WE HEARD YOU

We share the concern of First Nations and members of the public that farm-raised salmon shed pathogens and might cause population-level effects on wild salmon. Salmon farmers recognize the importance of safeguarding fish health and supporting wild salmon conservation. We know we must also demonstrate to others that our fish health measures have been effective. This chapter describes (i) the proactive steps salmon farmers use to keep fish healthy on farms and (ii) the verification for those critical steps.

SALMON FARMERS CARE ABOUT THE HEALTH OF WILD FISH

Salmon farmers live and work in the small communities and remote areas of coastal British Columbia (Figure 1).

Fish farmers come from diverse backgrounds - many have worked in commercial fishing, recreational fishing, or wild salmon enhancement and have family members who rely on wild salmon. They understand and agree that wild salmon are iconic to BC.

Most people in salmon farming believe they are helping to take pressure off wild salmon to feed the world, as well as farming one of the world's most climate-friendly animal proteins (6-8).

Farmers the licensed veterinarians, and fish health professionals in the salmon farming sector apply best practices and the highest standards in fish health care (Figure 2). These practices have been developed over the past 40 years through gains in veterinary medicine, farming technologies, and partnerships with First Nations communities.

Figure 1. View of Gold River, Vancouver Island. A salmon farm hatchery (near the water) has operated since 1998 in the community of approximately 1,300 residents.

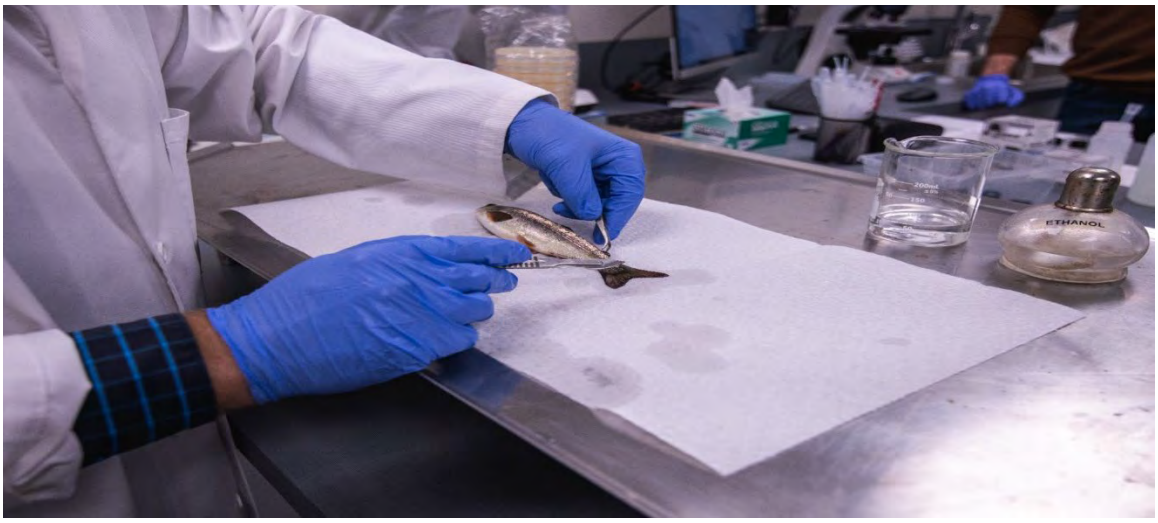


Figure 2. Fish health inspection and testing

ROLE OF LICENSED VETERINARIANS

Licensed veterinarians are the cornerstone of maintaining good fish health at farms (Figure 3). They are the only professionals legally authorized to diagnose disease and prescribe treatment for animals.

Veterinarians that work with salmon farms have the same training and licence as veterinarians that work with other animal species in BC. Aquaculture veterinarians apply several steps to keep fish healthy:

a) Prevention – a series of structured barriers or "safeguards" to prevent disease outbreaks and potential transmission,

b) Detection – continuous and careful monitoring of fish behaviour and health at farms by veterinarians, fish health staff and farm staff; this is aided by advanced technologies that continuously monitor fish in real-time or near real-time; collection of fish tissue samples and submission to accredited laboratories for analysis (Figure 4),

c) Diagnosis – veterinarians review all available information (on-site observations, the pattern of clinical signs and mortality, medical history of the fish population, farm environmental conditions and laboratory test results) to diagnose (or not) a fish disease or health condition following accepted criteria for diagnosis of the disease (i.e., the medical case definition),

d) Treatment – the licensed veterinarian prescribes an appropriate treatment plan and follow up according to the diagnosis; this may include medicines (such as antimicrobials) or changes in fish husbandry practices,

e) Follow-up – veterinarians track the treatment results and incorporate the information from all of the steps into fish health databases; this information is constantly reviewed,

which allows for continual improvements in prevention, detection, diagnosis and treatment,

f) Record keeping – veterinarians maintain accurate and complete medical records. This includes several types of records,

g) Surveillance for pathogens and disease, including sampling and diagnostics,

h) Medicine use,

i) Fish mortalities by pen, including classifying cause of death,

j) Farm hygiene, disinfection and biosecurity requirements,

k) Reporting – the fish health team is responsible for timely reporting to various regulatory agencies.

Figure 3. All farms are supported by licensed veterinarians and fish health teams.

Licensed veterinarians are highly trained health professionals dedicated to keeping animals healthy, whether pets, terrestrial livestock, wildlife or farm-raised fish.

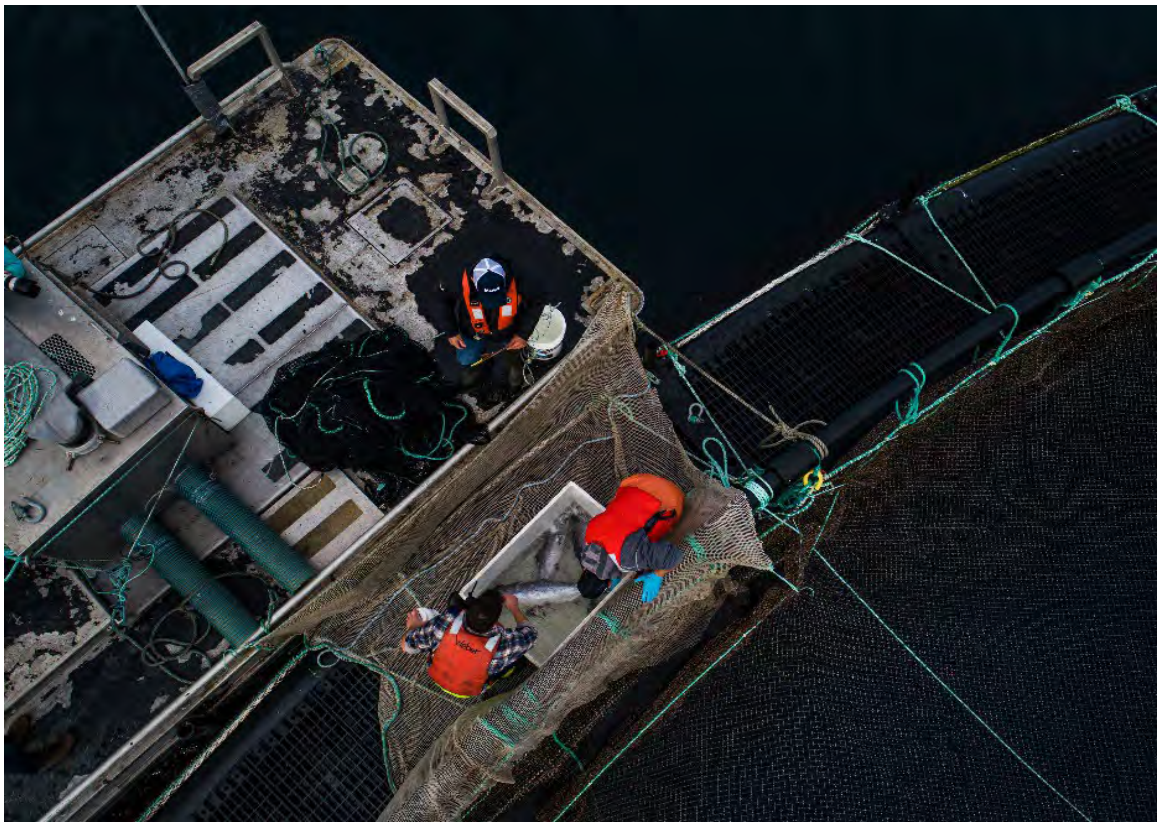


Figure 4. Sea lice and fish health check on farm-raised salmon.

When making a diagnosis, the veterinarian takes all available information into account: the pattern of clinical signs, medical history, observations (for example, feeding behaviour), data on the farm including environmental conditions and lab results.

The veterinarian's team includes trained staff at each site who observe the fish daily for signs of health and early detection of disease. In addition, the veterinarian, or fish health staff, visits the hatcheries and farms monthly, at a minimum, to monitor fish health and performance (Figure 5). This includes a close look at fish behaviour, feeding, fish condition and growth. Veterinary medical records document all of this information, along with the pattern of clinical signs, life history of the fish, and environmental conditions on the farms. These records must be accurate and complete for the veterinarian to diagnose health problems with the fish.

Figure 5. Licensed veterinarian, preparing sample container for next generation genetic sequencing sampling.

HISTORY OF FARM-RAISED FISH HEALTH (1980S – 2020S)

The medical profession has played a huge role in improving human health care and quality of life in the past hundred years. Medical doctors built the foundations in the twentieth century by developing the first widely distributed vaccines (e.g., polio; vaccines for childhood diseases), antimicrobials (Penicillin and sulfa drugs) and lifesaving medications like insulin and digoxin. The second half of the twentieth century saw an explosion of drug development and major advances in cancer and other treatments.

In the same way doctors have advanced human medicine over the past 100 years, aquatic animal veterinarians have brought their professionalism and proficiency to improve fish health in the last 40 years.

Veterinarians use *Evidence-based Medicine* to solve clinical problems. Working with fish health and site staff, they have spearheaded major improvements in the farms' understanding of fish diseases, developing vaccines, optimizing the nutrition and growth rate of the fish and significantly decreasing mortality rates due to several infectious diseases.

Advancements in veterinary practices for farm-raised salmon have been applied to enhancement facilities raising wild Pacific salmon in British Columbia.

Veterinarians undertook disease surveillance that became the foundation for the current body of knowledge about fish diseases in farm-raised salmon. They were essential in the development of vaccines administered to salmon for furunculosis, vibriosis and Infectious Hematopoietic Necrosis (IHN). Their Findings spilled over into knowledge about diseases in salmon enhancement hatcheries and in wild salmon.

Veterinarians developed biosecurity practices to prevent introduction and spread of pathogens and disease.

The result of these practices was reviewed favourably by the Cohen Commission of Justice Cohen who concluded that "Data presented during this Inquiry did not show that salmon farms were having a significant negative impact on Fraser River sockeye." Justice Cohen's final report describes the salmon farm disease data presented during the hearings as "impressive,"and he noted, "There was a statistically significant declining trend in the number of high risk diseases reported by salmon farms between 2003 and 2010."

Veterinarians began categorizing mortalities by cause on the farms for early disease detection so they could monitor and address changing trends in mortality. Surveillance and consistent categorizing of mortality causes shows that the prevalence of significant pathogens and infectious diseases is very low.

HOW HEALTHY ARE FARM-RAISED SALMON?

Only about 3% of BC farm-raised salmon in marine net pens die each year from infectious disease (Figure 6). For Atlantic salmon, another 17% die from other causes (e.g., low dissolved oxygen, toxic algal bloom, or handling), and 80% remain alive and grow to be harvested. For Pacific salmon, another 10% die from other causes (e.g., poor performers, early maturity, and predator attacks), and 87% remain alive and grow to be harvested.

According to the Canadian Food Inspection Agency (CFIA), no reportable diseases exotic to BC have been confirmed in farm-raised salmon in BC (9).

There are only two federally reportable viral diseases that naturally occur among wild fish in BC, but these diseases are rare among farm-raised salmon in BC.

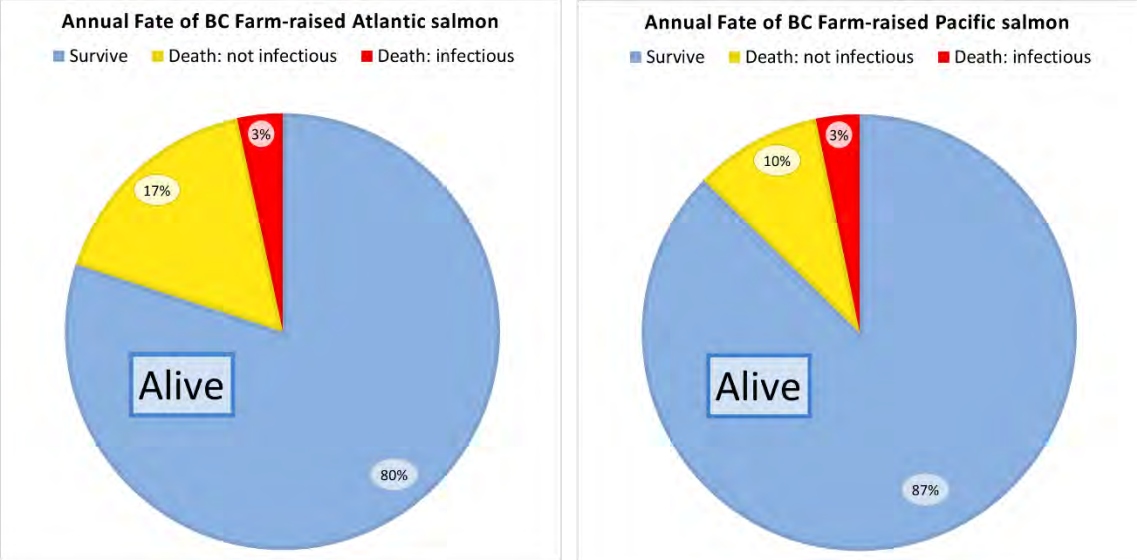


Figure 6. Annual fate of BC farm-raised Atlantic and Pacific salmon, 2018-2022.
These numbers, averaged from 2018 – 2022, are derived from two public sources:

Results of DFO fish health audits of British Columbian marine finfish aquaculture sites, by facility

Carcass classification of cultured salmon at British Columbian aquaculture sites by facility

Outbreaks of Infectious Haematopoietic Necrosis (IHN) have not occurred among BC farm salmon since 2012, when three farms were affected (10). DFO's Fish Health Audit Program reports 12 PCR+ test results for the Viral Haemorrhagic Septicemia (VHS) virus from 2011 – 2022. (11), but most of these results are associated with minimal mortality, and CFIA reports only three outbreaks of VHS among BC farm-raised salmon since 2011: one each in 2014, 2021, and 2022 (12).

With the introduction of effective vaccines, the use of antimicrobials on BC salmon farms declined from the high in 1997 to a low in 2020, from 516g to 50g per tonne of salmon (Figure 7) (13).

Farm-raised salmon are very healthy. About 87% of Pacific salmon and 80% of Atlantic salmon survive each year on farms in BC. Only 3% die of infectious disease.

Veterinarians are working to reduce usage even further, in accordance with Canadian Veterinary Medical Association (CVMA) guidelines (14).

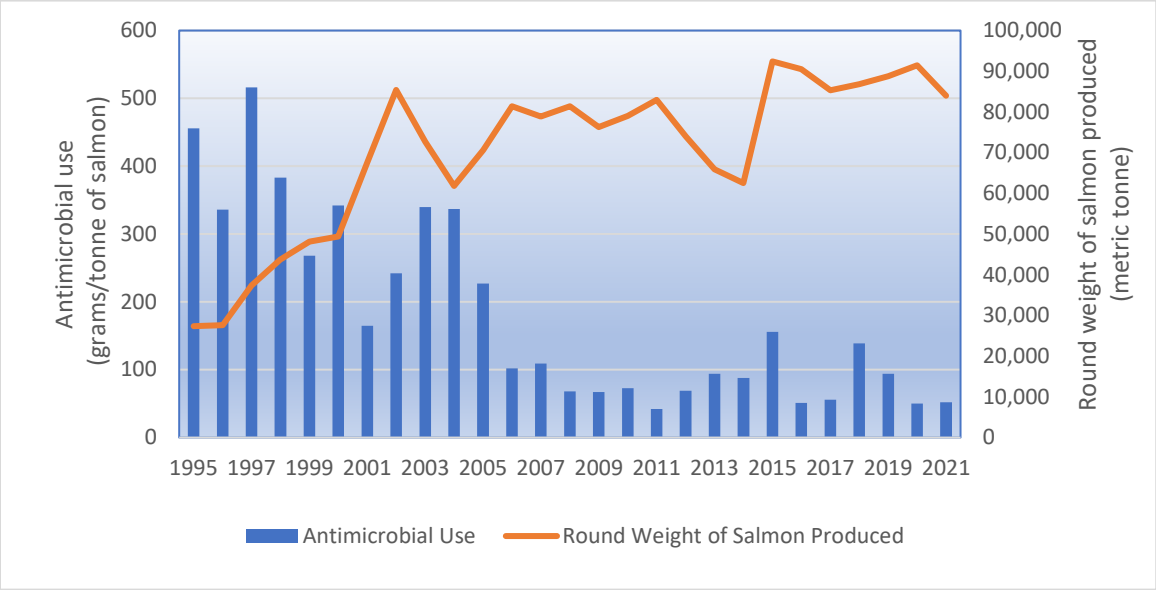


Figure 7. Reduction in antibiotic use in farm-raised Atlantic salmon in BC, 1995 – 2021. Source DFO open data (13)

Antimicrobial use at BC salmon farms has decreased by about 80% over the past 28 years with improved husbandry practices and the development of effective vaccines. Research is ongoing to develop additional vaccines.

Veterinarians have also contributed to large, collaborative fish health research projects. They provided robust data sets to support research or formal risk assessments on *Piscine orthoreovirus* (PRV) (15), *Tenacibaculum maritimum (1)*, sea lice (16) and other initiatives and contributed to current environmental modeling for sea pens. They also play a significant role in food safety as discussed in "Chapter 12 – Caring for Communities – Food Safety and Security".

FISH HEALTH MONITORING RESULTS

DFO collects and publicly reports data from salmon farmers about fish health (17). A summary of the health of salmon at BC farms is presented below.

FISH HEALTH EVENTS

A "Fish Health Event" refers to any suspected or confirmed disease that occurs within an aquaculture facility, that requires the involvement of a veterinarian, and warrants mitigation measures. Fish Health Events have been reported to DFO as a condition of license since 2016. Sea lice reporting and management are not included as Fish Health Events.

Each BC salmon farm, on average, reports about one Fish Health Event each year (from 2016 – 2022, 284 reports averaged 41 per year) (Figure 8).

From 2016 to 2022, each BC salmon farm on average, reported about one Fish Health Event each year.

Among the 284 farm salmon Fish Health Events reported to DFO from 2016 – 2022, 12 (4.2%) were from Pacific salmon species, and the veterinary diagnosis for all 12 was bacterial kidney disease; all of these reports were associated with broodstock that were not experiencing an outbreak but were treated to control background levels of infection before the fish were spawned.

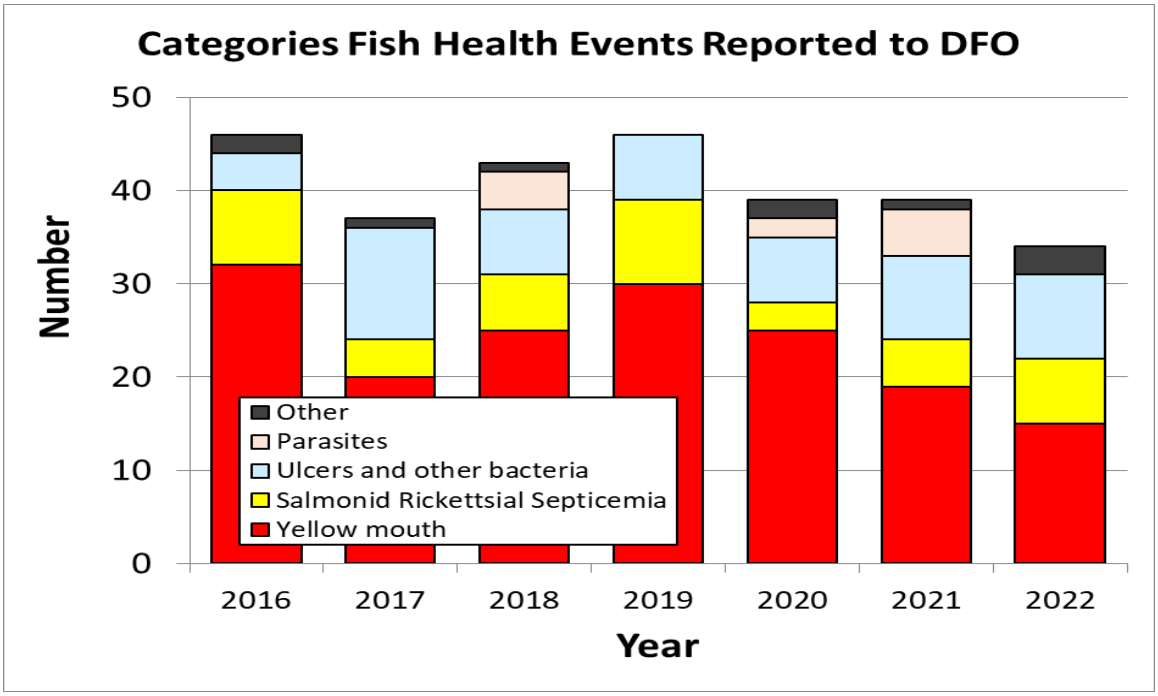


Figure 8. Fish health events at BC Atlantic and Pacific salmon farms, by category, 2016-2022.
Source DFO Open Data (18).

MORTALITY EVENTS

A "Mortality Event" must be reported to DFO within 24 hours of discovery if the number of dead fish at a farm exceeds the thresholds outlined in the conditions of the license. The threshold is specific to each facility and is determined by DFO based on variables that include the size of the farm, the species being farmed, and environmental conditions. Companies must continue to update DFO every 10 days for the duration of the mortality event, including daily mortality counts, mitigation applied, determination of the cause(s) of the event and any updated plan (18). Some Mortality Events require several reports before they are resolved. Mortality Events have been reported to DFO since 2011.

Each BC salmon farm, on average, reports about one Mortality Event each year (from 2011 – 2022, 579 reports averaged 48 per year) (Figure 9). Among the 579 farm salmon Mortality Events reported to DFO from 2011 – 2022, 24 (4.1%) were due to infectious disease, and five (0.9%) involved Pacific salmon species (two of these were infectious disease).

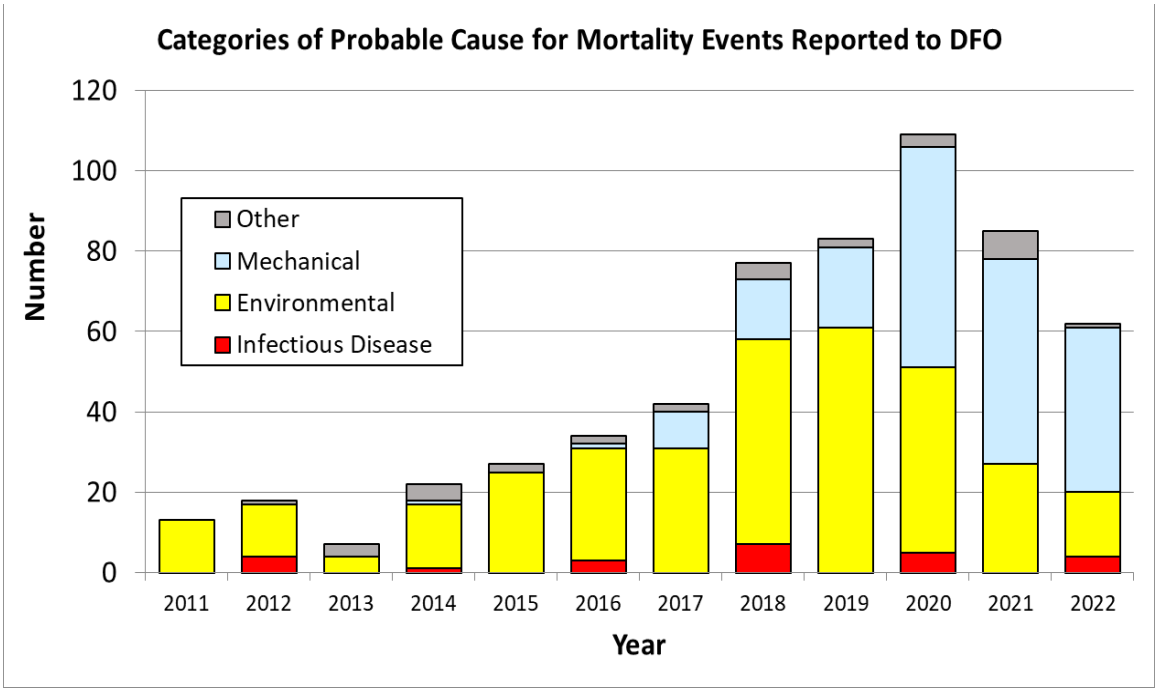


Figure 9. Probable causes of mortality events at BC Atlantic and Pacific salmon farms, 2011 – 2022.
Source DFO Open Data (19).

CARCASS CLASSIFICATION

BC aquaculture licence holders are required to remove dead fish from net pens on a regular basis and categorize the fish according to the cause of death (20). This "Carcass Classification" has been reported to DFO since 2013, as a condition of license.

Most infectious disease occurs in the "Fresh silver" and "Decomposed" categories; other than a spike in "Fresh silver" mortality. In 2018, the average annual mortality for these two categories combined was about the same from 2013 – 2017 (6.6%) as for 2019 – 2022 (6.3%) (Figure 10). In contrast, the average annual mortality for all other categories combined increased nearly 60% from 2013 – 2017 (7.2%) to 2019 – 2022 (11.4%). Most of this increase is a result of environmental issues (low dissolved oxygen and toxic algal blooms) and increased use of mechanical treatments to control sea lice. Salmon farmers are working to decrease these sources of mortality.

From 2011 to 2022, each BC salmon farm on average, reported about one Mortality Event each year; 4.1% involved infectious diseases. Most infectious diseases in BC salmon farms kill only a few fish daily. It is rare for infectious disease to kill enough fish to be reported as a Mortality Event.

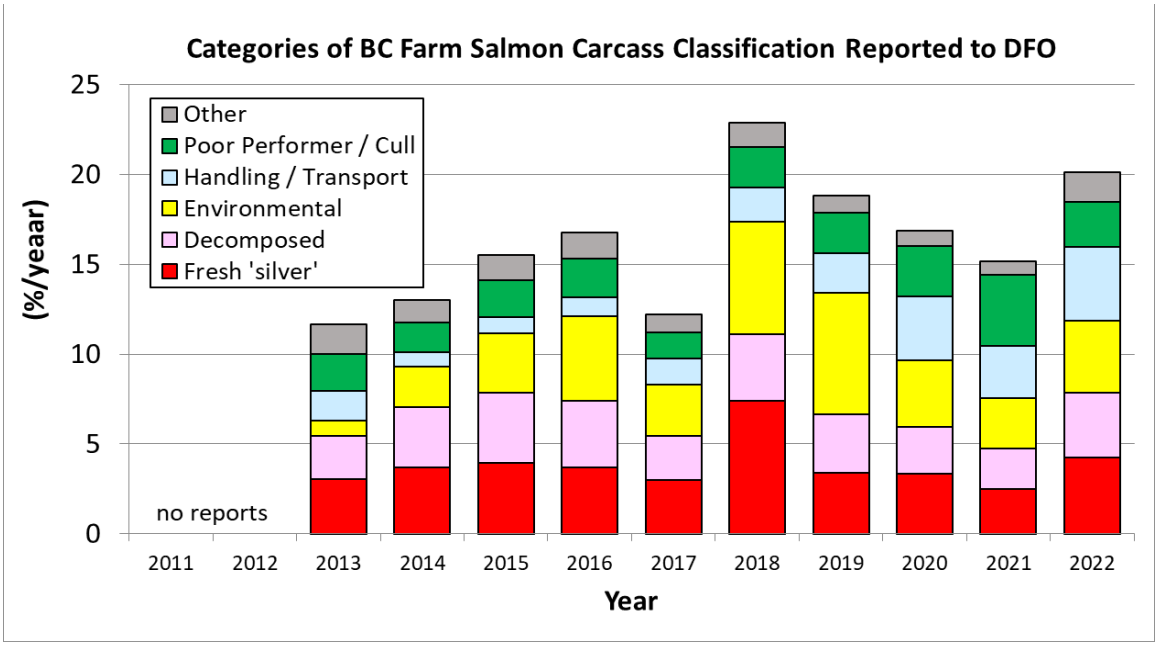


Figure 10. Cause of death of farm-raised Atlantic and Pacific salmon at BC farms 2013 to 2022.
Source DFO Open Data (20)

GOVERNMENT FISH HEALTH AUDITS

While Fish Health Events, Mortality Events, and Carcass Classification are all reported to DFO by salmon farm fish health teams, the reliability of these reports is confirmed through government "Fish Health Audits" (21). These audits were first developed in the early 2000s, when the Province of BC licensed salmon farms. Since DFO took over licensing of BC salmon farms in 2011, the audits have been conducted by DFO.

Each quarter, DFO biologists audit approximately 18 randomly selected farms based on species grown and location. During each fish health audit, the auditors sample dying and fresh-dead farmed fish for diseases.

These samples are similar to the "Fresh silver" Carcass Classification category reported by salmon farmers. For years with sufficient data (2006 – 2009 and 2014 – 2022), total annual sample size for the Audit Program varied from 470 – 784 Atlantic salmon and 61 – 134 Pacific salmon.

The government audit program increases the chance of finding new infectious diseases five- to 10-fold by focusing on "Fresh Silvers". This narrow category is for recently deceased fish that have not died from obvious causes such as plankton blooms or mechanical injury. "Fresh Silvers" are about 4% of deceased fish. Within this narrow category, audit program pathologists diagnosed infectious disease as the cause of death in 13 – 30% of Atlantic

salmon samples (average = 22%) and 25 – 62% of Pacific salmon samples (average = 42%) (Figure 11). Over the 16-year span of these data, there is no obvious trend in these proportions.

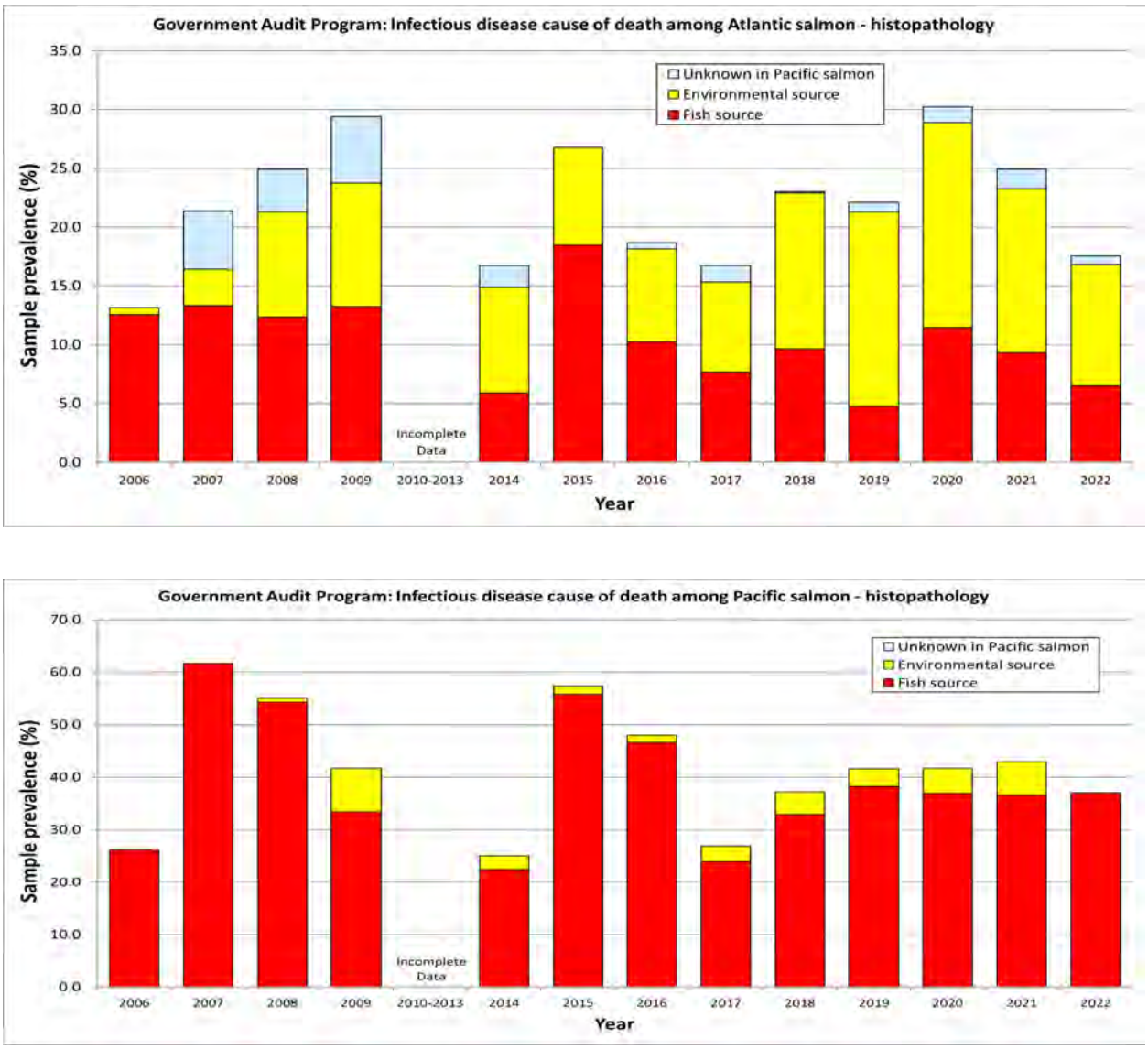


Figure 11. Among government audit program samples of BC farm-raised "fresh silvers," the proportion diagnosed as having died from infectious disease. "Fish source" diseases mostly come from other infected fish (e.g., bacterial kidney disease), while "Environmental source" diseases mostly come infectious agents in the water (e.g., yellow mouth)."

Source DFO data 2011 – 2022 DFO Open Data and Data from BC, 2006 – 2010: Cohen Commission Exhibit #1678 (22).

DFO confirms the low prevalence of infectious disease in Mortality Events by reviewing diagnostic reports submitted by salmon farm veterinarians for each Mortality Event.

To increase the chance of finding new diseases during audits, government audits limit detailed diagnostic analysis of fish that have any obvious single disease (i.e., auditors are more interested in searching for new diseases than confirming well-known diseases). This protocol results in common diseases like yellow mouth being underrepresented in Atlantic salmon audit samples. Therefore, for a better estimate of the proportion of "Fresh silvers" dying of infectious disease, salmon farm veterinarians recommend doubling the average prevalence of infectious disease in audit samples (23.6%) to 47%. Also, the prevalence of infectious disease among carcasses classified as "Decomposed" is probably about the same as for "Fresh silvers."

Therefore, a reasonable estimate of total annual marine mortality of BC farm-raised Atlantic salmon due to infectious disease is 3%, which is:

(i) the average proportion of "Fresh silver" and "Decomposed" categories combined in the Carcass Classification from 2018 – 2022 (7.2%), times

(ii) the doubled average prevalence of infectious disease in Audit Program samples from 2018 – 2022 (47%).

No single disease dominates Pacific salmon mortality enough to require adjustment from Audit Program results. Therefore, **a reasonable estimate of total annual marine mortality of BC farm-raised Pacific salmon due to infectious disease is also 3%**, which is:

1. the average proportion of "Fresh silver" and "Decomposed" categories combined in the Carcass Classification from 2018 – 2022 (8.1%), times
2. the average prevalence of infectious disease in Audit Program samples from 2018 – 2022 (40%).

WHAT DID JUSTICE COHEN SAY ABOUT THE IMPACT OF SALMON FARMS AND FRASER RIVER SOCKEYE SALMON?

Photo by Brian Kingzett

In 2009, Canada established the Cohen Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River to investigate the perceived decline of sockeye salmon stocks. Salmon farms were assessed as one of the potential reasons for the decline.

The Honourable Justice Cohen stated, "***Data presented during this Inquiry did not show that salmon farms were having a significant negative impact on Fraser River sockeye.***"[1] Justice Cohen's final report describes the salmon farm disease data presented during the hearings as "***impressive***,"[1] and he noted, "*There was a* ***statistically significant declining trend in the number of high-risk diseases reported by salmon farms between 2003 and 2010***."[1]

Justice Cohen also said (emphasis added), "*I therefore conclude that the* ***potential*** *harm posed by salmon farms to Fraser River sockeye salmon is serious or irreversible*." Cohen Commission Final Report, Volume 3, p. 92 col 2 (23) This is not a statement based on evidence presented during the hearings; instead, it is a statement of fact consistent with the science of disease in populations (epidemiology).

Any disease that can impact individuals has the *potential* to impact populations. The key word in Justice Cohen's statement is "potential." If Justice Cohen had concluded that salmon farms were causing serious or irreversible harm to Fraser River sockeye salmon, he could have recommended immediate termination of all aquaculture licences. He did not do this. Instead, he recommended, "*Precautionary measures should focus on filling the knowledge*

gaps and enabling DFO to adapt mitigation measures to new scientific information." Cohen Commission Final Report, Volume 3, p. 93 (23)

In the decade since Justice Cohen's final report was published, the new scientific information demonstrates the *potential* is minimal as described in the next section

FORMAL RISK ASSESSMENTS OF SALMON PATHOGENS

In response to Justice Cohen, the Canadian Science Advisory Secretariat (CSAS) completed risk assessments for nine pathogens to determine the risk of pathogen transfer from farm-raised Atlantic salmon to Fraser River sockeye salmon. In all cases, the assessment concluded that the risk to Fraser River sockeye salmon populations is minimal (24, 25).

See Appendix A for details on each pathogen, the results of the assessment, and veterinary measures to reduce the risk of transmission to farm-raised and wild salmon.

A recent "Perspective" paper in the Canadian Journal of Fisheries and Aquatic Sciences includes concerns about the independence of the CSAS process: "Idiosyncrasies of this process, however, preclude independent review and undermine the ability of CSAS to provide robust science advice, especially on controversial topics like salmon aquaculture." (26) The paper used PRV as an example, but the paper does not include results from an independent body that assessed the threat of PRV to Pacific salmon as low.

In 2017, the Pacific Northwest Fish Health Protection Committee (PNFHPC), an American organization of technical and policy representatives from conservation agencies, indigenous peoples, and commercial fish producers from the Pacific Northwest concluded, "The ubiquitous nature of piscine orthoreovirus (PRV), its apparent historic presence in wild Pacific salmonid stocks in the Pacific Northwest and the lack of clear association with disease in Pacific salmonids suggest the virus poses a low risk to wild species of Pacific salmonids." (27)

Similar to the Canadian Science Advisory Secretariat (CSAS), the Pacific Northwest Fish Health Protection Committee of the United States concluded that PRV "poses a low risk to wild species of Pacific salmonids".

This conclusion was updated in 2022 by the lead author of the 2017 paper: "The scientific information continues to support the conclusion that endemic PRV-1a in the PNW should be considered as posing a low risk (not zero) to Pacific salmon, thus requiring no significant changes to agency fish health policies…" (27, 28). This independent assessment is

consistent with the CSAS assessment of minimal risk of PRV. Unlike the CSAS assessment, which was limited to the threat of PRV from Discovery Islands fish farms to Fraser River sockeye salmon, the American organization assessed the threat of PRV, regardless of source, to all Pacific salmon.

WHAT HAS HAPPENED WITH FISH HEALTH ON SALMON FARMS SINCE THE COHEN COMMISSION OF 2012?

In the decade since Justice Cohen's final report was published, scientific information demonstrates the continued declining trend in significant infectious diseases affecting farm-raised salmon.

Two such diseases include the virus that causes the disease Infectious Hematopoietic Necrosis (IHN) and the bacterium that causes bacterial kidney disease (*Renibacterium salmoninarum*).

From 2001 to 2003, an outbreak of IHN among BC farm-raised Atlantic salmon spanned 23 months and affected 36 farms (29). The only IHN outbreak on BC salmon farms since then, in 2012, was limited to three farms and spanned only 3 months (10). All BC farm-raised Atlantic salmon are now vaccinated against IHN, and BC salmon farms have had no IHN outbreaks since 2012.

Among government samples of sick and freshly dead BC farm-raised Atlantic salmon, bacterial kidney disease decreased from 40% in the early 1990s (30-33), to 9.2% in 2006, and even further to 1.1% in 2022 (11).

WHAT DOES THE LOW FARM-RAISED SALMON DISEASE MORTALITY MEAN FOR WILD SALMON?

Infectious disease kills only about 3% of BC farm-raised salmon every year. Most of the 97% that do not die of infectious disease are never even infected with the pathogens that kill 3% of their cohort (11, 34-36).

Unlike farm-raised salmon, which spend their entire life in salmon farms, juvenile Fraser River sockeye salmon spend only a few minutes to hours of their life near salmon farms (37). Therefore, we expect infectious disease from salmon farms to infect and kill *much* less than 3% of Fraser River sockeye salmon.

Other salmon species might spend more time around salmon farms (e.g., some Chinook salmon), but we have no evidence that any diseases that affect farm-raised salmon are more likely to spread among wild Pacific salmon species.

Therefore, based on basic principles of population medicine, which informs us that disease spreads more readily among concentrated farm fish than among dispersed wild fish, we expect farm-source disease to kill less than 3% of all species of wild Pacific salmon.

Diseases that affect Atlantic salmon more than Pacific salmon are readily identified, as was the case for the IHN virus, which is carried by migrating sockeye salmon with little affect but is highly lethal to unvaccinated farm-raised Atlantic salmon (38, 39).

Photo by Bill Pennell

Photo by Steel_Snorkel

Other than sea lice, which are strictly regulated to protect wild salmon, we have no evidence that Atlantic salmon carry diseases that affect Pacific salmon but not Atlantic salmon. Pacific salmon species like coho salmon and steelhead have been cultured for more than 30 years in regions with abundant farmed Atlantic salmon (e.g., Norway and Chile), and no such diseases have been identified.

ADULT RETURNS OF ICONIC WILD SALMON POPULATIONS WERE SIMILAR BEFORE AND DURING THE SALMON FARMING YEARS

Wild salmon populations are naturally highly variable. An important measure of the success of salmon farmers in controlling infectious disease is whether changes in infectious disease on farms are associated with changes in wild salmon populations. Infectious disease is a natural component of all animal populations, including humans, and diseases in every population pose a potential threat to all susceptible populations in contact with those diseases. However, potential threats of infectious disease rarely result in real consequences at the population level.

Like humans, all animals have well-developed immune systems that protect them against ongoing exposure to infectious diseases in their environment. We understand that places people gather can be a source of infectious disease for other people, but those disease rarely—if ever—result in human population decline. Likewise, wild salmon are a source of infectious diseases for farm salmon, and farm salmon are a source of infectious diseases for wild salmon. As with people, diseases in one population (salmon farms) rarely impact other populations (wild salmon).

Iconic salmon populations in the Fraser River and the Broughton Archipelago provide an excellent example to examine the effect of salmon farms. Between 2019 and 2023, nearly all salmon farms in the Broughton Archipelago and Discovery Islands were removed, primarily because of perceived concerns about the threat of salmon farm diseases to wild salmon.

These regions had salmon farms since the late 1980s, and government records of wild salmon runs date back to at least the early 1960s. Because population trends account for all threats—known and unknown—data on population size over time help answer questions about the impact of salmon farms on wild salmon populations:

A. During the time that wild salmon populations were exposed to salmon farms, were average adult returns less than they were before salmon farming?

B. Did wild salmon populations exposed to salmon farms vary in relation to nearby wild salmon populations not exposed to salmon farms?

Answering these questions also requires understanding whether any trends in wild salmon populations are explained by natural population change or variables other than salmon farms (e.g., changes in climate, habitat, food availability, predators, or the human population).

The lack of population impact of salmon farms among three iconic wild salmon populations supports the conclusion that salmon farms have no more than minimal impact on wild salmon populations:

- Fraser River **sockeye salmon**, average total adult returns (40).
  - 6.8 million per year before salmon farming began (1962 – 1989)
  - 8.0 million per year during the salmon farming years (1990 – 2022)
- Fraser River **pink salmon**, average total adult returns (40)
  - 11.9 million per year, before salmon farming began (1963 – 1987)
  - 13.2 million per year, during the salmon farming years (1989 – 2021)
- Broughton Archipelago **pink salmon**, average total adult returns (16, 41)
  - 0.8 million per year, before salmon farming began (1950 – 1987)
  - 1.1 million per year, during the salmon farming years (1988 – 2014); DFO data for this region are incomplete after 2014.

See "Chapter 10 – Caring for Wild Salmon – Sea Lice Management" Figures 17, 18 and 30 for charts of the fisheries data.

HOW HAVE ADVANCES IN AQUACULTURE VETERINARY MEDICINE HELPED TO IMPROVE WILD SALMON ENHANCEMENT?

Only a small proportion of the science behind aquaculture veterinary practice is published in peer-reviewed scientific journals; instead, much of the supporting science is generated through propriety research conducted or contracted by aquaculture companies.

Transfer of this technology among government and private veterinarians occurs through meetings of relevant organizations (e.g., The Association of Aquaculture Veterinarians of British Columbia) and informal discussions.

Examples important to government-run wild salmon enhancement hatcheries in British Columbia include the following (42):

- Increase water use efficiency by replacing rectangular raceways with circular tanks (Figure 12),
- Prevent and control bacterial kidney disease through screening and treatment methods,
- Early detection of "atypical gill disease",
- Control of fungus-like oomycetes (*Saprolegnia* and related species), and
- Optimize feeding methods to ensure that all hatchery fish get enough to eat and grow at rates like their cohorts.

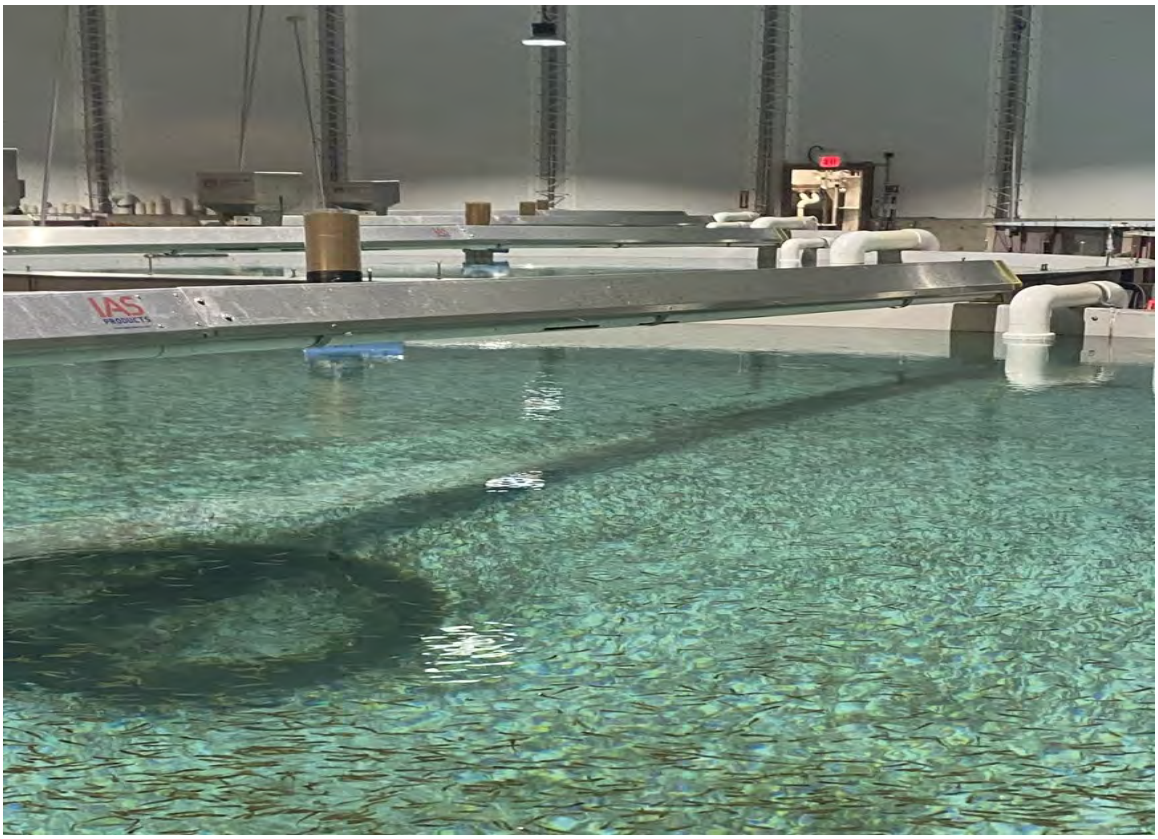


Figure 12. Circular tank system at recirculating hatchery.

WHAT SAFEGUARDS KEEP FARM-RAISED SALMON HEALTHY?

Many safeguards are in place during a farm-raised salmon's journey from hatchery to marine site to harvest vessel. Fish health starts with the careful selection of healthy parent fish. This leads to healthy eggs in the hatchery. Veterinarians apply proactive health measures at the hatcheries to produce healthy smolts for marine sites. Because wild fish are a common source for many high-risk pathogens, several hatcheries are land-based closed containment sites that have no contact with wild fish. Other hatcheries use ground water in which no fish have been present and/or filter and disinfect their water if using surface water. All hatcheries keep out predators and pests that could carry disease. The marine sites have further safeguards in place to keep fish healthy while at sea.

Seven safeguards protect wild fish from exposure to farm-source pathogens (Figure 13):

- Safeguard 1: enhance fish health through selective breeding (Table 1)
- Safeguard 2: prevent pathogen entry and spread in hatcheries (Table 2)

- Safeguard 3: barriers to the entry of fish pathogens from hatcheries into marine sites (Table 3)
- Safeguard 4: barriers to the spread of fish pathogens within and between marine sites (Table 4)
- Safeguard 5: treatments prescribed by a licensed veterinarian (Table 5)
- Safeguard 6: fish health monitoring and record keeping (Table 6)
- Safeguard 7: regulatory compliance, verification and transparency (Table 7)

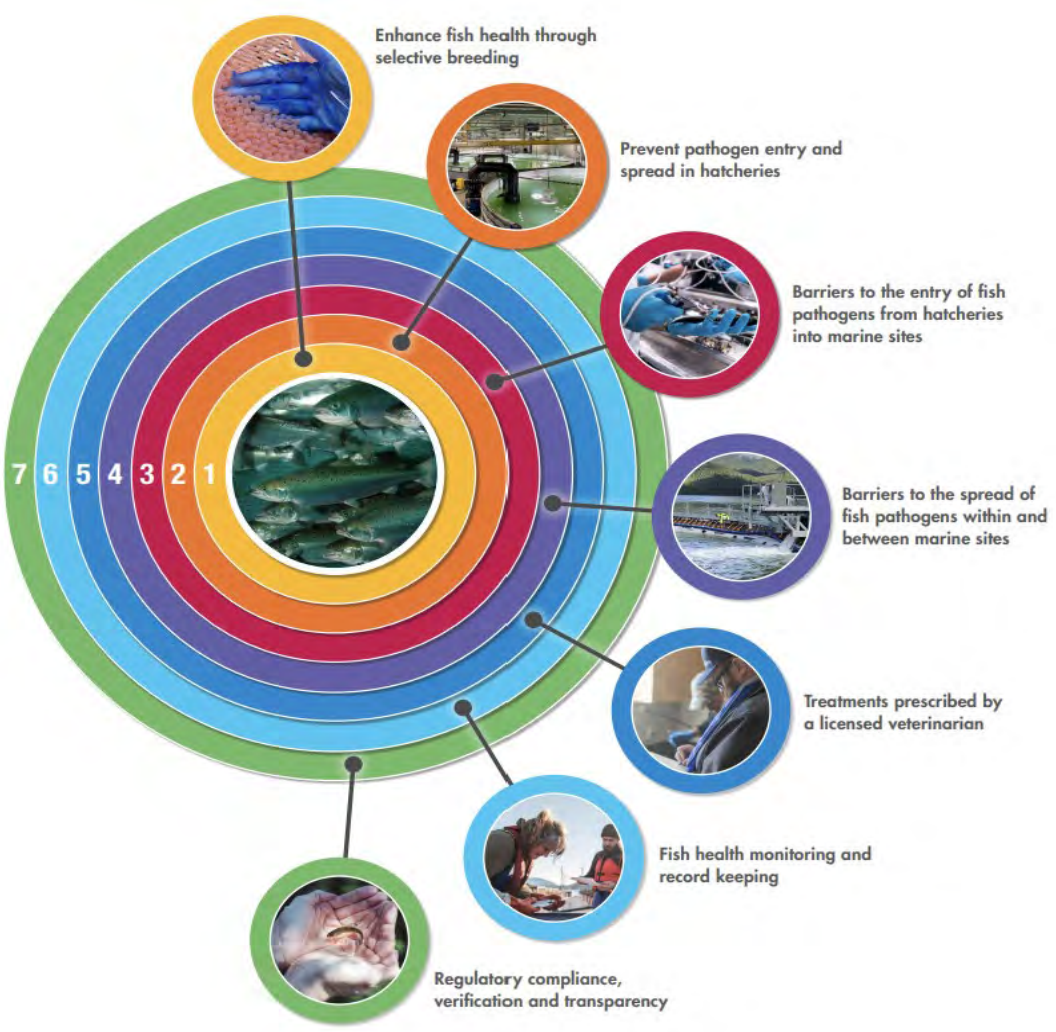


Figure 13. Seven safeguards protect wild fish from exposure to farm-source pathogens.

Table 1. Safeguard 1 – Enhance Fish Health Through Selective Breeding

Objective	Measures
Domestic BC broodstock programs only	No imports of eggs or breeding stock into Canada since 2012.
Selection of the healthiest fish	Modern genetic technologies, such as DNA markers and genomic selection, enable salmon farmers to make more informed decisions about broodstock selection. These tools provide valuable insights into the genetic profiles of fish, allowing salmon farmers to select individuals with desired traits more accurately (Figure 14).
Fish tagging and tracking	To aid in the selection process, salmon farmers collect fin clippings from brood fish and send them for analysis. All fish, upon selection, are tagged for tracking.
Maintain genetic diversity	To ensure genetic diversity and minimize the risk of inbreeding, salmon genetics programs often maintain multiple breeding lines. These lines may come from different generations of selected broodstock. Genetic diversity helps to maintain robustness and adaptability in the farm-raised salmon population.
Disease resistance	Breeding programs select individuals with strong innate immunity and disease resistance.
Growth performance	Selective breeding aims to enhance growth rates and feed conversion efficiency in farm-raised fish. Populations with improved growth performance are often healthier and more robust (Figures 15 and 16).
Stress tolerance	Fish in aquaculture systems often face various stressors, such as handling, transportation, and environmental fluctuations. Selective breeding programs improve stress tolerance and adaptability.
Reproductive performance	Breeding programs also select broodstock based on reproductive traits such as fertility, egg quality, and reproductive success to help ensure healthy and viable offspring.

Figure 14. Selection of brood fish is a complex process involving modern genetic technologies.

Figure 15. The selection of broodfish is made with genetic experts, veterinarians and farm staff.

Figure 16. All fish family groups are tagged and monitored throughout their life cycle.

Table 2. Safeguard 2 – Prevent Pathogen Entry and Spread in Hatcheries

Objective	Measures
Eggs and hatchery fish are separated from ambient water containing significant pathogens	Most hatcheries are closed containment land-based systems using ground water that has not had wild fish in it. Some hatcheries use recirculating ground water or flow through that is filtered and disinfected to keep out fish pathogens (Figure 17).
Eggs are free of significant pathogens when arriving at the hatchery	Eggs come from domestic BC broodstock, i.e., brood fish that have been raised in BC for several generations in closed broodstock programs. No new eggs or stocks have been introduced for more than a decade.
	Most domestic broodstock have been raised in land based closed containment systems. Some eggs come from marine broodstock sites in which the fish are kept healthy and closely monitored so no pathogens are passed to the eggs.
	Some broodstock get booster vaccines prior to spawning.
	All brood females are screened for salmon pathogens during spawning. Egg lots that do not meet strict cutoff standards are segregated and destroyed.
	Eggs are disinfected at water hardening, before being transported to the hatchery, or at the hatchery after eggs and milt were transported separately.
Pathogens are prevented from entering on equipment or clothing	Gear is dedicated to each hatchery.
	Strict biosecurity measures: cleaning and disinfection of all egg trays, fish tanks and equipment (small and large) prior to stocking the next generation of fish.
	Access is limited to authorized personnel and only with management instructions.
	Visitors must use dedicated boots and protective clothing.
	In some facilities staff are dedicated to separate parts of the hatchery to prevent cross contamination between different fish groups.
Pathogens are prevented from entering on/in biological vectors	Methods include pest control programs, including barriers like lids and bird netting for outside tanks, keeping bays closed, and physical barriers in all entry ways.
Pathogens are prevented from entering in/on fish feed	Production of commercial fish feeds include a high temperature process that kills any fish pathogens (e.g., parasites and bacteria). No farm-raised salmon are

	included in commercial diets. Feed is packaged in bags or totes that create barriers to possible contamination during transport and storage.
Boosting the fishes' immune system	Hatchery Atlantic salmon are vaccinated for the major pathogens (e.g., IHNv, *Aeromonas salmonicida* (Furunculosis), *Vibrio anguillarum* (2 types), *Vibrio salmonicida* (Cold Water Vibriosis), and *Moritella viscosa* (Winter Ulcer). Some are also vaccinated against BKD. Pacific salmon are vaccinated for BKD and Vibriosis (Figure 18).
Early detection of disease	Fish are constantly monitored for abnormal behaviour including subtle changes in feeding. Hatchery staff have been trained to look for early signs of disease and fish health challenges (Figure 19).
	Most hatcheries have invested in newer equipment and monitoring that gives hatchery staff near real-time feedback and early detection capabilities.
	Mortalities are collected daily, classified and examined for signs of disease. Trends are followed closely.
	Site and fish health staff do routine fish health sampling and screening for pathogens and disease.
	Most hatcheries have a minimum of monthly fish health team visits, and some much more frequently.
Prevent pathogen movement within the site	Strict biosecurity measures are in place, including dedicated equipment for each tank or group of fish, cleaning and disinfection of any equipment used for different fish groups. At some hatcheries, dedicated sections and dedicated staff and water filtration separate groups of fish.
	Staff handling dead fish wear special clothing, gloves and/or other protective equipment.
	Some hatcheries have separate water filtration and fallowing between parts of hatchery.
Maintain and monitor healthy growing conditions for fish	Stock at optimal densities to reduce stress for fish.
	Continuously monitor water quality inside hatchery (Figure 20).
	Continuously monitor feed consumption, fish behaviour, growth and any behavioural changes.
Further investigation	Further fish health visits, investigation, and sampling in the event of elevated mortality or unusual behaviour.

Figure 17. Grieg Seafood's BC Gold River hatchery.

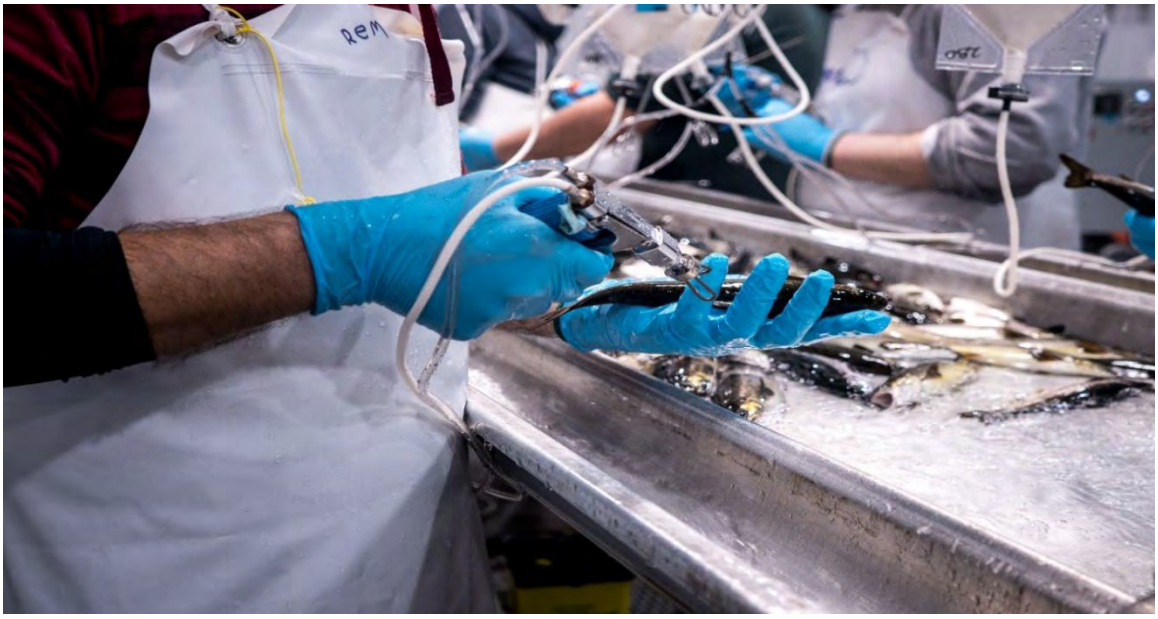


Figure 18. Vaccines boost the fishes' immune system.

Figure 19. Routine fish health visit by a licensed veterinarian to hatchery.

Figure 20. Water quality and growing conditions are constantly monitored at hatcheries.

Table 3. Safeguard 3 – Barriers to the Entry of Fish Pathogens from Hatcheries into Marine Sites

Objective	Measures
Only healthy fish populations can be stocked at sea sites	Fish health must be approved by the federal and provincial governments *before* transferring to sea sites.
	Pre-transfer sampling program for viruses and bacteria according to the BC Introduction and Transfers Committee (a joint federal-provincial committee comprised of members from DFO, the BC Ministry of Environment and Climate Change Strategy, and the BC Ministry of Forests, Lands & Natural Resource Operations).
	No fish can be transferred without regulatory approval from the BC Introductions and Transfers Committee.
	Veterinarians examine the fish and review fish health data and lab reports before transfer to ensure that they are healthy, doing additional testing if indicated.
	If mortality exceeds 0.05% for four consecutive days in the thirty days before transfer (not including fungus or handling), it must be reported to the regulator, who may block the transfer or request additional requirements.
New fish only go into cleaned and fallowed sites	Each production site is fallowed between crops. During the fallow, farms are thoroughly cleaned and disinfected before stocking (Figure 21). Nets are removed for cleaning and the site infrastructure is cleaned and disinfected. Benthic monitoring is done prior to new fish introduction[1]. In the rare cases where small numbers of broodstock are retained, they are kept at a distant and physically separate part of the site.
Transport water is contained	The fish are moved in clean water sourced from the hatchery. Fish may be dewatered prior to going into saltwater on the transport vessels. If saltwater is used, it is sourced away from any marine site. In most cases only small amounts of that water is discharged when transferring the fish from vessels to the net pens.
Fish are transported in cleaned and disinfected vehicles and vessels	Each transport vehicle and vessel is thoroughly cleaned and disinfected before the fish are onboarded (Figure 22).
	Each vehicle/vessel has dedicated equipment for mechanical transfer of the fish and, in most cases, crew clothing that only travels with them.
	Vehicles, vessels and equipment are thoroughly disinfected after each group of fish has been delivered.

[1] See "Chapter 8 – Caring for the Environment – Protecting Biodiversity" for information on benthic monitoring requirements.

Figure 21. Staff setting up farm site to receive fish.

Figure 22. Specialized transport vessels and equipment are used to transport fish into sea sites.

Table 4. Safeguard 4 – Barriers to the Spread of Fish Pathogens Within and Between Marine Sites

Objective	Measures
Minimize susceptibility to infectious disease	Before fish are transferred from the hatchery, they are vaccinated for major pathogens (see Safeguard 1 for details).
Maintain and monitor healthy growing conditions for fish	Pens are stocked at optimal densities to reduce stress for fish.
	Water quality is continuously monitored to minimize any environmental challenge for fish (plankton, water temperature, oxygen levels). Many marine sites have invested in extensive and sophisticated oceanographic and weather monitoring and instrumentation that gives staff near real-time feedback from each pen (Figure 23).
	Daily system inspections by the site staff, which include the visible sections of the nets from the surface and from the underwater cameras, as well as the visible system moorings and cage arrays (Figure 24).
	At a minimum, diver inspection of all nets on the system every 60 days, and divers keep an eye on the nets every time they are in the pens. Predator nets that are secondary containment nets that encompass the entire system are inspected as well. Some sites have remotely operated underwater vehicles (ROVs) that inspect nets and other infrastructure. Net washers may use ROVs as well (Figure 25).
	Daily inspection of fish; continuous monitoring for feed consumption, fish behaviour, mortalities and growth.
	Marine site staff are on the pen systems daily (unless conditions are unsafe, such as during extreme seas or weather). They have been trained to look for early signs of disease and fish health challenges. Updating and on-the-job training provides for consistency in monitoring.
	Careful handling of any live fish during treatments, grading, and transport to harvest.
	Pathogens are prevented from entering in/on fish feed. Commercial fish feeds include a high temperature process that kills any fish pathogens, e.g., parasites and bacteria.
	No farm-raised salmon are included in commercial diets.
Prevent pathogen movement within the site	Strict biosecurity measures including dedicated equipment for each site or group of fish within a site where practicable; cleaning and disinfection of any equipment used for different fish groups.
	Dedicated equipment is used where possible. Every effort is made to reduce the use of equipment at multiple sites to help maintain each site's

	biosecurity. If equipment must be shared, it is only used on fish of the same age (year class) (Figure 26).
	Site staff and visitor protocols include using footbaths to disinfect footware on site.
	Keep nets clean. Nets are frequently inspected. Approximately every 10-14 days (maximum 28 days), each salmon net is cleaned using high volume water jets and then inspected by divers, cameras and/or underwater ROVs (Figure 27).
	Unless conditions are unsafe, each day staff retrieve carcasses and classify the cause of death. For smaller fish this might be twice weekly.
	Dedicated clothing and equipment are set aside for staff handling mortalities.
	Dedicated staff for each site. In the few sites where this is not possible, there are strict biosecurity protocols in place.
No, or minimal access by personnel to multiple sites	Strict visitor protocols upon entering a site including contractor protocols.
	Visitors require management and/or veterinary approval before going on a site. Some sites have visitor protocols in which the fish groups are visited in a specific order as directed by veterinarians.
No, or minimal, transfer of fish between sites	Fish transfers between marine sites are not common and are governed by Fish Health Zones as defined by DFO; transfers require a BC Introductions and Transfer Committee permit. No fish are moved without regulatory and veterinary/management approval.
Fish are transported in cleaned and disinfected vehicles and vessels	Strict biosecurity measures with respect to boats, feed, people or equipment taken into farms. All movements require management approval. Strict cleaning and disinfection protocols are in place.
	Boats and equipment are cleaned and disinfected on a regular basis and after every use.
	Where between-site usage is necessary, boats and equipment are cleaned and disinfected between sites and must show evidence of effective cleaning and disinfection prior to the next use.
Early detection of disease	Farm fish behaviour and the ambient water are frequently monitored visually and/or with sophisticated instruments capable of collecting large amounts of real-time data or near real-time data.
	Routine fish health sampling and screening for pathogens and disease, as per veterinary direction, supervision and/or training (Figure 28).

	Daily dead fish retrieval and classification allows rapid and frequent evaluation of trends in mortality.
	Onsite contact information and staff are trained to report any abnormal behaviour or mortality to the fish health team.
	Minimum of monthly Fish Health Team visits as per veterinary direction, supervision and/or training.
Further investigation	Further fish health visits, investigation, and sampling in the event of elevated mortality or unusual behaviour. Veterinarians diagnose problems as they arise.
Plan next steps	Veterinarians provide fish health recommendations, proactively and in real time.

Figure 23. Water quality and plankton are continously monitored at each site.

Figure 24. Daily inspections of farm systems. Fish are secured within the cages with additional jump fences, bird nets and secondary predator nets.

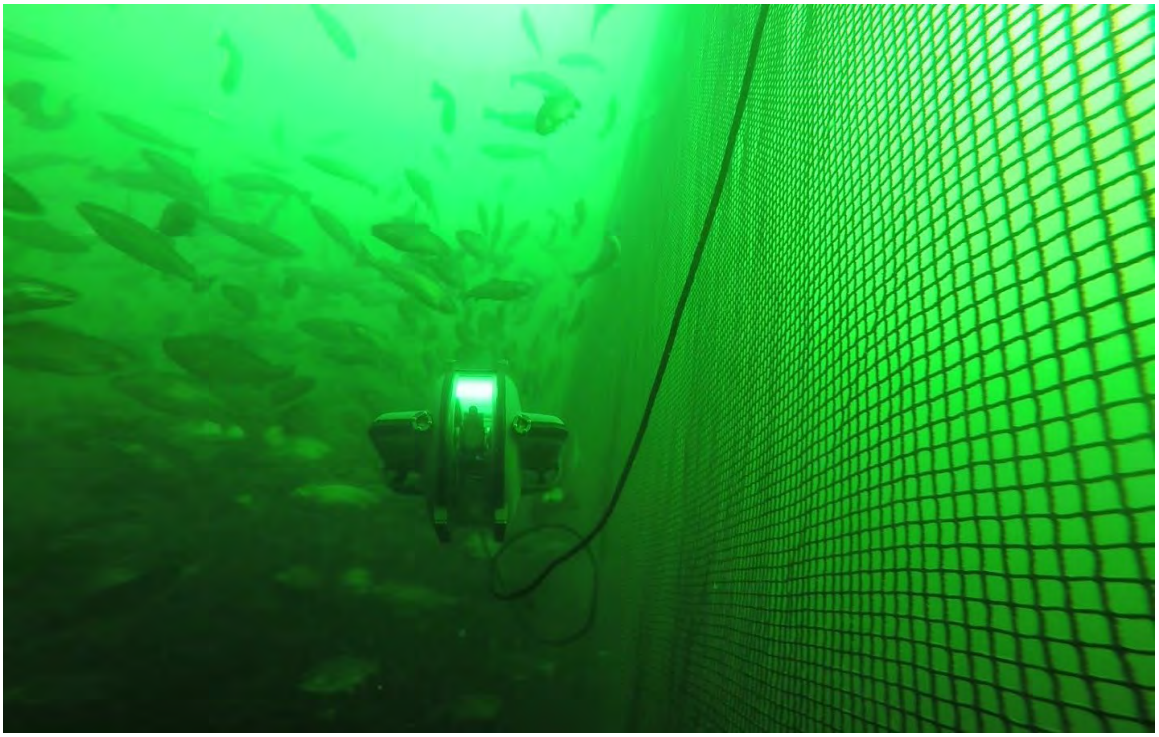


Figure 25. ROV inspection of a net pen.

Figure 26. Transport to and between marine sites is through authorized crew boats.

Figure 27. Net cleaning devices are used to keep containment nets clean to maximize water flow for fish health.

Figure 28. Routine fish health and sea lice check.

Care for fish continues through to harvest, where specialized vessels have been purpose built to harvest salmon safely and humanely from marine pens (Figures 29 and 30).

Figure 29. Specialized vessels have been purpose built to harvest salmon safely and humanely from marine pens.

Figure 30. Staff getting equipment ready for harvesting fish from the farm.

Table 5. Safeguard 5 – Treatments Prescribed by a Licensed Veterinarian

Objective	Measures
Identify the need	Veterinarians determine if treatment is needed to enhance fish health and welfare, including welfare of wild fish (e.g., sea lice treatments).
Treat as needed	Ensure that treatment dose and duration meet medical best practice standards and government regulations.
Integrated Pest Management (IPM)	Best practices in management of pests like sea lice include coordination of treatment timing and method with all farms in a region (regardless of who owns each farm), rotating treatments to minimize development of resistance, and coordinated stocking and fallowing of farms in a region (Figures 31 and 32).
Monitor effectiveness	Monitor effectiveness of treatments (e.g., antimicrobials or sea lice treatments) and continued health and welfare of the fish.

Figure 31. Veterinary practices are supported by specialized equipment, such as the hydrolicer barge shown above that removes sea lice with water jets.

Figure 32. Specialized ships, such as the Aqua TromØy, allow for freshwater bath treatments to remove sea lice under the supervision of licensed veterinarians.

Figure 33. Licensed veterinarians maintain extensive records of all practices.

Table 6. Safeguard 6 – Fish Health Monitoring and Record Keeping

Objective	Records
Extensive Veterinary documentation and record keeping	Records of surveillance for pathogens and disease, including sampling and diagnostics (Figure 33).
	Records of any medicine use.
	Records of any fish mortalities by pen, including classifying cause of death.
	Records of farm hygiene, disinfection, and biosecurity requirements and actions.
	Records of any stock movement between pens, including stocking densities and origins.
	Tracking of the specific growth and feeding rates of each pen of fish, expressed as the percentage body weight gain per day.
	Details of the feed used, including composition of the feed, quantity used and manufacturing date.
	Video clips of fish behavior including feeding sent to veterinarian and management if anything unusual seen.
	Environmental conditions that the fish experience, including extensive and robust monitoring of water quality parameters.
Fish Health Management Plans	Annual review and continuous updates of each company's Fish Health Management Plan, which include detailed Standard Operating Procedures.

Stringent regulatory record keeping requirements for farm fish health are overseen by multiple agencies, including the Canadian Food Inspection Agency (CFIA) and Fisheries and Oceans Canada (DFO). Required record-keeping includes health records for all aquaculture sites.

The data systems provide the backbone for accurate and timely required reporting to government agencies. They also provide information for reports to First Nations Rightsholders and third-party certification programs.

Table 7. Safeguard 7 - Regulatory Compliance, Verification and Transparency

Objective	Measures
Compliance with federal and provincial regulations, licenses and reporting requirements	Meet requirements of the Canadian Food Inspection Agency, Environment and Climate Change Canada, Health Canada, Transport Canada, Agriculture and Agri-Food Canada and Fisheries and Oceans Canada (DFO); BC Ministry of Agriculture and Food, BC Ministry of Environment & Climate Change Strategy
Mandatory reporting of fish health and disease per provincial and federal regulatory requirements	HATCHERIES
	Structured federal regulatory program for land-based facilities, with detailed Freshwater Land-Based Aquaculture License Conditions (43).
	MARINE SITES
	Structured federal regulatory program for all marine facilities (44).
	Mandatory reporting of sea lice treatments (13). This includes treatments without medicinal products (e.g., freshwater bath treatments).
	Regular reporting of Fish Health status and events to First Nations under collaborative agreements.
	HATCHERIES and MARINE SITES
	Mandatory reporting of Fish Health Events – When a suspected or active disease occurrence arises, veterinarians must notify, report, and take immediate and follow-up actions, including additional diagnostic testing and reporting to address the concern as per the conditions of the DFO Freshwater/land-based condition of license (43) or Marine Finfish Aquaculture License (45).
	Mandatory reporting of Mortality Events - Immediately notify DFO within 24 hours of discovery and report and address mortality events, which may include additional diagnostic testing and reporting to address the concern as per the conditions of the DFO Freshwater/land-based condition of license (43) or Marine Finfish Aquaculture License (45)
	Report the use of all medicines and water treatment chemicals to DFO (46).
	Mandatory reporting of listed reportable and immediately notifiable diseases to CFIA (9) and all reportable and notifiable diseases to the BC Chief Veterinarian (47).
	Mandatory reporting of antibiotic usage (13).
Multiple third-party verifications that proactive fish health	HATCHERIES
	Unannounced audits by DFO regulators to ensure compliance with all regulatory requirements (48).

practices are being followed	Audits by third-party certification auditors to monitor compliance with certification standards.
	Audits by First Nations through partnership agreements to ensure fish are healthy and standards are met.
	Additional oversight by First Nations and third-party certification schemes can occur in the hatcheries to ensure fish are healthy prior to moving them to sea.
	MARINE SITES
	Unannounced and announced audits by DFO regulators to ensure compliance with all regulatory requirements.
	Audits by third-party certification auditors to monitor compliance with certification standards.
	Sites with organic certification have audits as per CFIA's organic Standards Program for aquaculture (49).
	Audits by First Nations partners through partnership agreements to ensure fish are healthy and standards are met.

Salmon aquaculture is the only commercial animal farming in Canada for which all health events, mortality events, and veterinary treatments must be reported to regulatory veterinarians (e.g., DFO). Salmon farmers must seek permission from DFO for any fish transfers to the ocean. DFO fish health staff audit the fish health status on multiple farms every three months (21); nothing like these audits occurs with other livestock-rearing farming anywhere else in the world.

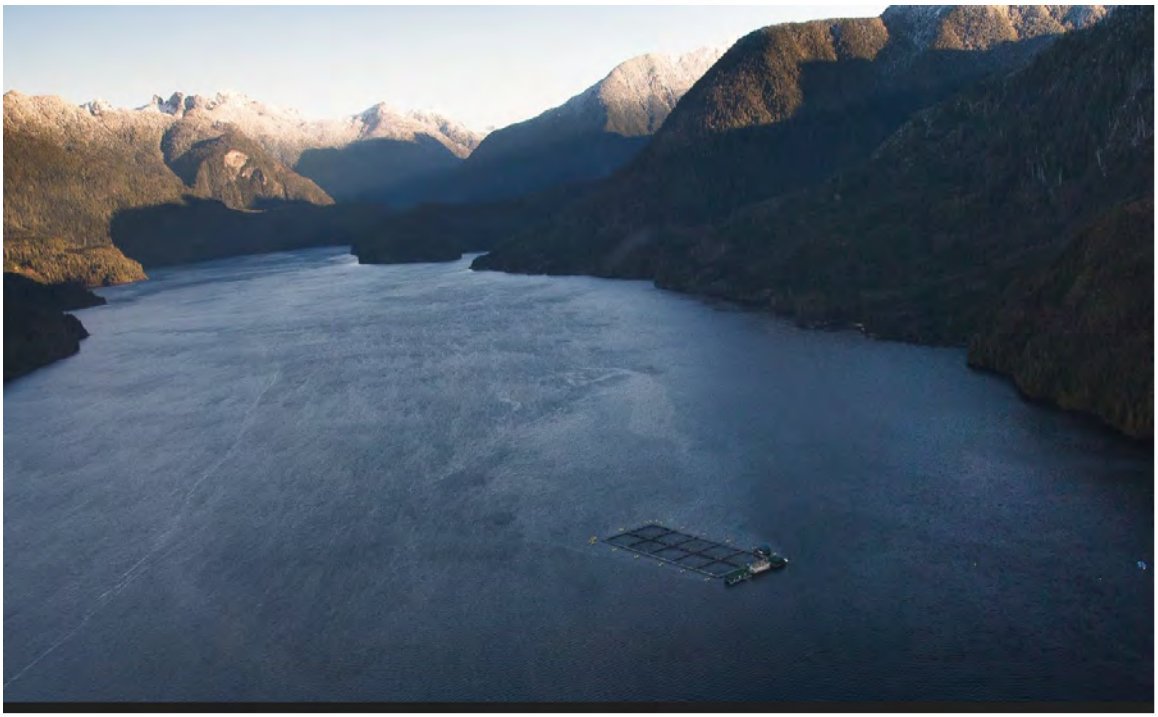
Additional oversight requirements for certification programs (ASC Salmon Standard, BAP Farm Standard) and First Nation partners can lead to a triple on-site review of veterinary practices at farms (Table 8 and Figure 34).

Figure 34. Rightsholders First Nations are leading the oversight and monitoring of aquaculture operations within their traditional territories using their Guardian and stewardship programs.

Table 8. Summary of independent oversight of fish health practices at salmon farms.

Oversight	Description
Veterinary Practices at the Farm	Follow approved veterinary practices as per professional medical licensing BC industry-wide Memorandums of Understanding for Integrated Pest Management for Sea Lice and Viral Management.
First Nation Partners and Businesses	Oversight as per collaborative partnership agreements.
Provincial Level	BC Introductions & Transfers Committee. Control movements of fish into and between sites.
Federal level	National Aquatic Animal Health Program (NAAHP). Co-chaired by CFIA and DFO. Control export and imports of aquatic species, domestic disease controls, and emergency response (contingency) plans as these relate to diseases regulated under the Health of Animals Act (Health of Animals Regulations and Reportable Disease Regulations).
	Canadian Food Inspection Agency (CFIA). Canadian authority to control imports, exports, disease management and control, domestic movements of aquatic animals, and biosecurity.
	DFO. Primary regulator of salmon farms in British Columbia.
International Level	World Organization for Animal Health (WOAH). Prevent the spread of diseases that are a significant threat to sustainable farm-raised and wild aquatic stocks worldwide.
	WOAH maintains a list of fish diseases of international concern (50).
Certification Bodies	Aquaculture Stewardship Council (ASC). Additional requirements for veterinary practices, including limiting the amount and types of medicines used and public reporting elements.
	Global GAP Best Aquaculture Practices (BAP). Additional requirements for veterinary practices including procedures for fish movements and the use of medicines.
	Global GAP Best Aquaculture Practices (BAP). Additional requirements for veterinary practices including procedures for fish movements and the use of medicines.

EYES ON THE OCEAN – IMPORTANT DIGITAL ADVANCES



With the advent of high-speed internet in remote areas, salmon farms are incorporating automation to rapidly improve data collection. Communication with sites is real time even if they are remotely situated.

Instrumentation can record oceanic conditions every few minutes at multiple depths in every pen (for example, see Figure 35). Many of these sites also collect detailed weather information. Government agencies like DFO and Environment Canada use some of the sites' infrastructure and weather instrumentation to collect data for their forecasts. They also collect information on previously undocumented microclimates in remote inlets. Some sites are also coastal zooplankton reference monitoring sites. The large data sets generated by this equipment are being shared with universities for specific collaborative projects.

Artificial intelligence programs at several sites are rapidly evolving to help evaluate the fishes' general health status. On some sites, camera trials in pens can capture up to 150,000 images per day (Figure 36).

Programs have been developed on other sites to combine several kinds of data streams (e.g., camera data, water quality data) to look at complex indices like fish behaviour, health and welfare. Feedback from these data streams can be as frequent as minute-by-minute. These data are constantly being compiled to refine understanding of complex interactions (Figure 37). Other sites use more manual recording but do similar analysis of the information.

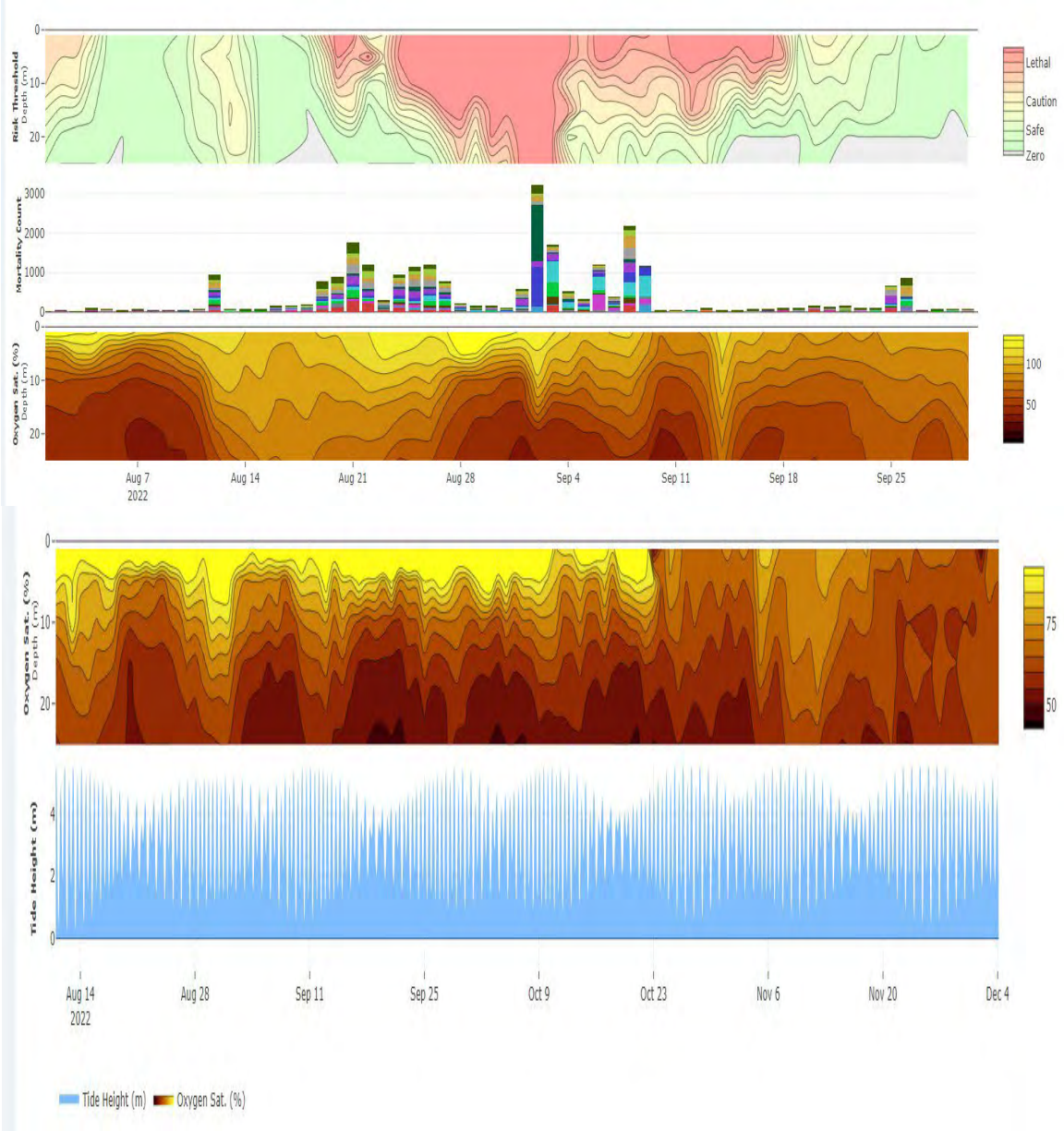


Figure 35. Example of pen tracking data, which charts oxygen saturation, tidal heights, documented fish mortality and calculates the potential risks for salmon in each pen.

Data collection is undergoing a digital revolution. With the arrival of in-sea data loggers, wireless point-to-point communication towers and artificial intelligence, farmers are installing technology at many sites that can collect several hundred thousand data points daily at each farm. This amounts to collecting millions of datapoints on oceanic conditions each day in BC.

Figure 36. Cameras are used to monitor fish. Some farms collect up to 150,000 images per day.

Figure 37. Site staff constantly monitor fish behaviour during feeding using underwater cameras.

Some in-pen underwater cameras now utilize optical recognition to identify the characteristics of individual fish. This is being used to further fine tune feeding, optimize growth rates and further minimize already significantly reduced feed waste.

Farms add other observations to this automated data collection. This can include:

- video clips of any abnormal behaviours or findings,
- 2-3 times-per-day plankton observations (more when there are plankton blooms),
- jellyfish and hydroid observations,
- daily mortality numbers and attributable causes,
- results of veterinary and fish health team visits to the sites, including sampling and diagnostic testing,
- results of audits for third party certification,
- handling and weight sampling as they occur, and
- information from major handling events is recorded, such as seines being pulled and mechanical delousing with boats.

Coupled with the rapid advancement of tools, communications and databases, this huge amount of accessible data is a game changer for veterinarians and farm managers. BC salmon farms are spread over 400 km of our coastline, and aquaculture veterinarians cannot be at all sites all the time. With these tools, veterinarians successfully manage fish health without needing to be at all sites all the time.

Treatments, should they occur, are recorded in detail including duration, feeding and fish response (see Figure 38). Farms have internal systems that combine important fish health data to forecast growth rates and assess trends and changes in population parameters. Some sites have early alerts set for abnormal behaviour and other unusual findings so site staff can react immediately. These systems use both the frequent data coming in and the years of data from individual sites to provide accurate information for planning and forecasting, trend analysis and decision making.

Sites can be reliably monitored remotely, so the veterinarian is made aware of unusual findings much more rapidly. For many sites, data is frequently sent to veterinarians and company management, some in near real time. This facilitates many eyes on the data and more likely detection of, and quick responses to, early signs of disease and other fish health issues.

Figure 38. View of pen monitoring system during sea lice treatment.

UNDERSTANDING DISEASE IN SALMON

WHAT ARE MICROBES AND PATHOGENS?

Microscopic organisms (also known as 'microbes') are organisms that are too small to be seen with the naked eye. Examples of microbes include bacteria, plankton, viruses, and animals such as the dust mite and other parasites.

Microbes are among the most diverse and abundant organisms in nature. Their abundance is staggering; a simple teaspoon of seawater typically contains about 50 million viruses (51). The genetic material (DNA or RNA) from microbes can be detected everywhere we look in the environment.

Pathogens are organisms that can cause disease. They can be microscopic like viruses and bacteria, or macroscopic (visible to the naked eye) like external parasites (e.g., sea lice). Pathogens have co-existed with other species for millions of years. All animals, including salmon, live in environments with potential pathogens.

The rapidly evolving field of microbiology has shown that microorganisms and hosts can cooperatively co-exist, and in fact, the co-existence may be mutually beneficial for survival (52). For example, microbiota (large populations of microorganisms) can be found on every surface - inside and outside - of the human body. Massive numbers of microbes in the human gut (the microbiome) are beneficial for digestive health and other functions in the human body.

Salmon and their pathogens have co-evolved over time. Animals can co-exist with pathogens and not be diseased. If this were not true, virtually all organisms, including people, would be diseased almost all the time.

Researchers currently estimate that there are about 30 trillion cells in each person and an additional 39 trillion cells that are other microorganisms (e.g., in the human gut, air passages and skin) – meaning that as an organism we are only about 43% "human" (Figure 39) (53).

Figure 39. Study: less than half of the human body is human. Click link for video (53)

WHAT IS MOLECULAR DETECTION?

Medical technology has advanced very rapidly in the last two decades. Many laboratory tests have become exquisitely sensitive in detecting pathogens and very small fragments of their genetic code using polymerase chain reaction (PCR) tests and other molecular testing. When correctly used and correctly interpreted, these are extremely useful tools.

Fish represent about 50% of the vertebrate species on earth and likely host an enormous diversity of yet undiscovered viruses (54), some of which might benefit fish, while others might not.

Detecting the genetic material of an organism in a fish or in the fish's environment by environmental DNA (eDNA) techniques does not necessarily mean that the detected genetic code can sicken or kill fish (55). Only a handful of viruses have been documented to cause massive losses and rapid disease spread in salmon populations (e.g., Infectious Hematopoietic Necrosis virus [IHNv]) (56).

The finding of a "new" potential pathogen must be evaluated carefully. In 2022, independent fish health professionals developed a stepwise decision tree to guide fish health practitioners and managers when a potential pathogen is detected by molecular technology (Figure 40) (28). This includes multiple tests to confirm the valid detection of the pathogen. Proof is then required to show that the pathogen is the causative agent of infection and disease.

In veterinary medicine, this is usually shown in infection challenge studies conducted in laboratories. If yes, the decision tree also requires testing to show whether the pathogen can be detected in clinically healthy fish. Very importantly, if there is no mortality and associated disease but the potential pathogen can be detected in clinically healthy fish, then a risk assessment should be conducted by fully qualified professionals to determine whether further follow up and surveillance is necessary.

Photo by Steel_Snorkel

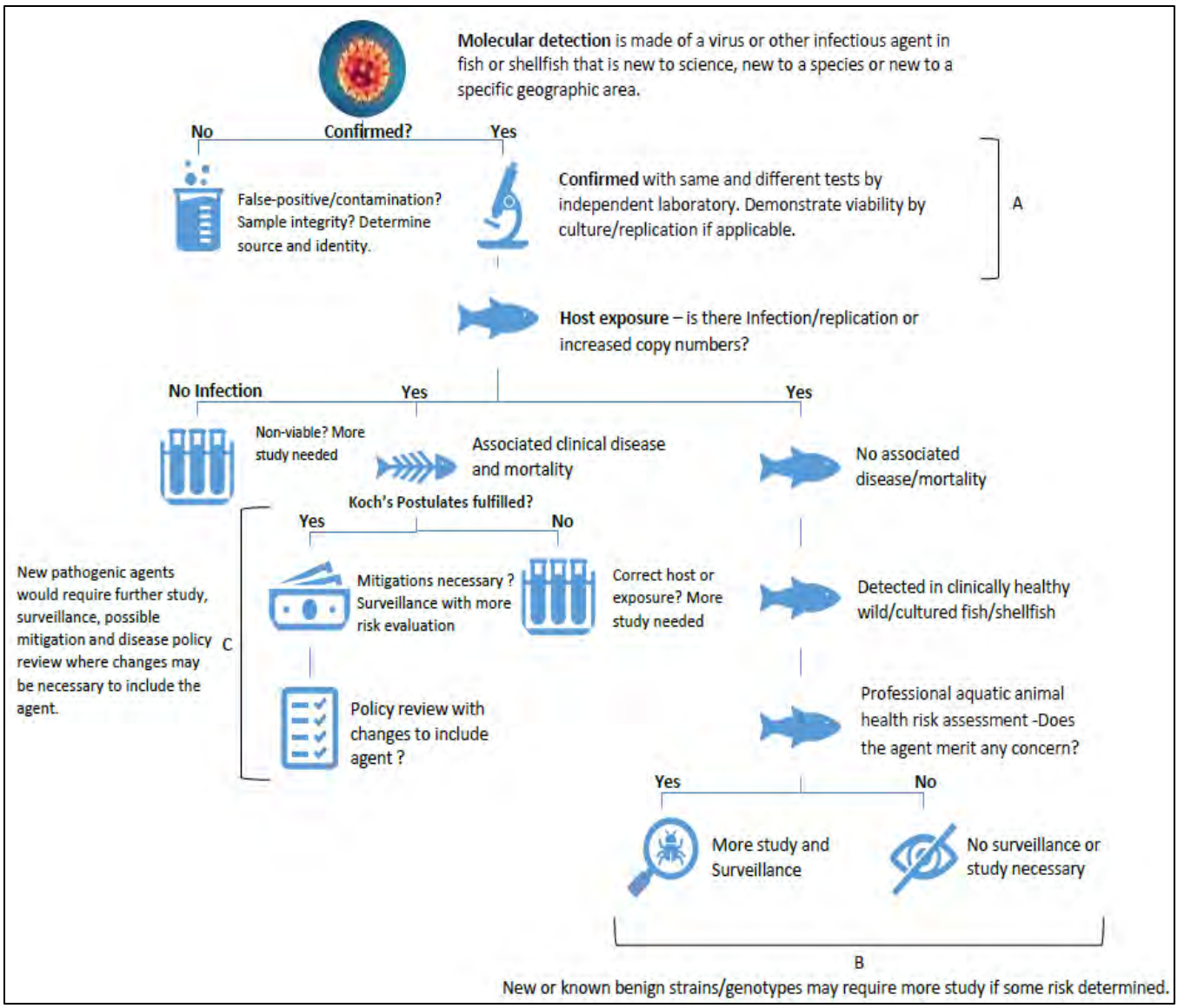


Figure 40. Decision tree following molecular detection of a new infectious agent (28)

WHAT CAUSES INFECTIOUS DISEASE IN FISH?

The spread of infectious disease in fish, like infectious disease in people or terrestrial animals, is a complex process. Fish live in an environment with vast numbers of microbes, only some of which are sometimes harmful (pathogenic). Many variables must align for infectious disease to occur, and other variables must align for disease to spread within a population; fish health professionals call this process "the chain of infection" (Figure 41). If any one step does not occur, then the population does not become diseased.

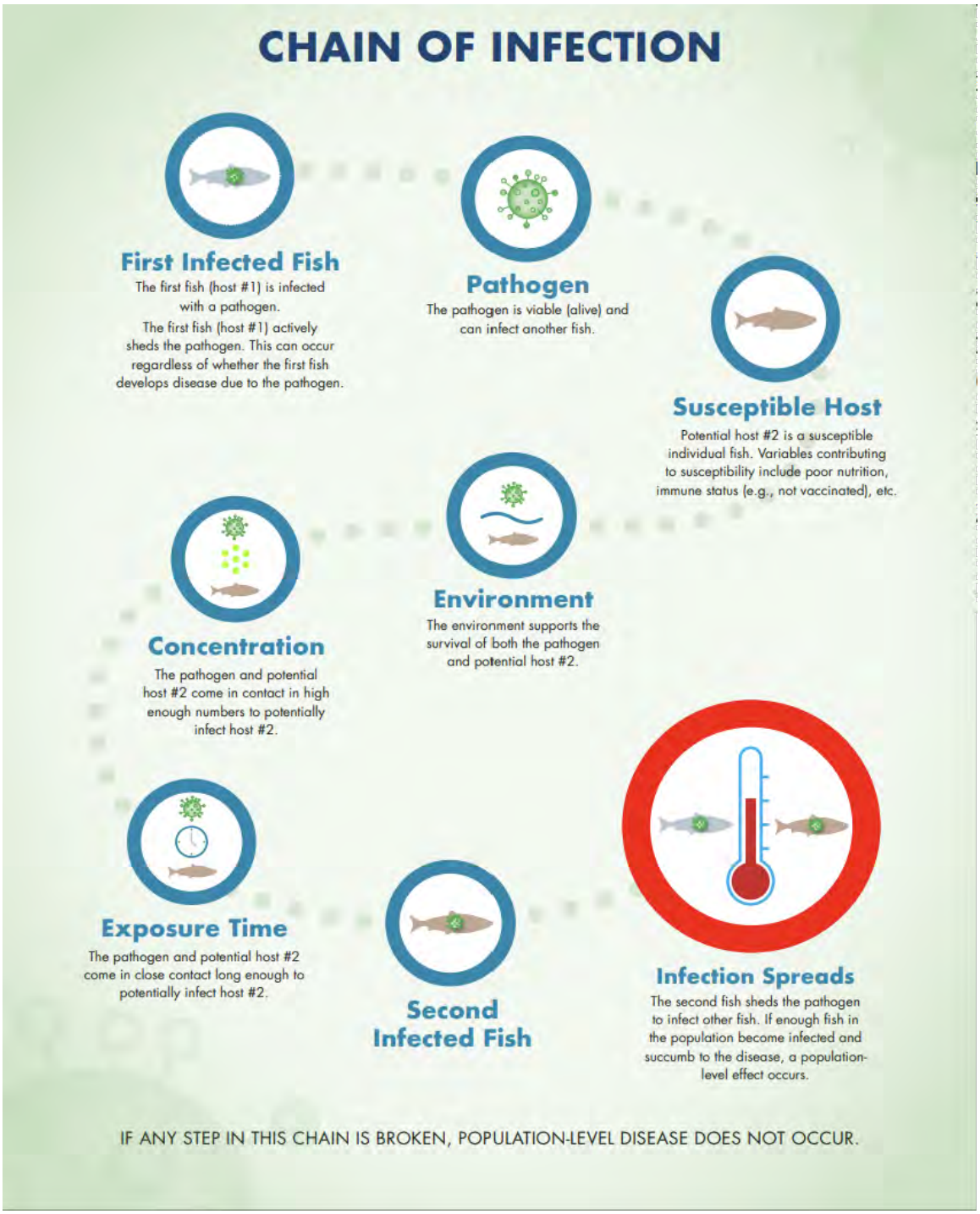


Figure 41. Variables that must align in order for infection to spread and population-level disease to occur. If any step in this chain is broken, population-level disease does not occur.

OUTCOMES

If the second fish has become infected (i.e., all the above conditions are in place) then the fish may succumb to the disease. However, if the fish's immune system clears the pathogen, then the fish may recover. Treatment such as antimicrobial therapy might be required to support the fish's immune system in clearing the pathogen out of its system. If enough fish in the population are resistant to the infective organism or have recovered from infection, then herd immunity occurs.

Disease can ONLY occur if there is a specific alignment of host, pathogen and the environment. If the alignment does not occur, neither does disease.

If the correct alignment of host, pathogen, and environment does not happen, then disease does not occur. As in terrestrial livestock farming, salmon farmers have figured out ways to intervene – put up effective barriers – so the perfect alignment of host, pathogen and environment are less likely to occur. Some of these may be physical separation (walls and enclosures) and some may be functional (i.e., preventative or mitigative action).

Differences in conditions within farms and the surrounding environment minimize the spread of infectious diseases from farm salmon to wild salmon (Figure 42). Pathogens shed by farms are diluted and degraded in the environment (see Table 9.1 in (57)); this decreases the chance of the first wild fish getting infected from a farm-source disease. Most wild fish are more dispersed than farm fish; this decreases the chance that the first infected wild fish will spread the pathogen to other wild fish.

For example, an otherwise healthy person vaccinated for flu, measles or chicken pox has an immune system that is primed to respond to those pathogens if encountered in the environment (e.g., someone else who is sick with flu, measles or chicken pox). The vaccinated person has a much lower chance of becoming infected and diseased from those pathogens than a person who is not vaccinated.

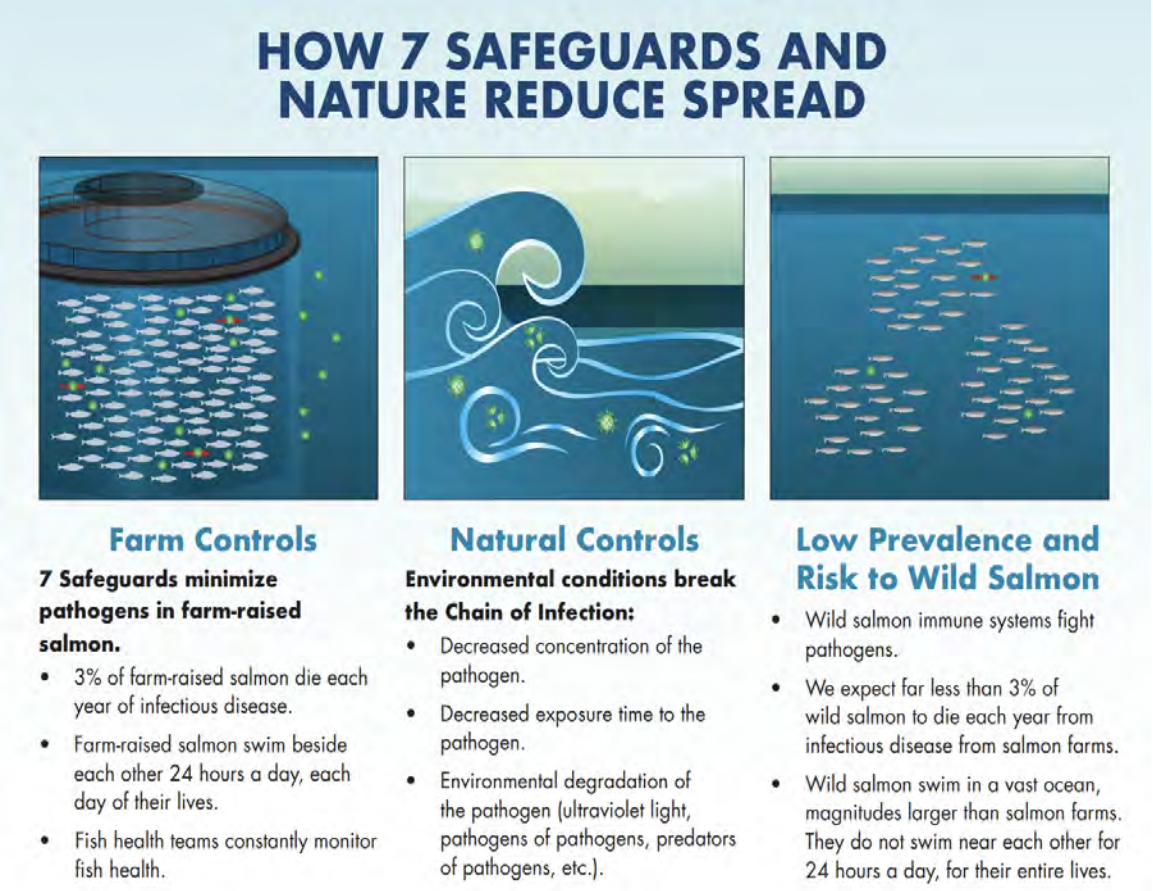


Figure 42. Farm controls and nature reduce spread of infectious disease from farm-raised to wild salmon.

HOW DO SALMON FARM VETERINARIANS DETERMINE THE CAUSES OF DISEASE IN THEIR FISH?

When aquaculture veterinarians investigate the cause of disease in their fish, they rely on a wide range of information, including farm history, water quality, feeding, growth, recent mortality, and several types of diagnostic test results:

1. Physical examination – "look at the fish" is a simple, yet powerful, diagnostic tool; abnormalities include ulcers, red spots (hemorrhage), or pale spots (inflammation or dead tissue).
2. Histopathology – probably the best single method for diagnosing the cause of disease in sick animals, histopathology uses microscopic examination of thin sections of tissues sampled from the fish. This method requires referral to a pathologist that is trained to identify parasites and bacteria in the sections. A trained pathologist can also identify abnormalities associated with viral infections, toxin exposure, nutritional state, and new diseases.
3. Immunohistochemistry – this is a special type of histopathology in which tissue sections are specifically stained to identify proteins specific for microorganisms; this method helps the pathologist identify parasites, bacteria, and viruses in the sections.
4. In situ hybridization – this is a special type of histopathology in which tissue sections are specifically stained to identify specific genetic codes of microorganisms; this method helps the pathologist to identify parasites, bacteria, and viruses in the sections.
5. Molecular tests – PCR tests are used to detect specific genetic codes of microorganisms; this method helps the veterinarian to identify parasites, bacteria, and viruses in the fish.[2]
    a. Screening tests – this term is used for PCR tests that are not validated for diagnostic purposes or for results reported by a laboratory

[2] Polymerase chain reaction (PCR) is a method widely used to make millions to billions of copies of a specific DNA sample rapidly, allowing scientists to amplify a very small sample of DNA (or a part of it) sufficiently to enable detailed study. Source Wikipedia

that is not accredited as a diagnostic laboratory

i. Veterinarians use these tests to help confirm other findings like lesions detected by histopathology.

ii. Veterinarians do not use screening tests alone as the basis for making decisions (i.e., the screening test results need to be corroborated with consistent lesions or clinical signs).

b. Validated tests – this term is used for PCR tests that are validated for diagnostic purposes. Several levels of validation are possible.

i. The highest level of validation described by the World Organisation for Animal Health (WOAH) is needed for demonstrating that a region is free from a given pathogen (58). This level of validation is expensive and not needed for routine diagnostic investigation.

ii. Most tests used by accredited diagnostic laboratories will be validated for sensitivity (ability to detect the genetic code when it is in the sample) and specificity (ability to generate a negative result when the tested genetic code is not in the sample).

6. Synthesis – salmon farm veterinarians follow best practices for diagnostic medicine and ensure that they have confirmatory information from more than one diagnostic test before making a final diagnosis.

Photo by Steel_Snorkel

WHAT IS THE SIGNIFICANCE OF MOLECULAR DETECTION OF A PATHOGEN IN A FISH?

The significance of pathogen detection in a fish increases with each of five stages described below:

1. Exposure – The fish is in contact with the pathogen. For example, a bacterium in the water might adhere to the surface of the gill.
2. Infection – The invasion and growth of the pathogen in the fish. Methods to confirm infection include histopathology and immunohistochemistry.
3. Lesion – The pathogen causes an area of abnormal tissue (e.g., a skin ulcer). Methods to confirm this include physical examination and histopathology.
4. Disease – The pathogen causes illness or sickness characterized by specific clinical signs.
    a. Clinical signs are defined as any objective evidence of disease.
    b. Examples includes not eating, gasping at the water surface, or congregating at the corner of the net pen.
    c. Clinical signs also include demonstrated effects on fish growth, survival, and reproduction.
5. Population decline – the pathogen decreases the population size of infected fish. Because the diagnosis of disease depends on observing clinical signs, which is difficult in wild fish, and wild fish might die before they are sampled to confirm lesions, mathematical models can be used to assess the relation of the pathogen and fish survival.

For assessment of whether PCR detection causes population decline, mathematic models most likely to produce reliable results are based on evidence rather than imagination/hypothesis. Lines of evidence that increase the reliability of mathematical models of disease impacts include the following:

- Results from controlled laboratory exposure challenge trials can answer several questions:
    - Does the pathogen cause disease in the species of interest? Disease significant in wild fish includes impacts on swimming ability, predator avoidance, feeding, and growth.
    - What markers of infection, if any, occur before the fish becomes diseased (e.g., gene expression or microscopic lesions)?
    - How much of a pathogen is needed to infect and cause disease in the species of interest?
    - How much of the pathogen is shed from an infective host?
    - After being shed, how long does the pathogen survive in the environment?
- What proportion of PCR+ test results in wild fish are associated with changes known to be associated with the tested pathogen under controlled laboratory conditions?
    - For example, if a bacterium is known to cause skin ulcers under

controlled laboratory conditions, PCR+ test results for that bacterium in wild fish are more likely to be significant if they are associated with skin ulcers in the wild fish.

- Are the PCR+ test results associated with changes in population structure of the exposed wild fish population but not adjacent unexposed populations?

When BC licensed aquaculture veterinarians examine PCR+ test results for a pathogen from such scientific studies, they must determine whether the results are significant and interpret the results in context:

1. Reliability of the PCR test result.
    a. Results generated by accredited diagnostic laboratories are more reliable than results from other laboratories.
        i. Accreditation is "a voluntary, third party-reviewed process by a certifying body providing formal recognition of laboratory competence and quality (2)."
        ii. Laboratories used by salmon farm veterinarians are accredited by the American Association of Veterinary Laboratory Diagnosticians (AAVLD), the Standards Council of Canada (SCC), or the Canadian Association for Laboratory Accreditation (CALA).
2. Results generated using a validated standard operating procedure are more reliable than results from tests that do not follow a validated standard operating procedure.
    a. Validation is "a process that determines the fitness of an assay, which has been properly developed, optimised and standardised, for an intended purpose." (4)
    b. Validation provides confidence that the test can detect a pathogen when the pathogen is present in the fish.
    c. Just as important, validation provides confidence that the test will *not* detect the pathogen when the pathogen is *not* present in the fish.
3. A standard operating procedure (SOP) is "a set of written instructions that describes, in detail, how to perform a laboratory process or experiment safely and effectively." (5)
4. Status of interaction of the PCR+ test result and the tested fish. The significance of the interaction increases with each of five stages from exposure to population (exposure – infection – lesion – disease – population decline).
5. Synthesis of information
    a. If a bacterium is known to produce lesions, but the PCR+ test results are not associated with lesions among sampled fish, then the veterinarian is confident that the sampled fish do not have disease associated with the PCR+ test result.
    b. Lack of lesions in a PCR+ fish does not rule out the potential that disease might have developed if the fish had been sampled later, but the more PCR+ fish are sampled without lesions, the greater the confidence that the PCR+ test result is not a marker of disease.
6. Significance of information
    a. In practice, the transition between exposure, infection, lesion, and disease is not always easy to determine, particularly in wild fish.
    b. Along the continuum from exposure to disease, by definition only disease might impact wild or farmed salmon growth, reproduction, or survival.
    c. A virus or bacterium is not a threat to wild or farm-raised salmon if its interaction with fish never exceeds exposure, infection, or lesions.

RECENT CONCERNS

Recent concerns have been raised about *Tenacibaculum maritimum* and Piscine Orthoreovirus (PRV). These concerns are partly due to detections in the environment surrounding fish farms.

> "Decisions **should not be made solely on the basis of diagnostic test results,** especially in the absence of corroborating epidemiological, clinical, or gross evidence." (3)

TENACIBACULUM MARITIMUM

What is it?

Tenacibaculum maritimum is a bacterium that is common in ocean environments worldwide. Under the right conditions, it can cause disease in some marine fish species. In most parts of the world an infection with *T. maritimum* bacteria can result in a condition called tenacibaculosis; however, among farm-raised Atlantic salmon in BC and the US Pacific Northwest, infection can lead to a unique form of tenacibaculosis called "yellow mouth".[3] This disease has yellow bacterial mats in and around the teeth and mouth of marine fish.

[3] Also known as "mouth rot"

Is this a new disease?

Yellow mouth is not new to the region. By 1989, it was widely known to affect cultured salmon in BC, where it typically affected smolts within six to eight weeks of introduction into the ocean (59). Yellow mouth is what veterinarians consider a "production disease", that is, it mostly manifests in animals held under production conditions, in this case on a salmon farm.

Is it harmful?

Yellow mouth has never been described for any wild fish in BC or Washington State (1). There has only been one report of "jaw plaques consistent with mouthrot" in three farm-raised Chinook salmon (15-20g) from a farm in Discovery Passage in 2009 (1), and in a single farm-raised coho salmon sampled from a farm on the Sunshine Coast in 2014; however, these findings were not associated with farm-level disease by the government veterinarians in charge of the audits (11).

From 2002 – 2018, government veterinarians in BC diagnosed farm-level yellow mouth in 106 of 1446 Atlantic salmon farm audits but 0 of 273 Pacific salmon farm audits (1).

T. maritimum is not harmful to humans but can kill affected fish if left untreated. Young Atlantic salmon are most susceptible, with yellow mouth generally appearing in the first 3-4 months after transfer from a hatchery to sea cages.

What is the risk to wild Pacific salmon?

In 2019, DFO conducted a risk assessment to determine the potential magnitude of impacts on the abundance and diversity of Fraser River sockeye salmon from *T. maritimum* from farm-raised Atlantic salmon in the Discovery Islands area.The overall assessment concluded that *T. maritimum* attributable to these Atlantic salmon farms posed a minimal risk to Fraser River sockeye salmon abundance and diversity (60).

Since this assessment was conducted, a few papers have been published that could be examined to determine if the risk has increased. The potential for revision is typical of any risk assessment.

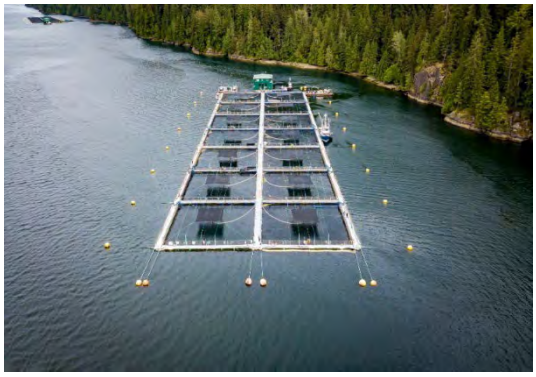
One new study that might be considered is a recent scientific report on juvenile Fraser River sockeye salmon migrating away from the mouth of the Fraser River (61). The report includes two major findings related to potential *T. maritimum* exposure from farms:

1. "Our best models (with 99.8% empirical support) describe constant background infection pressure, except around Discovery Islands salmon farms, where farm-origin infection pressure peaked at 12.7 (approximate 95% CI: 4.5 to 31) times background levels."
2. "*...between 6.5% and 56.1% of sockeye smolts appear to die as a result of farm-origin T. maritimum exposure* (61)".

A case study on how licensed veterinarians review information provided in this research paper follows.

CASE STUDY: A VETERINARY PERSPECTIVE OF *TENACIBACULUM MARITIMUM* AND FRASER RIVER SOCKEYE SALMON

Based on the veterinary approach to assessing the significant of PCR+ test results (see previous sections), the diagnostic results supporting these estimates come with extreme uncertainty and are, therefore, not reliable to (i) make decisions about how *T. maritimum* affects sockeye salmon, or (ii) estimate the role of farms increasing *T. maritimum* infection in wild salmon (Table 9 [follows]).



In summary, the research paper did not provide evidence of the first step in the Chain of Infection – the First Infected Fish (Figure 41). Rather, the lack of infection, lesions, or disease in salmon sampled in this research paper supports an evidence-based hypothesis that 0% of Fraser River sockeye smolts die because of farm-origin *T. maritimum* exposure.

Table 9. Veterinary approach to reviewing the analysis and conclusions of a recent research paper on T. maritimum, salmon farms, and Fraser River sockeye. (61)

Veterinarian's Question	Answer	Comment
Were the PCR tests for *T. maritimum* conducted in a laboratory accredited for diagnostic testing?	No	The tests were conducted in a research laboratory that is not accredited for diagnostic testing.
Was the PCR test used for *T. maritimum* validated for diagnostic testing?	No	The research paper cites a CSAS report (62) as a reference for test validation; however, the cited CSAS report does not include information about *T. maritimum (62).* Also, the cited CSAS report says, "We did not evaluate the platform for diagnostic use…" and, "We contend that the purpose of the assay, in its current application, is research rather than diagnosis."

Veterinarian's Question	Answer	Comment
Can PCR results from tests not validated for diagnostic purposes still be used to corroborate other findings?	Yes	Such tests are called "screening tests. These test results are not reliable when used on their own, but they may be used to help corroborate other tests (e.g., histopathology) or clinical signs (e.g., skin ulcers or gill lesions).
Does the research paper report corroborating evidence to confirm the PCR+ test results for *T. maritimum*?	No	Among the 2,270 juvenile Fraser River sockeye salmon sampled, none were reported to have skin ulcers or gill lesions, and no histopathology results were reported.
Can the false positive rate be estimated for the *T. maritimum* PCR test?	Yes	*T. maritimum* does not grow in fresh water (63). Therefore, the *T. maritimum* prevalence in freshwater samples provides a good estimate of false positive rate for the PCR test. For the laboratory that conducted these tests, the demonstrated false positive rate is 4.2%.[4]
Can PCR+ test results be adjusted to account for the false positive rate?	Yes	The CSAS report cited for test validation says, "…it is imperative that the assays run on the platform be carefully evaluated for sensitivity (limit of detection) …so that the limitations of what can and cannot be concluded are well established and measures are implemented to minimize the potential for false positive or negative results."
Does the research paper apply a limit of detection to minimize the potential for false positive test results for *T. maritimum*?	No	The research paper does not mention a limit of detection; instead, "If duplicate qPCR tests on the same sample both detected the bacterium, we considered that sample to be positive…"
Does the research paper provide PCR results in a	No	This research paper does not provide the data it analyses. This lack of data transparency precludes independent assessment of the analysis (26).

[4] 18 of 427 (4.2%) of fish sampled from fresh water are reported as PCR+ for *T. maritimum* in another paper by the same research group: Bateman, A.W., Schulze, A.D., Kaukinen, K.H., Tabata, A., Mordecai, G., Flynn, K., et al. 2021. Descriptive multi-agent epidemiology via molecular screening on Atlantic salmon farms in the Northeast Pacific Ocean. Sci. Rep. 11: 3466. doi:10.1038/s41598-020-78978-9. PMID:33568681.

Veterinarian's Question	Answer	Comment
dataset that can be independently reviewed?		
Does the research paper demonstrate that the sampled fish were exposed to *T. maritimum*?	No	The laboratory's false positive rate (4.2%) is greater than the PCR+ rate for many of the samples in the research paper, but the research paper did not adjust results based on this information. Therefore, the proportion of test results that are true positives cannot be independently estimated.
Does the research paper demonstrate that the sampled fish with PCR+ test results were infected with *T. maritimum*?	No	The CSAS report cited for test validation says, "*As with any PCR-based assay, a molecular assay alone cannot discern whether an animal is diseased or if a microbe is infective…*" The research paper provides no corroborative evidence that the PCR+ fish were infected.
Does the research paper demonstrate that the sampled fish had lesions associated with the PCR+ test results for *T. maritimum*?	No	Among the 2,270 juvenile Fraser River sockeye salmon sampled, none were reported to have skin ulcers or gill lesions, which can be detected by looking at the fish when they are sampled.
Does *T. maritimum* infection result in lesions in other Pacific salmon species?	Yes	*T. maritimum* infection has not been described in sockeye salmon. However, other studies report *T. maritimum* in Pacific salmonids: 1. Infected rainbow trout had "severe tail rot, frayed fins, haemorrhagic mouth with a compromised jaw (Figure 1 [in the research paper]) and, occasionally, damaged gills…" (64) 2. "The gills of 10 of 15 moribund chinook salmon…had severely eroded, white to pale pink areas (Figure 1 [in the research paper]) associated with rapid mortality." (65)
Does the research paper use the best estimate of mortality related to *T. maritimum* infection?	No	The research paper several times mentions the severity of *T. maritimum* in farm-raised BC Atlantic salmon, but it does not mention the lack of disease associated with *T. maritimum* in farm-raised BC Pacific salmon species. From 2002 – 2018, government

Veterinarian's Question	Answer	Comment
		veterinarians in BC diagnosed farm-level yellow mouth in 106 of 1446 Atlantic salmon farm audits but 0 of 273 Pacific salmon farm audits (1).
Does the research paper demonstrate that the PCR+ test results for *T. maritimum* are associated with decreased population-level survival of Fraser River sockeye salmon?	No	A study of 64 stocks of sockeye salmon from BC, Washington, and Alaska from 1950 – 2009 reported that recent decreases in abundance and productivity of Fraser River sockeye salmon occurred across a large geographic area ranging from Washington, BC, southeast Alaska, and up through the Yakutat peninsula, Alaska (66). The new research paper does not cite or update this analysis.
Did changes in Discovery Islands farm practices after 2009 increase the potential for farm-source *T. maritimum* to impact sockeye salmon?	No	Instead, changes in farm practices decreased the potential for farm-source *T. maritimum* to impact sockeye salmon. Around 2010, farmers stopped stocking Discovery Island farms with Atlantic salmon directly from hatcheries—instead stocking these farms with larger fish, which are resistant to yellow mouth. Fish Health Events due to yellow mouth reported by Discovery Islands farms decreased 90% from 2004 – 2007 (71 reports) to 2016 – 2019 (7 reports) (1).
Does the research paper demonstrate that the *T. maritimum* PCR+ test results in the Discovery Islands region are "farm-origin"?	No	Telemetry studies provide evidence that 27 – 50% of Fraser River sockeye migrate through Discovery Passage, where Atlantic salmon farms are absent (37, 67). Bateman et al. (2022) does not differentiate results from Discovery Islands' passages with and without salmon farms. Therefore, the proportion of the increase in PCR+ test results originating from salmon farms vs. the environment cannot be independently assessed.

Photo by Brian Kingzett

PISCINE ORTHOREOVIRUS (PRV)

What is it?

Briefly, PRV is a common virus of salmonids worldwide(68). PRV was initially identified from Atlantic salmon in Norway diagnosed with heart-skeletal muscle inflammation (HSMI), using advanced (next-generation) molecular sequencing methods (68-70). HSMI is an infectious disease (71). Since PRV was first identified, three different genotypes have been identified (PRV-1, 2, and 3), and PRV-1 has been identified in the Northeastern Pacific (including BC) (68, 70). The history and current body of knowledge regarding piscine orthoreovirus (PRV) in BC has been summarized in recent studies by the DFO's Aquatic Animal Health Laboratory at the Pacific Biological Station (68), as well as the U.S. Geological Survey (70).

Is this a new virus?

When PRV-1 was first reported in farm-raised Atlantic salmon in BC in 2013, it was assumed to be a virus that had been introduced to the region recently (72). Subsequently, PRV-1 has been identified among wild salmonids in the Northeastern Pacific ranging from Alaska through BC and Washington State (73) and in archived fish tissue samples since as early as the 1970's (34, 74-76).

Is it harmful?

One research group diagnosed HSMI in BC farm-raised salmon,(77) and they speculated that PRV was the cause, but they did not confirm that the lesions they diagnosed as HSMI were infectious. Speculations were raised that PRV could reduce fitness or cause disease such as jaundice syndrome among local Pacific salmon species (78, 79). However, these studies did not examine the actual effects of the virus on fish, only if it was detected. About 0.3% of BC farm-raised Atlantic salmon die each year with various types of unexplained heart disease, and many of these fish are positive for PRV (15, 80). Controlled laboratory infection challenges using a PRV-1 isolate from BC have demonstrated that the virus multiplies in new hosts and sometimes causes minor microscopic changes (lesions), but it does

not cause disease among Pacific salmon (70, 81, 82) or Atlantic salmon (15, 81-84).

What is the risk to wild Pacific salmon?

Photo by Brian Kingzett

In 2019, DFO conducted a risk assessment to determine the potential magnitude of impacts on the abundance and diversity of Fraser River sockeye salmon from PRV from farm-raised Atlantic salmon in the Discovery Islands area. The overall assessment concluded that PRV attributable to these Atlantic salmon farms posed a minimal risk to Fraser River sockeye salmon abundance and diversity.

In 2020, DFO convened a workshop of veterinarians from Canada, the United States, and Norway. The majority of workshop participants agreed there was not sufficient evidence to demonstrate population-level HSMI in BC, nor was there enough evidence to confirm a causal link between PRV and the development of jaundice in Chinook salmon (85).

Since this assessment was conducted, a few papers have been published that could be examined to determine if the risk has increased. As discussed for *T. maritimum* above, each of these papers could be examined to determine if their results are based on sound science and warrant an updated risk assessment. As of early 2024, this work has not been undertaken by DFO.

As discussed earlier in this chapter, the Pacific Northwest Fish Health Protection Committee (independent fish health professionals from the USA) also concluded that Piscine orthoreovirus (PRV) is low risk to Pacific salmon.

FUTURE GOALS

We visualize a future where First Nations and the general public are confident that farm-raised salmon and wild Pacific salmon can successfully coexist in BC. We believe that significant changes within the social-political and scientific landscape enable this.

Firstly, all salmon raised in farms are under the watch and guidance of First Nations who have been the stewards of their lands, water and wild salmon since time immemorial. Traditional knowledge, which has been learned over many generations, is now being shared with fish health teams, bringing powerful knowledge together.

Secondly, innovative advancements in artificial intelligence, machine learning, digital platforms, molecular science, continuous in-pen monitoring of environmental and fish conditions, trend analysis and communications are rapidly improving veterinary oversight of farms and ultimately veterinary medicine. Active engagement with universities, such as identifying better methods to minimize outbreaks of yellow mouth, will continue to have a large role in the future of salmon farming.

APPENDIX A. SUMMARY OF SALMON PATHOGENS SUBJECTED TO FORMAL RISK ASSESSMENT BY THE DFO CSAS PROCESS

From 2017 – 2020, DFO completed formal risk assessments on nine salmonid pathogens that occur or have occurred on farm salmon in British Columbia (25). The assessments focused on the effect of the pathogens among salmon farms in the Discovery Islands region on Fraser River sockeye salmon. The assessments were led by the Canadian Science Advisory Secretariat (CSAS). The CSAS concluded that the risk to Fraser River Sockeye salmon from each pathogen is minimal. Highlights of each assessment are included below.

This section also includes (i) information about how salmon farm veterinarians prevent specific diseases from occurring, and (ii) a summary of salmon farm reports to DFO of Fish Health Events (2016 – 2022) and Mortality Events (2011 – 2022).

Methods used by salmon farmers to minimize spread of all diseases include (i) strict biosecurity measures, (ii) daily mortality monitoring, and (iii) regular diagnostic investigation.

Definitions (48):

Fish Health Event – Any suspected or confirmed disease that occurs within an aquaculture facility, requires the involvement of a veterinarian, and warrants mitigation measures. Not included is routine management of the salmon louse (*Lepeophtheirus salmonis*). Fish Health Events have been reported to DFO as a condition of license since 2016. Each BC salmon farm, on average, reports about one Fish Health Event each year (from 2016 – 2022, 284 reports averages 41 per year).

Mortality Event – A Mortality Event must be reported to DFO within 24 hours of discovery if the number of dead fish at a farm exceeds the thresholds outlined in the conditions of the license. The threshold is specific to each facility and is determined by DFO based on variables that include the size of the farm, the species being farmed, and environmental conditions. Mortality Events have been reported to DFO since 2011. Each BC salmon farm, on average, reports about one Mortality Event each year (from 2011 – 2022, 579 reports averaged 48 per year).

AEROMONAS SALMONICIDA AND FURUNCULOSIS:

Characterization – *Aeromonas salmonicida* is a bacterium that causes furunculosis in salmon and trout species around the world. BC farm-raised Atlantic salmon are vaccinated for *A. salmonicida* before being transferred to the ocean. Cases develop among a small proportion of farm salmon as vaccine immunity fades when fish approach harvest size. For sockeye salmon, infections have been detected most commonly among adults that have returned to freshwater to spawn (86).

CSAS Assessment – The risk to Fraser River sockeye salmon from *A. salmonicida* is **minimal** (87).

- The key reason for this conclusion is that the amount of A. salmonicida released from an infected farm is estimated to be lower than what is required to cause infection or mortality in Fraser River sockeye salmon.
- The main uncertainties are:
    - the unknown number of fish with *A. salmonicida* infection on farms, and
    - the unknown consequences to sockeye salmon from an infection that does not cause mortality.

Occurrence – (18, 19)

- Among the 272 Atlantic salmon Fish Health Events reported to DFO from 2016 – 2022, 11 (4.0%) were due to *A. salmonicida* infection.
- Among 849 dead or dying BC farm-raised Pacific salmon sampled as part of the DFO Fish Health Audit Program from 2011 – June 2022, only 2 (0.2%) were positive for *A. salmonicida* infection (one each sampled in 2012 and 2015).
- Among the 579 farm salmon Mortality Events reported to DFO from 2011 – 2022, 4 (0.7%) were due to *A. salmonicida* infection.

Prevention – Some Atlantic salmon farmers vaccinate against *A. salmonicida* with an effective commercial vaccine.

INFECTIOUS HEMATOPOIETIC NECROSIS VIRUS (IHNV):

Characterization – IHNV is a virus native to the Pacific Northwest. IHNV infection can cause a disease called infectious hematopoietic necrosis (IHN). Atlantic salmon are highly susceptible, while Pacific salmon species in marine waters are resistant to disease. No cases of IHN have been confirmed among farm-raised Pacific salmon species in BC (88).

CSAS Assessment – The risk to Fraser River sockeye salmon from IHNV is **minimal** (89).

- Key reasons:
    - All farm-raised Atlantic salmon have been vaccinated against IHN since 2012,
    - no outbreaks have occurred among farm salmon since 2012, and
    - if infection does occur, the aquaculture companies will remove all infected fish
- The main uncertainty is the unknown impact to sockeye salmon from IHNV exposure in the marine environment.

Occurrence –(18, 19)

- Among the 272 Atlantic salmon Fish Health Events reported to DFO from 2016 – 2022, 0 (0%) were due to IHNV infection.
- Among the 579 farm salmon Mortality Events reported to DFO from 2011 – 2022, 2 (0.3%) were due to IHNV infection (both were in 2012).

Prevention – All Atlantic salmon farmers vaccinate against IHNV with an effective commercial vaccine.

MORITELLA VISCOSA:

Characterization – *Moritella viscosa* is a bacterium that causes a disease called winter ulcer in farm-raised Atlantic salmon(90). As the name suggests, it typically occurs in the winter, when water temperatures drop below 10° C. Winter ulcer is not known to occur among Pacific salmon species in British Columbia. Among affected Atlantic salmon, the ulcers are disfiguring, but associated mortality is usually low, and fish recover with warming temperatures in the spring.

CSAS Assessment – The risk to Fraser River Sockeye salmon from *M. viscosa* is **minimal** (91).

- The key reason is that winter ulcers on Discovery Islands farms do not occur when Fraser River sockeye salmon are in the area.
- Uncertainties: none are significant.

Occurrence –(18, 19)

- Among the 272 Atlantic salmon Fish Health Events reported to DFO from 2016 – 2022, 16 (5.9%) were due to ulcers, including *M. viscosa* infection.
- Among the 579 farm salmon Mortality Events reported to DFO from 2011 – 2022, 1 (0.2%) was due to ulcers, including *M. viscosa* infection.

Prevention – Some Atlantic salmon farmers vaccinate against *M. viscosa* with a new effective commercial vaccine.

PISCINE ORTHOREOVIRUS (PRV):

Characterization – Different forms of PRV occur around the world, but only PRV-1 has been reported in North America(92). Nearly all sea-farm-raised salmon eventually become infected with PRV before harvest, and PRV-1 has been detected in archived specimens dating back to at least the mid 1980's in British Columbia. Among BC farm salmon infected with PRV-1, Heart and Skeletal Muscle Inflammation (HSMI) has been diagnosed in Atlantic salmon, and some Chinook salmon develop jaundice; controlled laboratory studies confirm that the PRV from these fish is infectious, but the infected fish do not develop HSMI or jaundice. The prevalence of PRV in sockeye salmon in Western North America over the past decade is approximately 1.5%. Experimental infection of sockeye salmon with BC PRV-1 leads to abundant virus replication in the blood and minor transient impairment of blood function, but no significant disease.

CSAS Assessment – The risk to Fraser River sockeye salmon from PRV is **minimal**. (93)

- The key reason is scientific evidence that PRV-1 infection does not cause disease, mortality, or physiologically relevant swimming impairment in sockeye salmon.
- An uncertainty is how to apply laboratory study results to interactions that occur in the marine environment.

Occurrence –(18, 19)

- Among the 272 Atlantic salmon Fish Health Events reported to DFO from 2016 – 2022, none (0%) were due to PRV infection.
- Among the 579 farm salmon Mortality Events reported to DFO from 2011 – 2022, 0 (0%) were due to PRV infection.

Prevention – Juvenile Atlantic salmon and Pacific salmon in freshwater hatcheries are screened for PRV, and only PRV-negative populations are transferred into seawater.

PISCIRICKETTSIA SALMONIS AND SALMONID RICKETTSIAL SEPTICAEMIA (SRS):

Characterization – *Piscirickettsia salmonis* is a bacterium that can cause a disease called salmonid rickettsial septicaemia (SRS) in marine fish species (94). The bacterium infects many organs, with the liver often the most severely affected; a significant proportion of infections are limited to the brain. Among farm-raised salmon, SRS is a problem during peak water temperatures that occur most commonly on the west side of Vancouver Island in the late summer and early fall (i.e., not during migrations of juvenile sockeye salmon). SRS has not been reported in sockeye salmon, but Chinook salmon are susceptible.

CSAS Assessment – The risk to Fraser River sockeye salmon from *P. salmonis* is **minimal**. (95)

- The key reason is that P. salmonis on a farm is very unlikely to infect Fraser River sockeye salmon.
- Uncertainties:
    - how much bacteria are shed by fish infected with *P. salmonis,*
    - how long the bacteria can survive in the marine environment, and
    - the minimum dose required to cause infection and disease in sockeye salmon.

Occurrence –(18, 19)

- Among the 272 Atlantic salmon Fish Health Events reported to DFO from 2016 – 2022, 42 (15%) were due to *P. salmonis* infection.
- Among the 579 farm salmon Mortality Events reported to DFO from 2011 – 2022, 7 (1.2%) were due to *P. salmonis* infection.

Prevention – use methods common for all diseases

RENIBACTERIUM SALMONINARUM AND BACTERIAL KIDNEY DISEASE (BKD):

Characterization – *Renibacterium salmoninarum* is a bacterium that can cause bacterial kidney disease (BKD) in salmon. (96) Despite its name, the bacterium infects many organs, and a significant proportion of infections are limited to the brain. BKD is a global disease and occurs in both freshwater and marine environments. Under controlled laboratory conditions, sockeye salmon and Chinook salmon are more susceptible to infection and disease than Atlantic salmon. Among farm salmon, BKD is most common in the spring.

CSAS Assessment – The risk to Fraser River sockeye salmon from *R. salmoninarum* is **minimal** (97).

- The key reason is that the concentration of R. salmoninarum estimated on a farm is much lower than the one required to cause infection or death in Chinook salmon, which are more vulnerable to *R. salmoninarum* infection than sockeye salmon.
- The key uncertainty is the unknown minimum dose of *R. salmoninarum* needed to infect and cause disease in sockeye salmon in the marine environment.

Occurrence –(18, 19)

- Among the 272 Atlantic salmon Fish Health Events reported to DFO from 2016 – 2022, 10 (3.7%) were due to *R. salmoninarum* infection.
- Among the 12 Chinook salmon Fish Health Events reported to DFO from 2016 – 2022, all (100%) were due to *R. salmoninarum* infection. All of these were associated with broodstock that were not experiencing an outbreak but were treated to control background levels of infection before the fish were spawned.
- Among the 579 farm salmon Mortality Events reported to DFO from 2011 – 2022, 0 (0%) were due to *R. salmoninarum* infection.

Prevention –

- Some Atlantic salmon farmers and all Pacific salmon farmers vaccinate against BKD with an effective commercial vaccine
- Comprehensive broodstock monitoring for *R. salmoninarum* minimizes spread from the parent fish to eggs.

TENACIBACULUM MARITIMUM:

Characterization – *Tenacibaculum maritimum i*s a marine bacterium that occurs worldwide in the environment and in several species of marine fish (1). *T. maritimum* does not occur in fresh water. It is an opportunistic bacterium, meaning that it occurs on healthy fish but can cause disease in fish that are stressed. In BC, the bacterium causes the disease yellow mouth (also called mouthrot), primarily in Atlantic salmon within a few months of transfer from fresh water to seawater.

CSAS Assessment – The risk to Fraser River sockeye salmon from *T. maritimum* is **minimal**. (60)

- Key reasons
  - Pacific salmon are less susceptible than Atlantic salmon to disease, and
  - Fraser River Sockeye salmon have a short and limited interaction with the farms in the area.
- The key uncertainty is whether sockeye salmon can get infected with *T. maritimum* and develop mouthrot.

Occurrence –

- Among the 272 Atlantic salmon Fish Health Events reported to DFO from 2016 – 2022, 166 (61%) were due to *T. maritimum* infection.
- Among the 579 farm salmon Mortality Events reported to DFO from 2011 – 2022, 7 (1.2%) were due to *T. maritimum* infection.
- From 2002 – 2018, government veterinarians diagnosed farm-level yellow mouth in 106 of 1446 (7.3%) Atlantic salmon audits but 0 of 273 (0%) Pacific salmon audits (1).[5]

Prevention – (18, 19)

- Because *T. maritimum* is common in the marine environment, and younger fish are generally more susceptible to infection and disease, a key to prevention is minimizing stress when fish are transferred from freshwater hatcheries to seawater. To do this, fish are tested in hatcheries to ensure that their body is ready to transfer to seawater.
- When outbreaks occur, antimicrobial treatments minimize disease and transmission to other fish.

[5] The number of Pacific salmon audits was provided by Howie Manchester, DFO, personal communication)

VIRAL HEMORRHAGIC SEPTICEMIA VIRUS (VHSV):

Characterization – Viral hemorrhagic septicemia virus (VHSV) is the causative agent of viral hemorrhagic septicemia (VHS), which can occur in a wide range of cultured and wild fish species in both marine and freshwater environments(98). Different forms of VHSV occur around the world, but only Genotype IVa has been reported in BC and the surrounding northeastern Pacific Ocean. VHSV-IVa causes recurring mortality events in Pacific herring and Pacific sardine. A risk factor for farm salmon developing VHS is proximity to abundant herring. Sockeye salmon are not susceptible to VHSV-IVa under controlled laboratory conditions.

CSAS Assessment – The risk to Fraser River sockeye salmon from VHSV-IVa is **minimal**. (99)

- The key reason for this conclusion is that sockeye salmon are not susceptible to VHSV.
- Uncertainties: none are significant.

Occurrence – (18, 19)

- Among the 272 Atlantic salmon Fish Health Events reported to DFO from 2016 – 2022, 2 (0.7%) were due to VHSV-IVa infection.
- Among the 579 farm salmon Mortality Events reported to DFO from 2011 – 2022, 1 (0.2%) was due to VHSV-IVa infection.

Prevention – use methods common for all diseases

YERSINIA RUCKERI AND ENTERIC REDMOUTH DISEASE (ERM):

Characterization – *Yersinia ruckeri* is a bacterium that causes enteric redmouth disease (ERM) (100). It is primarily a freshwater pathogen and rarely causes disease in healthy and unstressed fish in the marine environment. Controlled laboratory studies are limited, but the consensus is that sockeye salmon are less susceptible than Atlantic salmon to infection and disease.

CSAS Assessment – The risk to Fraser River sockeye salmon from *Y. ruckeri* is **minimal** (101).

- The key reason is that *Y. ruckeri* infection on farms in the Discovery Islands area is extremely rare, and there is no evidence of spread within farm-raised Atlantic salmon.
- The main uncertainty is the unknown susceptibility of sockeye salmon. ERM has not been reported in sockeye salmon.

Occurrence –(18, 19)

- Among the 272 Atlantic salmon Fish Health Events reported to DFO from 2016 – 2022, 4 (1.5%) were due to *Y. ruckeri* infection.
- Among the 579 farm salmon Mortality Events reported to DFO from 2011 – 2022, 0 (0%) were due to *Y. ruckeri* infection.
- Among 849 dead or dying BC farm-raised Pacific salmon sampled as part of the DFO Fish Health Audit Program from 2011 – June 2022, none (0.0%) were positive for *Y. ruckeri* infection (11).

Prevention – Some Atlantic salmon farmers vaccinate against *Y. ruckeri* with an effective commercial vaccine.

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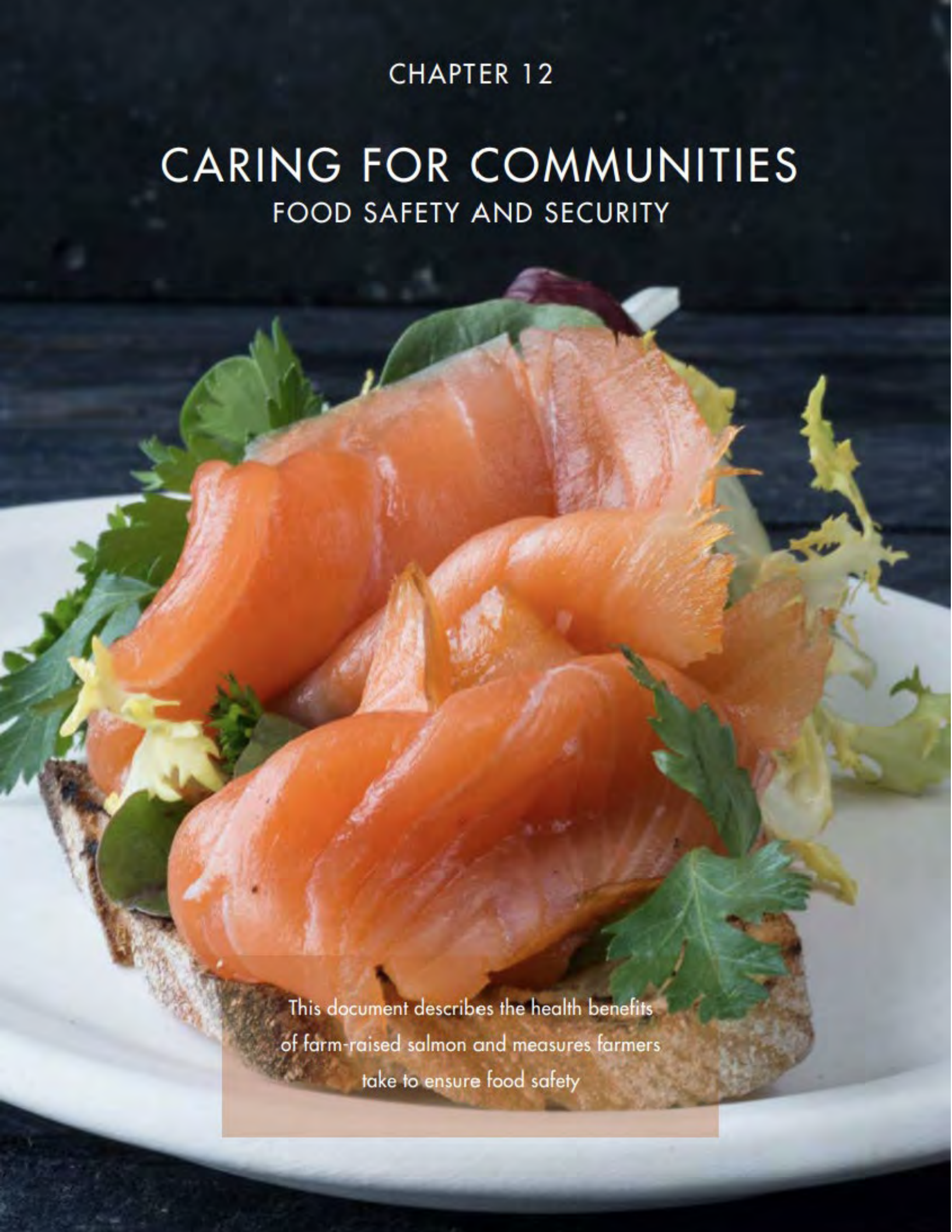
CHAPTER 12

CARING FOR COMMUNITIES

FOOD SAFETY AND SECURITY



This document describes the health benefits of farm-raised salmon and measures farmers take to ensure food safety

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Citation: BC Salmon Farmers Association. 2024. Caring for Communities Food Safety *in* Modern Salmon Farming in BC: A Review. BC Salmon Farmers Association, Campbell River, British Columbia. 12 pages. available at www.bcsalmonfarmers.ca

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CHAPTER HIGHLIGHTS – CARING FOR COMMUNITIES – FOOD SAFETY

Healthy – supports heart and eye health

Nutritious – high protein, rich in essential omega-3 fatty acids, vitamins and minerals

American Heart Association – recommends eating fish rich in omega-3 fatty acids twice a week

Safe – rigorously tested by the Canadian Food Inspection Agency

By Canadians – provides 38 million meals per year

No growth hormones

Locally grown

All chemical residues - well below food safety limits

Processed in licensed facilities

Did you know that three-quarters of the salmon harvested in British Columbia are raised on farms yearly? BC salmon farmers proudly grow healthy, high-quality food for Canadian families like terrestrial farmers. BC produces approximately 56,000 tonnes of farm-raised salmon annually, or about 38 million healthy, nutritious meals.

Farm-raised salmon is a healthy food, recommended by experts, as it is rich in essential fatty acids and low in mercury. Studies have demonstrated the many health benefits of omega-3 fatty acids found in farm-raised salmon, including reducing the risks of heart disease and supporting eye health.

To ensure that BC farm-raised salmon is safe to eat, there are safeguards in place. For example, fish can only be processed in licenced processing facilities. Farm-raised salmon are regularly tested for residues, including antibiotics and pesticides, heavy metals, and PCBs, by the sector and the Canadian Food Inspection Agency to ensure fish are safe for Canadians to eat.

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