is the number of fish per compartment (susceptible, exposed, infected, recovered and dead) for each day of the outbreak. The output of the model was used to determine the day on which daily mortality reached 0.03% which is assumed to be when the outbreak would be detected. From this day, five days were added for confirmation of results and another 14 days were added for depopulation. The number of infected fish at the end of this time period was determined to be the maximum number of infected fish on Atlantic Salmon farm under described conditions.

10.2.3. Interpretation and application

Under current fish health management practices, the model suggested that infection would not spread on the farms, i.e., that the initial number of infected fish would be the maximum number of infected fish. Other scenarios were conducted (see Appendix E and F) to explore the effect of different vaccine failure rates.

The maximum number of fish was then used to estimate the maximum concentration of IHNV present on an Atlantic Salmon farm at depopulation under the following assumptions:

- At depopulation, 40% of the infected fish are shedding at a peak of 3.2×10^7 pfu/fish/hour and 60% of the infected fish are shedding at half this rate.
- The average volume of water in net pens on an Atlantic Salmon farm is 194,705 m^3.
- Only virus particles that were shed in the 24 hours prior to depopulation are considered.

There is no decay and no dispersion of the virus from the infected farm during the 24 hours prior to depopulation (i.e., virus accumulates with in the net pens as there is no flushing in or out).

10.3. APPENDIX C: IHNV DISPERSION MODEL

IHNV dispersion from marine salmon farms in the Discovery Islands was modeled using the ocean circulation and IHNV dispersion, inactivation and re-infection models (Foreman et al., 2012; Foreman et al., 2015a) and the following assumptions and calculations:

- Each of the farms (Table 1) was assumed to have the dimensions of 100 m by 100 m by 20 m (200,000 m^3).
- Thirty particles (pfu cohorts) were released every hour from random positions within each farm and tracked for a period of eight days (reported time to complete virus inactivation after eight days in the Discovery Islands region (Foreman et al., 2015a)). The first release was at 0100 GMT of the 6th day (allowing for five days of spin-up for the circulation model) of each month (April and July) and the last was on either the 22nd or 23rd day so there would be a full eight days of tracking before the month-end.
- Using the same susceptibility to UV radiation and marine biota as described in Foreman et al. (2015a), the fractional survival (and thus ability to infect) of each cohort was computed for each hour of its tracking period. These survival rates were then “scaled-up” to actual pfu numbers based on shedding rates consistent with assumed risk assessment parameters such as vaccine efficacy.
- Using the estimated shedding rate on the first day of infection, the scale-up factor under current fish health management practices was 3.66×10^6 for each cohort.
- IHNV concentrations were computed at each of the approximately 36,000 nodes in the circulation model grid as the number of pfu within a specific volume of water around that node. In light of the relatively low number of cohort releases (due to computer limitations) and their subsequent dispersion over the channels in the Discovery Islands, concentration values were found to vary with the particular volume choices.
- Sensitivity tests showed these variations were relatively small compared to the minimum infective dose. Therefore, the volumes used were disks of 100 m radius and specific depth range, such as 0 to 5 m.
- This approach differs from the farm-to-farm dispersion study conducted in Foreman et al. (2015a). Specifically, whereas very little is known about the behavior (e.g., schooling density) of migrating Sockeye Salmon smolts in the open environment, we do know that the average density of fish within farms is approximately 2.5 per m^3. This means that Foreman et al. (2015a) can argue that if any pfu cohort with a fractional survivability above the threshold corresponding to the minimum infective dose went anywhere within the domain of a neighboring farm (i.e., within any one m^3 volume), it would cause an infection. For example, if a pfu cohort originating from farm A entered the domain of farm B with a fractional survival of 10^{-3}, this would scale-up to 1.97×10^7 pfus. As any 1 m^3

volume around this cohort could be expected to have 2.5 fish, each of them would be exposed to a concentration above the minimum infective dose of 10^7 pfu/m^3 for Atlantic Salmon and an infection would be assumed to have occurred. Not knowing the density or migration routes of migrating sockeye smolts in the open environment meant that in this case, pfu concentrations had to be computed everywhere within the model domain and then compared with the sockeye minimum infective dose.

10.4. APPENDIX D: REDUCTION IN NUMBER OF RETURNING SOCKEYE SALMON

Mathematically, the percent reduction in the number of returning Fraser River Sockeye Salmon can be expressed as follows:

$$A(\%) = \frac{R - R_{IHN}}{R} \cdot 100$$

Where:

A Percent reduction in the number of returning Fraser River Sockeye Salmon (abundance)
R Number of returning adults if there is no exposure to IHNV released from salmon farms
R_{IHN} Number of returning adults if there is exposure to IHNV released from salmon farms

Figure 10 illustrates the number of returning Fraser River Sockeye Salmon, assuming that there are no correlations between IHN mortality and marine survival, i.e., the marine survival rate is the same in the sub-population of IHN-infected fish as in the sub-population of non-infected fish.

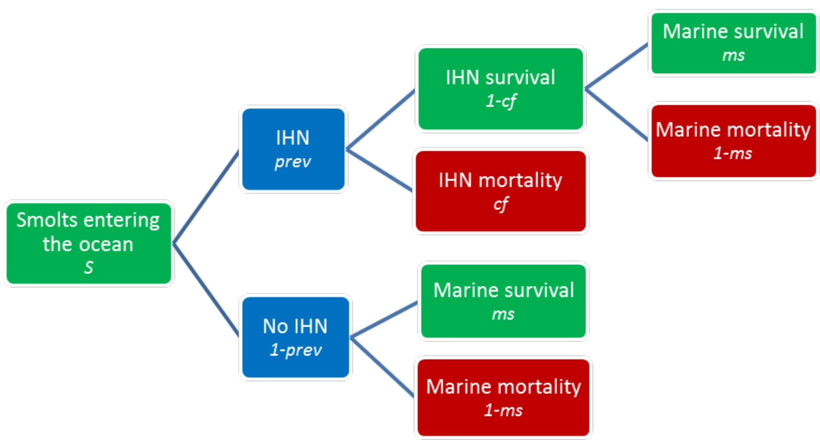

Figure 10. Model of the number of returning adult Fraser River Sockeye Salmon in the absence and presence of IHN.

Mathematically, the number of returning adults, if there is exposure to IHNV released from salmon farms, can be expressed as follows:

$$R_{IHN} = S \cdot [prev \cdot (1 - CF) + (1 - prev)] \cdot ms$$

Where:

S	Number of smolts entering the ocean
ms	Marine survival
prev	IHN prevalence
CF	IHN case fatality rate

In the absence of IHN, the prevalence is equal to 0, thus $R = S \cdot ms$, and consequently:

$$A = \frac{S \cdot ms - S \cdot [prev \cdot (1 - cf) + (1 - prev)] \cdot ms}{S \cdot ms}$$

which reduces to:

$$A = prev \cdot CF$$

Based on the above, the percent reduction in the number of returning Fraser River Sockeye Salmon is equivalent to the product of IHN prevalence and IHN case fatality rate, in other words to the number of fish dying from IHN.

No data are available to estimate separately the IHN infection prevalence and case fatality rate in exposed Fraser River Sockeye Salmon. Therefore it was reasonable to assume that the mortality rates observed in the Alaska outbreaks (Burke and Grischkowsky, 1984) and in laboratory trials (Traxler et al., 1993; Long et al., 2017) represent both the prevalence (proportion of the population that is infected) and the case fatality rate in fish exposed to an infectious dose of IHNV:

$$Observed\ IHN\ mortality = prev \cdot CF$$

Therefore, the consequence on abundance, defined in the risk assessment as the percent reduction in the number of returning Fraser River Sockeye Salmon, is equal to the observed IHN mortality, assuming that there is no correlation between IHN mortality and marine survival in Fraser River Sockeye Salmon:

$$A = prev \cdot CF = Observed\ IHN\ mortality$$

10.5. APPENDIX E: PARTIAL VACCINATION FAILURE SCENARIO

The impact of partial IHN vaccine failure on the risk to the abundance and diversity of Fraser River Sockeye Salmon was explored as a sensitivity analysis. Partial failure was defined as 33% (67% vaccine efficacy) based on ranges for consistency testing (Novartis, 2012) (refer to Appendix A).

A partial vaccination failure scenario is considered very unlikely given current management practices which include batch vaccination of all Atlantic Salmon for IHN in the Discovery Islands (see section 4.1.2.5) and that there has never been a detection of IHNV in an APEX-IHN® vaccinated farmed Atlantic Salmon (Garver and Wade, 2017).

10.5.1. Likelihood assessment

10.5.1.1. Disease assessment

It was concluded that the likelihood of an IHN outbreak on Atlantic Salmon farms in the Discovery Islands under partial failure of IHN vaccination would be **very unlikely** given that the only two index cases on Atlantic Salmon farms in the Discovery Islands over the last 25 years occurred in unvaccinated fish and under less rigorous fish health management practices.

This conclusion was made with **reasonable certainty** given that some fish health management practices are agreed through a Memorandum of Understanding and some are licence conditions.

10.5.1.2. Release assessment

Same as under current fish health management practices (see section 4.2).

10.5.1.3. Exposure assessment

Same as under current fish health management practices (see section 4.3).

10.5.1.4. Infection assessment

The infection assessment for juvenile Sockeye Salmon under partial vaccination failure is addressed below. The infection assessment would remain the same as under current fish health management practices for adult Fraser River Sockeye Salmon and other IHN susceptible fish species (see section 4.4).

10.5.1.4.1. In net pens

The maximum waterborne IHNV concentration in net pens of a farm under partial vaccination failure (Table 13) was estimated with the same methodology used under current fish health management practices (see section 4.4.2.2). The maximum IHNV concentration in net pens was estimated to be 1.0 x 10^7 pfu/m^3 under partial failure of the vaccine, which is 10 times lower than the minimum one-hour lethal dose for juvenile Sockeye Salmon (10^8 to 10^9 pfu/m^3) (Long et al., 2017).

Table 13. Estimated maximum waterborne IHNV concentrations in net pens on an Atlantic Salmon farm in the Discovery Islands assuming partial IHNV vaccination failure. Assumptions include a constant peak shedding rate for 40% of the infected fish and half-peak shedding rate for the remaining 60%, no viral dispersion and no viral decay.

Step to estimate maximum IHNV concentration in net pen	**Estimations based on SEIR model**
Average number of fish on farm *(refer to section 3.4.2)*	517,000
Vaccine efficacy *(refer to Appendix A)*	67%
Vaccine failure *(100 – vaccine efficacy)*	33%
Average number of susceptible fish on farm *(number of fish on farm x vaccine failure)*	170,610
Number of fish initially exposed to IHNV *(arbitrarily determined[1])*	100
Number of fish initially infected with IHNV *(number of fish initially exposed x vaccine failure)*	33
Number of IHNV infected fish at depopulation (*determined through SEIR model)*	3,725
IHNV shedding rate per hour at depopulation *(# of infected fish at depopulation x shedding rate[2])*	8.3×10^{10} pfu
IHNV average concentration on farm at depopulation *(shedding rate per hour x 24 hrs / farm volume)*	1.0×10^{7} pfu/m^3

[1] Sensitivity analyses suggest that the maximum number of infected fish is not sensitive to the number of initially infection fish. It is therefore reasonable to assume that 100 fish were initially exposed.
[2] Assuming a constant peak shedding rate for 40% of the infected fish and half-peak for the remaining 60% of infected fish

10.5.1.4.2. In plumes

The maximum IHNV concentration in plumes during an IHN outbreak was modeled as per the same methodology used under current fish health management practices (see section 4.4.2.3). Under partial failure of the vaccine, modeled concentrations in plumes dispersed from infected farms simultaneously releasing IHNV reached a maximum of 6.6×10^5 pfu/m^3 in April, which is 151 times lower that the minimum one-hour lethal dose of IHNV for juvenile Sockeye Salmon (10^8 to 10^9 pfu/m^3).

10.5.1.4.3. Likelihood of infection

It was concluded that the likelihood for juvenile Fraser River Sockeye Salmon to be exposed to IHNV in net pens of Atlantic Salmon farms in the Discovery Islands at a dose and for a period of time sufficient to cause infection and disease under partial vaccination failure would be **very unlikely** given that the estimated maximum IHNV concentrations is 10 times lower than the IHNV minimum one-hour lethal dose for juvenile Sockeye Salmon and would consequently not be expected to result in infection and disease.

Similarly, it was concluded that the likelihood for juvenile Fraser River Sockeye Salmon to be exposed to IHNV in dispersed plumes of Atlantic Salmon farms in the Discovery Islands at a dose and for a period of time sufficient to cause infection and disease under partial vaccination failure would be **extremely unlikely** given that the estimated maximum IHNV concentrations is

151 times lower than the IHNV minimum one-hour lethal dose for juvenile Sockeye Salmon and would consequently not be expected to result in infection and disease.

These conclusions are made with **reasonable uncertainty** given the limited data about waterborne IHNV concentrations, the incomplete knowledge of the time juvenile Sockeye Salmon spend in net pens and the outcome of a prolonged exposure of juvenile Sockeye Salmon to sublethal doses.

10.5.1.5. Overall likelihood assessment

It was concluded with **reasonable uncertainty** that the likelihood that Atlantic Salmon farms in the Discovery Islands release IHNV into the environment and expose susceptible wild fish populations to a dose and for a period of time sufficient to cause infection and disease is **very unlikely** (Table 14).

Table 14. Likelihood and uncertainty estimates for each step of the likelihood assessment assuming partial (67%) efficacy of the IHN vaccine which does not represent current management practices. Estimates are reported in white cells and likelihood combination results are reported in tan cells.

Disease assessment	**Likelihood of disease**	Very unlikely *Reasonable certainty*					
Release assessment	**Release pathways**	**Farmed Atlantic Salmon**		**Mechanical vectors**		**Fomites**	
	Likelihood of release	Expected *High certainty*		Very unlikely *High certainty*		Very unlikely *High certainty*	
	Combined likelihood of release	Expected *High certainty*					
Exposure and infection assessments	**Exposure group**	**Juvenile Fraser River Sockeye Salmon**		**Adult Fraser River Sockeye Salmon**		**Other IHN susceptible fish**	
	Exposure route	**In net pens**	**In plumes**	**In net pens**	**In plumes**	**In net pens**	**In plumes**
	Likelihood of exposure	Likely *Reasonable uncertainty*	Very likely *Reasonable certainty*	Extremely unlikely *Reasonable certainty*	Very likely *Reasonable certainty*	Likely *Reasonable certainty*	Very likely *Reasonable certainty*
	Likelihood of infection	Very unlikely *Reasonable uncertainty*	Extremely unlikely *Reasonable uncertainty*	Extremely unlikely *Reasonable certainty*	Extremely unlikely *Reasonable certainty*	Extremely unlikely *Reasonable certainty*	Extremely unlikely *Reasonable certainty*
Combined likelihoods for each exposure route in a given exposure group		Very unlikely *Reasonable uncertainty*	Extremely unlikely *Reasonable uncertainty*	Extremely unlikely *Reasonable certainty*	Extremely unlikely *Reasonable certainty*	Extremely unlikely *Reasonable certainty*	Extremely unlikely *Reasonable certainty*
Combined likelihoods for each exposure group		Very unlikely *Reasonable uncertainty*		Extremely unlikely *Reasonable certainty*		Extremely unlikely *Reasonable certainty*	
Overall likelihood of disease, release, exposure and infection		Very unlikely *Reasonable uncertainty*					

10.5.2. Consequence assessment

Same as under current fish health management practices (see section 5).

10.5.3. Risk estimation

It was concluded, that under partial vaccine failure, the risk to the abundance and diversity of Fraser River Sockeye Salmon as a result of IHNV infection attributable to Atlantic Salmon farms operating in the Discovery Islands would be **minimal**.

10.5.4. Discussion

The above scenario was conducted to determine the impact of a reduced vaccination efficacy (67% vaccine efficacy) on the risk to Fraser River Sockeye Salmon compared to current fish health management (95% vaccine efficacy).

The only difference between the two scenarios would be an increase in the likelihood of infection for juvenile Sockeye Salmon in net pens (from extremely unlikely to very unlikely) which would result in an increase in the overall likelihood assessment (from extremely unlikely to very unlikely) but no impact on the risk to the abundance and diversity of Fraser River Sockeye Salmon which would remain minimal.

10.6. APPENDIX F: UNVACCINATED SCENARIO

The risk to the abundance and diversity of Fraser River Sockeye Salmon without vaccination against IHN was also determined.

Given current fish health management practices which include the industry-wide Viral Management Plan (Wade, 2017), an unvaccinated scenario is considered very unlikely to occur.

10.6.1. Likelihood assessment

10.6.1.1. Disease assessment

It was concluded that the likelihood for an IHN outbreak on Atlantic Salmon farms in the Discovery Islands without vaccination against IHN would be **unlikely** given the low prevalence of IHN on Atlantic Salmon farms over the last 25 years in BC and the 2012 IHN outbreaks on unvaccinated farms but with other fish health management practices (e.g., including early detection, mortality removal, and depopulation of infected fish) similar to the current ones.

This conclusion was made with **reasonable certainty** based on existing IHN outbreak data in British Columbia and on expert opinion.

10.6.1.2. Release assessment

Same as under current fish health management practices (see section 4.2).

10.6.1.3. Exposure assessment

Same as under current fish health management practices (see section 4.3).

10.6.1.4. Infection assessment

The infection assessment for juvenile Sockeye Salmon under an unvaccinated scenario is addressed below. The infection assessment would remain the same as under current fish health management practices for adult Fraser River Sockeye Salmon and other IHN susceptible fish species (see section 4.4).

10.6.1.4.1. In net pens

The maximum waterborne IHNV concentration in net pens of an unvaccinated farm (Table 15) was estimated with the same methodology used under current fish health management practices (section 4.4.2.2). The SEIR model assumed that infection would be detected when daily mortality reached 0.03%, and allowed for five days for confirmation of detection and a maximum of 14 days until complete depopulation of infected fish (see Appendix B). The maximum number of infected fish that would be reached on the day of depopulation was estimated to be 26,248 from which the maximum IHNV concentration in the net pens was estimated to be 7.3×10^7 pfu/m^3, which is 1.3 times lower than the IHNV minimum one-hour lethal dose for juvenile Sockeye Salmon (10^8 to 10^9 pfu/m^3) (Long et al., 2017). Estimations based on the 2012 outbreak data suggest that the SEIR model most likely overestimated the waterborne IHNV concentrations. Fish health management practices including collection and utilization of syndromic information; early detection of disease; biosecurity measures; depopulation of infected fish within 14 days of positive confirmation of the index case and upon approval by CFIA contributed to the limiting the potential spread on and/or between farms.

Table 15. Estimated maximum waterborne IHNV concentrations in net pens on an Atlantic Salmon farm in the Discovery Islands assuming no vaccination against IHNV. A constant peak shedding rate for 40% of the infected fish and half-peak shedding rate for the remaining 60% of infected fish, no viral dispersion and no viral decay were assumed.

Step to estimate maximum IHNV concentration in net pen	**Estimates based on SEIR model**
Average number of fish on farm *(refer to section 3.4.2)*	517,000
Vaccine efficacy *(refer to Appendix A)*	0%
Vaccine failure *(100 – vaccine efficacy)*	100%
Average number of susceptible fish on farm *(number of fish on farm x vaccine failure)*	517,000
Number of fish initially exposed to IHNV *(arbitrarily determined[1])*	100
Number of fish initially infected with IHNV *(number of fish initially exposed x vaccine failure)*	100
Number of IHNV infected fish at depopulation (*determined through SEIR model)*	26,248
IHNV shedding rate per hour at depopulation *(# of infected fish at depopulation x shedding rate[2])*	5.9×10^{11} pfu
IHNV average concentration on farm at depopulation *(shedding rate per hour x 24 hrs / farm volume)*	7.3×10^7 pfu/m^3

[1] Sensitivity analyses suggest that the maximum number of infected fish is not sensitive to the number of initially infection fish. It is therefore reasonable to assume that 100 fish were initially exposed.
[2] Assuming a constant peak shedding rate for 40% of the infected fish and half-peak for the remaining 60% of infected fish

10.6.1.4.2. In plumes

The maximum IHNV concentration in plumes during an IHN outbreak was estimated with the same methodology used under current fish health management practices (see section 4.4.2.3). Without vaccination against IHN, modeled IHNV concentrations in plumes dispersed from infected farms simultaneously releasing IHNV reached a maximum of 4.7 x 10^6 pfu/m^3 in April which is 21 times lower that the minimum one-hour lethal dose of IHNV for juvenile Sockeye Salmon (10^8 to 10^9 pfu/m^3).

10.6.1.4.3. Likelihood of infection

It was concluded that the likelihood for juvenile Fraser River Sockeye Salmon to be exposed to IHNV in net pens of an Atlantic Salmon farms in the Discovery Islands at a dose and for a period of time sufficient to cause infection and disease under an unvaccinated scenario would be **unlikely** given that the estimated maximum IHNV concentrations is 1.3 times lower than the minimum one-hour lethal dose for juvenile Sockeye Salmon and would consequently not be expected to result in infection and disease but could happen.

It was concluded that the likelihood for juvenile Fraser River Sockeye Salmon to be exposed to IHNV in dispersed plumes of Atlantic Salmon farms in the Discovery Islands at a dose and for a period of time sufficient to cause infection and disease under an unvaccinated scenario would respectively be **very unlikely** given that the estimated maximum IHNV concentrations is 21 times lower than the minimum one-hour lethal dose for juvenile Sockeye Salmon and would consequently not be expected to result in infection and disease.

These conclusions are made with **reasonable uncertainty** given the limited data about waterborne IHNV concentrations, the incomplete knowledge of the time juvenile Sockeye Salmon spend in net pens and the outcome of a prolonged exposure of juvenile Sockeye Salmon to sublethal doses.

10.6.1.5. Overall likelihood assessment

It was concluded with **reasonable uncertainty** that the likelihood that Atlantic Salmon farms in the Discovery Islands release IHNV into an environment and subsequently expose susceptible wild fish populations to a dose and for a period of time sufficient to cause infection and disease is **unlikely** (Table 16).

Table 16. Likelihood and uncertainty estimates for each step of the likelihood assessment assuming no vaccination against IHN. Estimates are reported in white cells and likelihood combination results are reported in tan cells.

<table>
<tr><td>Disease assessment</td><td>Likelihood of disease</td><td colspan="6">Unlikely
Reasonable certainty</td></tr>
<tr><td rowspan="3">Release assessment</td><td>Release pathways</td><td colspan="2">Farmed Atlantic Salmon</td><td colspan="2">Mechanical vectors</td><td colspan="2">Fomites</td></tr>
<tr><td>Likelihood of release</td><td colspan="2">Expected
High certainty</td><td colspan="2">Very unlikely
High certainty</td><td colspan="2">Very unlikely
High certainty</td></tr>
<tr><td>Overall likelihood of release</td><td colspan="6">Expected
High certainty</td></tr>
<tr><td rowspan="4">Exposure and infection assessments</td><td>Exposure group</td><td colspan="2">Juvenile Fraser River Sockeye Salmon</td><td colspan="2">Adult Fraser River Sockeye Salmon</td><td colspan="2">Other IHN susceptible fish</td></tr>
<tr><td>Exposure route</td><td>In net pens</td><td>In plumes</td><td>In net pens</td><td>In plumes</td><td>In net pens</td><td>In plumes</td></tr>
<tr><td>Likelihood of exposure</td><td>Likely
Reasonable uncertainty</td><td>Very likely
Reasonable certainty</td><td>Extremely unlikely
Reasonable certainty</td><td>Very likely
Reasonable certainty</td><td>Likely
Reasonable certainty</td><td>Very likely
Reasonable certainty</td></tr>
<tr><td>Likelihood of infection</td><td>Unlikely
Reasonable uncertainty</td><td>Very unlikely
Reasonable uncertainty</td><td>Extremely unlikely
Reasonable certainty</td><td>Extremely unlikely
Reasonable certainty</td><td>Extremely unlikely
Reasonable certainty</td><td>Extremely unlikely
Reasonable certainty</td></tr>
<tr><td colspan="2">Combined likelihoods for each exposure route in a given exposure group</td><td>Unlikely
Reasonable uncertainty</td><td>Very unlikely
Reasonable uncertainty</td><td>Extremely unlikely
Reasonable certainty</td><td>Extremely unlikely
Reasonable certainty</td><td>Extremely unlikely
Reasonable certainty</td><td>Extremely unlikely
Reasonable certainty</td></tr>
<tr><td colspan="2">Combined likelihoods for each exposure group</td><td colspan="2">Unlikely
Reasonable uncertainty</td><td colspan="2">Extremely unlikely
Reasonable certainty</td><td colspan="2">Extremely unlikely
Reasonable certainty</td></tr>
<tr><td colspan="2">Overall likelihood of disease, release, exposure and infection</td><td colspan="6">Unlikely
Reasonable uncertainty</td></tr>
</table>

10.6.2. Consequence assessment

Same as under current fish health management practices (see section 5).

10.6.3. Risk estimation

It was concluded, that with no vaccination against IHN, the risk to the abundance and diversity of Fraser River Sockeye Salmon as a result of IHNV infection attributable to Atlantic Salmon farms operating in the Discovery Islands would be **moderate**.

10.6.4. Discussion

The above scenario was conducted to determine the impact of not vaccinating farmed Atlantic Salmon against IHN on the risk to Fraser River Sockeye Salmon compared to current fish health management (95% vaccine efficacy).

Two rankings differed between the two scenarios. First, there would be an increased likelihood of IHN occurring on Atlantic Salmon farms in the Discovery Islands (from very unlikely to unlikely). Second, there would be an increased likelihood of infection for juvenile Sockeye Salmon in net pens (from extremely unlikely to unlikely) which would result in an increase in the overall likelihood assessment (from extremely unlikely to unlikely). Such changes would result in a moderate risk to the abundance and diversity of Fraser River Sockeye Salmon without vaccination against IHN.

The conclusion of the risk assessment without vaccination against IHN is considered to be very conservative as given the high variability in mortality rates during the 2012 IHNV outbreaks and the lack of spread of IHNV infection between cages during one of the 2012 IHNV outbreaks in British Columbia (Garver and Wade, 2017) under fish health management practices that included regular removal of dead fish and depopulation of infected fish prior to the maximum 14 days as prescribed in the industry-driven fish health management plan.