DISEASE RISKS ASSOCIATED WITH OPEN-NET SALMON AQUACULTURE IN B.C.

"Given the perilous state of Pacific salmon migrating past these fish farms filled with Atlantic salmon — that amplify harmful pathogens and sea lice — we believe strongly that moving the farms out of the water is urgent and essential in order to rebuild Pacific salmon stocks in British Columbia."

— Michael Meneer, President and CEO

Launched in 2013 with DFO and Genome B.C., the Strategic Salmon Health Initiative (SSHI) positioned PSF as a global leader in salmon health research. The ground-breaking SSHI research, led by DFO research scientist Dr. Kristi Miller-Saunders, brought new understanding of how infectious agents affect the health of wild Pacific salmon, and the findings informed the Government of Canada's commitment to transition away from open-net aquaculture in B.C. by 2025. The PSF Salmon Health Program builds on the SSHI with the same scientific team continuing to study disease and other stressors affecting B.C.'s wild salmon. The following report outlines disease risks associated with open-net salmon aquaculture in B.C. as identified through nearly a decade of independent scientific research.

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INTRODUCTION

Salmon farms present many risks to wild salmon in B.C. This summary focuses solely on the possible impacts to wild Pacific salmon in relation to pathogens, including sea lice; however, this is not an exhaustive review of the potential risks. (For a more comprehensive review of salmon farming, refer to the most recent Seafood Watch assessment[1].)

Most of the evidence we summarize below relates to open-net salmon farming in B.C., but we note that this information fits within a global context of wild-salmon declines widely associated with open-net salmon aquaculture[2]. Our research into disease covers a variety of pathogens and infectious agents. Many of these are newly discovered, or understudied in the context of wild Pacific salmon. This review focuses only on three pathogens for which we have the most information: sea lice, *Tenacibaculum maritimum*, and Piscine orthoreovirus (PRV).

In general, the large numbers of densely packed fish on salmon farms present ideal conditions for amplification of viruses, bacteria and parasites[3–5] (collectively "infectious agents"), offering a source of transmission to wild Pacific salmon that wouldn't otherwise exist naturally. Also, because farms can amplify, or "breed," infectious agents[3,4], associated farm risks are likely to be elevated *whether or not* any given agent (such as sea lice) was present prior to the introduction of open-net salmon farms in B.C. or was introduced via the farms themselves (such as PRV). Regardless, farms can raise the levels to which wild salmon are exposed.

SEA LICE

An established body of evidence links salmon lice, *Lepeophtheirus salmonis*, with impacts on salmon globally[6,7]. In B.C., most evidence of the impacts of sea lice comes from the Broughton Archipelago, where sea lice on salmon farms have been associated with reduced survival in pink and coho salmon[8–10]. In contrast, chum salmon in the Broughton do not appear to have declined as a result of sea lice from farms[11].

Sea lice also impact wild salmon physiology and behaviour. Ecological studies indicate that juvenile salmon infested with more sea lice experience increased predation[12] and have reduced competitive ability[13], feeding success[14], growth[15] and swimming endurance[16]. Controlled lab trials provide causal evidence that is perhaps even more compelling: sockeye salmon infected with salmon lice experience mortality, skin erosion, scale loss, and higher levels of stress[17]. Cumulatively, these effects of sea lice constitute a "profound physiological impact" on sockeye salmon relative to that seen in Atlantic salmon[18].

While some wild salmon populations began to recover after farm management practices improved, success appears to depend on the ability of salmon farms to manage infestations of sea lice[10]. Outbreaks of sea lice on B.C. salmon farms are, however, expected to become more frequent and severe as the ocean warms[19], as are the impacts of sea lice on their hosts[20]. Inaccurate reporting of sea-louse counts on farms may further exacerbate the challenges of sea louse management[19,21]. The recent revelation that sea lice in B.C. have developed resistance to the main chemical used to control outbreaks (emamectin benzoate, also known as EMB or SLICE®)[22,23] indicates that sea lice will be even more difficult to manage in B.C. moving forward. Indeed, severe sea-louse outbreaks on the central coast, in Clayoquot Sound, and in the Discovery Islands call the ability to manage lice—and therefore protect wild salmon—into question.

To combat drug-resistant sea lice, the industry relies heavily on physical removal of lice, using a so-called "hydrolicer," which employs pressurised water. This Norwegian technology is touted as an ecologically sustainable solution by industry, but it is less effective than preresistance EMB [24,25]. The approach can be highly stressful on the fish, removing mucous and scales required to fend off infection and making them more vulnerable to disease [25,26].

Figure 1 Sea-louse infestation negatively affects the physiology, growth, behaviour, and survival of Pacific salmon (Image credit: Tavish Campbell)

TENACIBACULUM MARITIMUM

The globally distributed marine bacterium *Tenacibaculum maritimum* has recently come to the fore as posing a substantial risk of harm to sockeye, Chinook, and coho salmon. The bacterium is widespread on Atlantic salmon farms in B.C., where it can cause acute oral ulcers (known as "mouth rot" disease; Figure 2) and death within days of ocean entry[27,28]. Although mouth rot is treatable with antibiotics, *T. maritimum* is detectable via genetic screening in farmed fish throughout their time on farms, displaying elevated levels in dead and dying fish for much of that time[29]. Further, in seawater screening, *T. maritimum* environmental-DNA has been almost exclusively detected near active versus inactive salmon-farm sites, showing one of the strongest associations with active salmon farming of 39 salmon pathogens studied[30]. Thus, although *T. maritimum* is globally common, it very much appears to be amplified by salmon farms.

Note of clarification: there is almost *no* risk of mouth rot disease in Pacific salmon, as that disease seems to be all but unique to Atlantic salmon; instead, the general disease caused by *T. maritimum* in Pacific salmon is "tenacibaculosis" Tenacibaculosis can cause severe mortalities, and is known to have caused substantial health issues for Pacific salmonids in California[31], Chile[32,33], and Alaska[34]. While infections on-farm can sometimes be managed with antibiotics, wild salmon do not have access to such veterinary care.

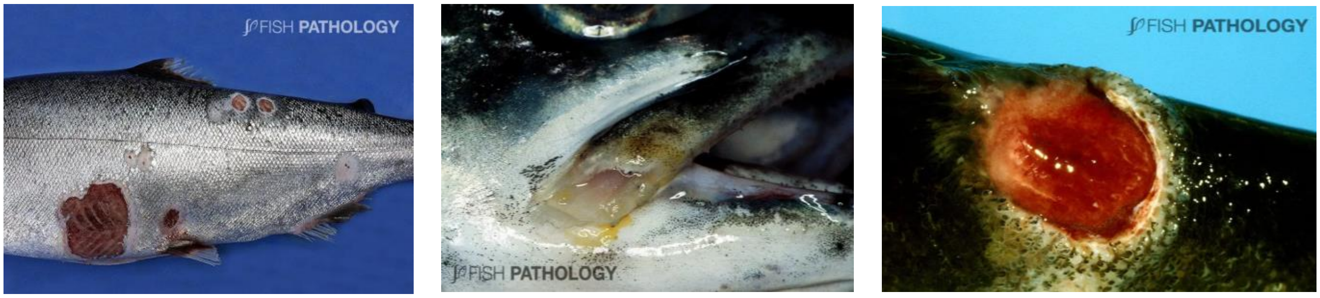

Figure 2 Disease lesions associated with Tenacibaculum infection in Chinook salmon (left) and Atlantic salmon (middle and right). Mouth rot (middle) is a specific form of tenacibaculosis - disease caused by Tenacibaculum - that has exclusively been identified in B.C., almost exclusively in farmed Atlantic salmon. (Image credit: fishhistopathology.com)

While a 2020 CSAS review of *T. maritimum* concluded that transmission from farms posed a "minimal risk" to Fraser River sockeye in the Discovery Islands region[28], several key shortcomings undermine that result. First, technical flaws in details of the risk assessment resulted in unduly reducing the assessed risk (PSF's Andrew Bateman was a participant in the relevant CSAS review meeting). Second, the risk assessment was *very* narrowly focused on only sockeye salmon, from only the Fraser River, considering only impacts from Discovery Islands salmon farms; the overall focus should be on the risk from all B.C. salmon farms to all B.C. wild salmon. Third, new relevant evidence [35,36], unavailable at the time of the CSAS risk assessment, came out of the joint PSF/DFO Strategic Salmon Health Initiative (SSHI).

Our research found that *T. maritimum* detection rates in juvenile Fraser River sockeye peaked as the fish migrated past the Discovery Islands[36]. Spatial/epidemiological models, fit to *T. maritimum* incidence data, suggest salmon farms in the Discovery Islands are the strongest source of *T. maritimum* infection along the Fraser River sockeye migration route [37]. Further, population-level sampling of wild salmon in their first year of marine residence, shows that *T. maritimum* infection is associated with decreased marine survival for Chinook and reduced body condition ("skinny" fish) in Chinook and coho[35]; this is one of the most consistent patterns across infective agents we studied[35]. Together, this evidence suggests that salmon farms elevate levels of *T. maritimum* in the marine environment, Fraser River sockeye become infected with *T. maritimum* as they pass salmon farms in the Discovery Islands, and Chinook and coho may suffer population-level impacts due to *T. maritimum* infection[35].

PISCINE ORTHOREOVIRUS (PRV)

PRV is a virus originating from the Atlantic Ocean, and in Europe it commonly causes disease issues on farms[38]. The virus was introduced to B.C. with the advent of Atlantic salmon farming in the region (Figure 3) [39]. It is now extremely common in Atlantic salmon on farms in B.C. Controlled laboratory challenge trials conducted in Norway have established that the lineage of PRV in B.C. can cause lesions diagnostic of the disease Heart and Skeletal Muscle Inflammation (HSMI)[40], and farmed Atlantic salmon in B.C. infected with PRV can develop HSMI[41,42].

Regardless of PRV's effects on farmed Atlantic salmon in B.C., it is PRV's potential impact on B.C.'s Pacific salmon species that is of primary concern. PRV is amplified by salmon farms, and spills over to wild Pacific salmon[39]. PRV has been associated with (and in some cases shown to cause) a disease in Pacific salmon species which is distinct to the disease it causes in Atlantic salmon. In Pacific salmon, PRV infection can result in rupture of the blood cells, which can lead to organ damage[43–47]. The lineage of PRV in B.C. has been tightly associated with the disease "jaundice/anemia" on Chinook salmon farms in B.C.[43], and similar pathology has been observed in wild Chinook salmon[48]. PRV infects nearly all farmed Atlantic salmon in B.C. by the time they are ready for harvest[29,49], and recent findings from our research group indicate that resident wild Chinook salmon are more likely to be infected with PRV the closer they are to a salmon farm[39]. The same work also shows, via genetic methods, that PRV regularly transmits between farmed and wild salmon and that the number of PRV infections have increased in recent decades. Together, this evidence paints a picture of a growing risk posed by PRV to Chinook. Further, as with *T. maritimum*, correlational analyses tie PRV to poorer survival in Chinook and coho stocks[35].

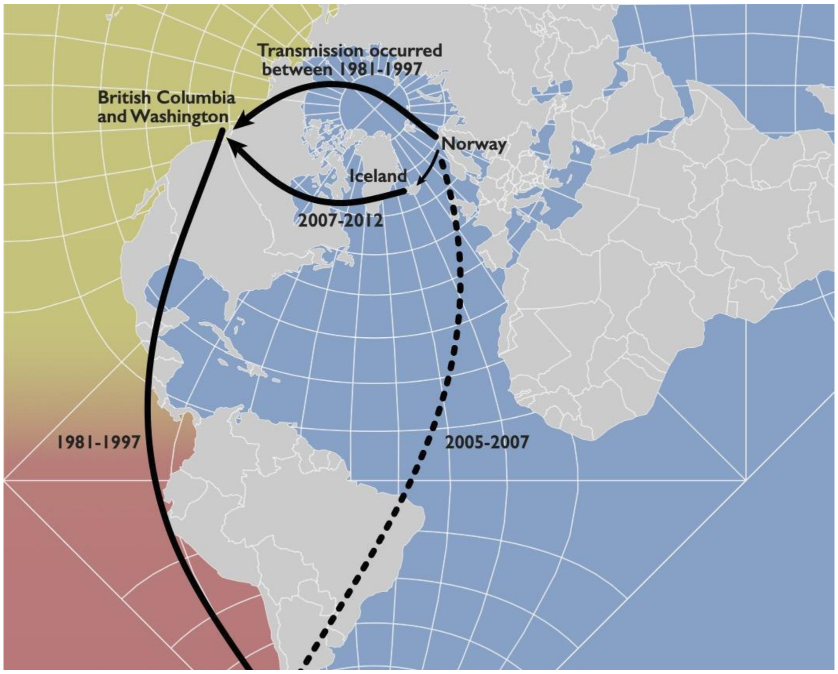

Figure 3 Schematic representation of the global emergence of PRV-1. Arrows depict estimated translocations of PRV lineages. Movements were determined by a phylogeographic analyses of PRV genome sequences[39]

The salmon farming industry relies on movements of live salmon from freshwater hatcheries to marine net pens, and in many cases, between marine sites during the marine "grow-out" period. While regulations prohibit inter-regional transfers of fish experiencing high levels of mortality or infectious disease outbreaks, this alone will not prevent the potential spread of pathogens that salmon can harbour, since even asymptomatic individuals can carry and spread pathogens. Pathogens are known to evolve increased virulence within aquaculture settings [50,51]. If higher virulence pathogens were to evolve or be introduced, movements between farms could quickly spread the new strains across the southern B.C. coast, enhancing risk to both farm and wild populations.

NOTE ON SEMI-CLOSED CONTAINMENT AQUACULTURE SYSTEMS

In response to challenges related to sea lice, the salmon farming industry in Norway has developed "semi-closed containment systems" (SCCSs) [52]. The concept is that cultured fish are separated from the natural environment by a physical barrier, and water is drawn into the system from depth, aiming to avoid sea lice and harmful algal blooms, which are more common in shallower water. Such systems have been shown in certain cases to provide protection against sea louse outbreaks within pens[53]. Similar systems have been suggested as possible tools for transitioning away from open-net farms.

Since large volumes of water are pumped into and out of the system, SCCSs do not provide direct protection from transmission of infectious agents (particularly viruses and bacteria) between farmed and wild fish[52,54]. A SCCS trial by Cermaq in Clayoquot Sound suffered die-offs, which resulted in the trial being ended early[55]. Although the industry reported that there were no overt signs of disease, evidence of the cause of mortality has not been made public[55]. The difficulties of maintaining oxygen, CO_2, turbidity, temperature, and pH within the physical barrier of a SCCS are also expected to increase disease risk[54]. Due to the lack of available data on this issue, it is precautionary to assume - until future studies prove differently - that SCCSs are similar to open-net farms in terms of pathogen transfer potential.

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