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COMMUNICATION

Fish Processing Facilities: New Challenge to Marine Biosecurity in Canada

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Abstract

The transmission of pathogens is a common consequence of animal food production. Marine salmon farms and their processing facilities can serve as sources of virulent fish pathogens; our study is the first to confirm the broadcast of a live fish pathogen from a farmed salmon processing facility into the marine waters of Canada's Pacific coast. We found live salmon lice *Lepeophtheirus salmonis*, mucus, and fish tissue in effluent from the processing facility. Sea lice transmitted from this source may pose a threat to wild salmon populations, and the release of untreated offal, including blood water, is of considerable concern. Further research is needed to quantify the extent to which processing facilities release sea lice and to determine whether more virulent fish pathogens are present in effluent. These data underscore the need for fish farming nations to develop mandatory biosecurity programs to ensure that farmed salmon processing facilities will prevent the broadcast of infectious fish pathogens into wild fish habitat.

Humans often play the role of catalyst in the spread of pathogens in the environment, such as when infected domestic animals are brought into contact with wildlife (Daszak et al. 2000). Several examples include the transmission of *Pasteurella* from domestic to wild sheep (Jessup et al. 1991), *Crithidia bombi* from commercial to wild bumblebees (Otterstatter and Thomson 2008), *Myxobolus cerebralis* (the agent of whirling disease) among trout populations (Hoffman 1970), and the ectoparasite *Gyrodactylus salaris* among Atlantic Salmon *Salmo salar* (Johnsen and Jensen 1991). Consequently, disease management has become an intrinsic part of animal food production (Bicknell et al. 1999).

Fish farming is the fastest growing agriculture sector globally (FAO 2009). Pathogen-mediated effects on marine life as a result of mariculture's global proliferation are not well understood, although increased rates of transmission and emergence of pathogens are well documented (Nowak 2007). The intensive growing conditions in open net-pen marine salmon farms, for example, are known to facilitate the introduction, amplification, and subsequent broadcast of pathogens to the surrounding environment (Murray and Peeler 2005; Murray 2009; Pulkkinen et al. 2010); thus, mariculture facilities such as salmon farms can serve as point sources for large pathogen contributions (Marty et al. 2010; Price et al. 2010; Krkošek et al. 2011). Although the number of fish diseases that are common to salmon farms is extensive (e.g., St-Hilaire et al. 2002; Sterud et al. 2003; Austin and Austin 2007), evidence of their transmission to wild populations is limited (but see Jørgensen et al. 1989; Johnsen and Jensen 1994), possibly because diseased wild organisms

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are difficult to detect if they are not tracked (Gozlan et al. 2006).

Disease transmission between fish occurs through contact with tissue, blood, or mucus from infected fish (Totland et al. 1996; Mikkelsen et al. 2009) and can disseminate over long distances via farm-to-farm infections (McClure et al. 2005; Saksida 2006) and parasites (Nylund et al. 1994). Diseases of farm-origin fish may be further broadcast through the release of untreated effluent from slaughterhouses that process the infected farmed salmon (Vågsholm et al. 1994; Jarp and Karlsen 1997), and these processing facilities may be far removed from the source farms. We were interested in examining the potential for a farmed salmon processing facility on Canada's west coast to act in an analogous fashion in transmitting infectious pathogens to wild Pacific salmon *Oncorhynchus* spp. One easily detectable pathogen is the salmon louse *Lepeophtheirus salmonis*, an ectoparasitic copepod that is commonly associated with salmon farms in western Canada (Marty et al. 2010) and that is found in depressed wild salmon populations exposed to salmon farms (Krkošek et al. 2007, 2011; Connors et al. 2010; Krkošek and Hilborn 2011). Our objective, therefore, was to evaluate whether sea lice such as *L. salmonis* can survive travel from salmon farms to processing facilities, mechanical disturbance during processing, and final treatment of effluent before release.

METHODS

We collected effluent samples from the Walcan Seafood fish processing facility situated off the east coast of Vancouver Island, British Columbia (Figure 1). During our sampling, Walcan Seafood was processing Atlantic Salmon that had been reared in net-pens on the west coast of Vancouver Island (~450 km via the most direct ocean route); to our knowledge, this facility processes only fish from British Columbia. Intensive net-pen salmon farming is sympatric with the processing facility, with 18–20 farms active in any one year (Korman 2011; our Figure 1). Our study region naturally supports numerous wild salmon populations, including Canada's largest annual migration of wild juvenile salmon (predominantly from the Fraser River; Groot and Cooke 1987). Infestations of salmon farms and adjacent wild salmon populations by *L. salmonis* and the sea louse *Caligus clemensi* have repeatedly occurred in the area (Morton et al. 2008; Price et al. 2010, 2011). Tidal currents in this region (i.e., Discovery Passage) can transport particles more than 8 km in either direction during a single tide cycle (Thomson 1981), and the Walcan Seafood processing facility has been considered a potential source of *L. salmonis* that infect migrating juvenile Sockeye Salmon *O. nerka* (Price et al. 2011). Endemic diseases that could be amplified and/or spread by the facility include infectious hematopoietic necrosis virus, furunculosis, bacterial kidney disease, and vibrio disease (Korman 2011); as may the newly discovered nonnative piscine reovirus (Kibenge et al. 2013), and the unidentified virus-like

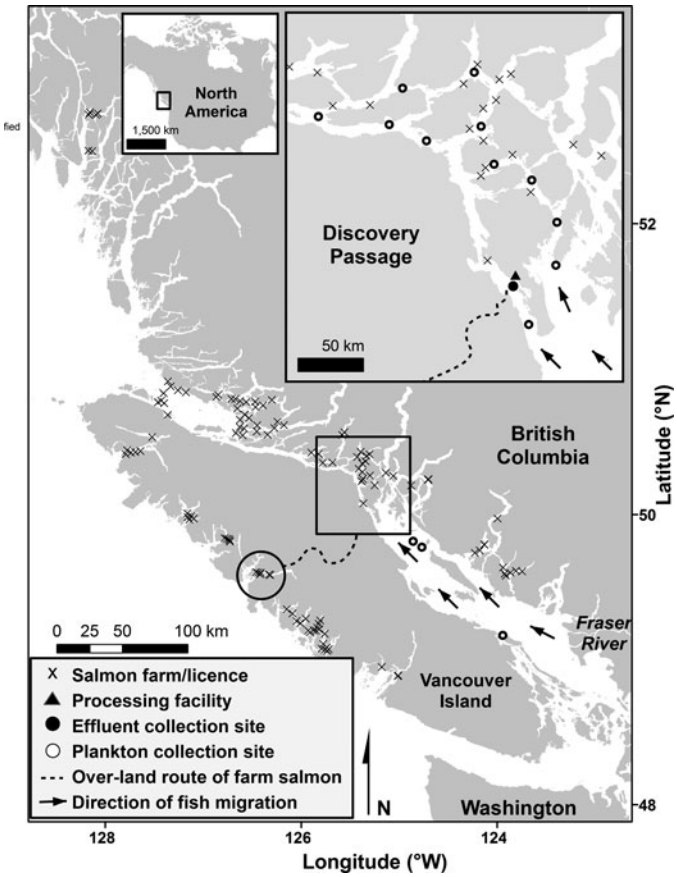

FIGURE 1. Collection site of effluent samples that were retrieved from a farmed salmon processing facility; and reference sites where plankton samples were collected on Canada's Pacific coast.

agent that has repeatedly caused prespawn mortality in Fraser River Sockeye Salmon (Miller et al. 2011).

We collected two effluent samples from an outflow pipe (20-cm diameter; Figure 2) located 27 m below the surface by using a plankton net (50-cm diameter; 125-μm mesh) during two daylight-hour dives conducted at slack tide on February 3 and

FIGURE 2. Still photograph from video of effluent discharged from the outflow pipe of a farmed salmon processing facility on Canada's Pacific coast.

8, 2010. We folded the plankton net over the net's entrance to prevent water from entering during the descent to the pipe. Upon arrival at the pipe, we held the plankton net over the mouth of the pipe for 5 min. However, the net filled within seconds, and more effluent billowed out than filtered through the net during our collection period due to the fluid's high viscosity and discharge volume. We were unable to quantify the rate of effluent discharge from the pipe. After 5 min, the opening of the plankton net was refolded and carried to the surface. Each effluent sample was transferred to a 1-L glass bottle, packed on ice, and transported to the laboratory for processing. Samples were filtered (200-μm mesh) in the laboratory, and residue was sorted and identified by using a dissecting microscope (10–30 ×) within 36 h of collection. Three fish scales recovered from the effluent were haphazardly selected and sent to the Sclerochronology Laboratory (Fisheries and Oceans Canada) for species identification.

We also collected 20 plankton samples during May and June 2010 (using the same plankton net towed vertically from a depth of 20 m) at 14 locations throughout the region, including Discovery Passage but south of the Walcan Seafood facility; we considered these locations to be reference sites. Plankton samples from each location were placed in 1-L bottles of a 10% formalin–seawater solution. In the laboratory, each sample was decanted into a sieve stack (mesh sizes = 1 mm, 500 μm, and 150 μm) and was rinsed with water to remove formalin. The filtrate was rinsed with ethanol and concentrated in a centrifuge. Subsamples of the concentrated plankton were examined with a counting slide under a compound microscope to determine the contents.

TABLE 1. Contents from two effluent samples retrieved during 5-min collections from the outflow pipe of a farmed salmon processing facility (February 3 and 8, 2010) and from plankton samples collected at 14 reference sites on Canada's Pacific coast (May and June 2010).

Contents	Effluent collection 1	Effluent collection 2	Plankton samples
Mucus, blood flakes, or tissue shards	Present	Present	Absent
Fish scales	436	401	
Salmon louse *Lepeophtheirus salmonis* eggs or nauplii	129	102	
L. salmonis adult males	4	2	
L. salmonis gravid females	7		
Sea louse *Caligus clemensi* adults			1
L. salmonis egg strings with eggs	3	4	
Empty *L. salmonis* egg strings	2	3	

RESULTS

Mucus was volumetrically predominant in both effluent samples. Fish scales, fish fragments, and blood flakes (fragments of congealed blood) were the most commonly identified discrete items (Table 1); fish scales ranged from 5 to 8 mm in diameter and were positively identified as belonging to adult Atlantic Salmon. We also identified more than 100 *L. salmonis* eggs and living nauplii from each 5-min sample as well as several live male *L. salmonis* and gravid female *L. salmonis* with attached egg strings. Behavioral cues during microscope observation confirmed that the parasites were alive: eggs hatched into nauplii, and both the males and gravid females showed mobility. Plankton samples from reference sites were dominated by zooplankton, and only one adult *C. clemensi* was identified; we did not observe any fish fragments, egg strings with eggs, or empty egg strings in the reference samples.

DISCUSSION

Processors of farmed salmon constitute an unacknowledged point source of a potentially harmful pathogen on Canada's Pacific coast. Although salmon farms routinely experience sea louse epizootics (Marty et al. 2010; Krkošek et al. 2011), processing facilities of farmed salmon have not previously been identified as a source of sea lice. We recovered hundreds of live *L. salmonis* (eggs, larvae, and adults) directly from the effluent of a facility processing fish that had been transported across numerous natural boundaries, resulting in a net addition of sea lice to a region that naturally hosts numerous wild salmon populations. *Lepeophtheirus salmonis* is not commonly found in the plankton of this region, as shown in our plankton surveys at reference sites despite several collections having occurred within 1 km of active salmon farms that are known to produce sea lice (Korman 2011). Accurate quantification of the magnitude of pathogen release from the processing facility is difficult given the inherent variation in the numbers of fish that are processed at any given time. However, considering that effluent from processing facilities has been identified as a source of fish pathogens that are more virulent than sea lice (Vågsholm et al. 1994; Jarp and Karlsen 1997), future research aimed at identifying known salmon pathogens and quantifying the associated magnitude of release is warranted.

Because fish processors and salmon farms are often separated by large distances, three underappreciated disease processes might occur. First, pathogens may be transferred to new regions. Fish scales that were retrieved from effluent discharged by the Walcan Seafood facility were positively identified as Atlantic Salmon scales and thus were of farm origin. Walcan Seafood only processes fish from open-net salmon farms on the west coast of Vancouver Island (Dill 2011); therefore, the sea lice we recovered undoubtedly originated from infected Atlantic Salmon that were farmed in a distant region (see Figure 1).

Second, a consequence of salmon farming is that sea lice exhibit reduced sensitivity to chemotherapeutants (Burridge et al. 2010), and this may result in resistant strains of sea lice. Resistance dynamics that are typically constrained within a population may spill over to new populations when pathogens and parasites are transferred between geographical regions. Because Atlantic Salmon that were processed at the Walcan Seafood facility originated from farms located on the opposite side of Vancouver Island, the sea lice we observed in the processing effluent must have survived overland transport across natural and management boundaries, which could promote accelerated resistance of sea lice to commonly used therapeutants. Finally, vulnerable populations will likely face unpredictable interaction effects from the introduced pathogens. The processing facility we investigated is situated along a primary corridor utilized by Canada's largest annual migration of wild juvenile salmon. Wild Fraser River Sockeye Salmon that were caught near the Walcan Seafood facility were found to host the highest numbers of *L. salmonis* among fish collected at any site both near and far from salmon farms in the region (Price et al. 2011). Sea lice from salmon farms are a known threat to already vulnerable wild salmon populations in British Columbia (Krkošek et al. 2007, 2011; Connors et al. 2010; Krkošek and Hilborn 2011), and processing facilities may intensify infection pressure on vulnerable fish. Importantly, populations of farm-origin sea lice will rise and fall as the salmon farms are stocked, harvested, and fallowed, whereas processing facilities have the capability of continuous pathogen release.

Current biosecurity regulations in Canada appear inadequate to mitigate the threat of pathogen release. Canada's guidelines for fish processors require effluent to be finely screened before release by using a mesh size no larger than 0.71 mm (Environment Canada 1975). Our recovery of adult *L. salmonis*, fish tissue, and fish scales measuring up to 8 mm reveals a deficiency in the mandatory physical treatment of effluent. However, mesh screening may be inadequate to remove flexible objects (i.e., sea lice) that could be forced through by strong discharge and highly viscous waste. The viability of sea lice and eggs from the effluent demonstrates a similar deficiency in the use of disinfection or chemical treatments to reduce pathogen transmission. Untreated blood, tissue, and mucus from infected fish pose a serious risk of disease transmission to wild fish and to fish in adjacent farms (Vågsholm et al. 1994; Jarp and Karlsen 1997), as has been shown for the transmission of infectious salmon anemia (Totland et al. 1996). Importantly, the disinfection of waste from farmed salmon processing has been effective at diminishing disease transmission in some regions of Europe (Murray et al. 2010). We recommend development of a mandatory biosecurity program in Canada to ensure that farmed salmon processing facilities minimize their release of infectious fish pathogens to wild populations. To be effective, such a policy would require, at minimum, the disinfection and mechanical treatment of effluent before release and a robust monitoring effort to ensure compliance, as has been implemented in Europe (Murray et al. 2010).

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