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Salmon Farming in British Columbia:
The environmental challenge and an effective solution

An Introduction:

Aquaculture is the fastest growing food production sector in the world, and is expected to be the dominant source of fish and seafood worldwide by 2030. With increasing human pressure on marine fisheries and ocean resources and declining catches of wild fishers, aquaculture is a promising response to increase future marine fish production (Dearden & Mitchell, 2009; Naylor et al., 2005). This report examines the aquaculture industry in British Columbia, Canada, with a specific focus on salmon farming *(See Map 1, page 12)*. British Columbia (B.C.) is Canada's largest producer of farmed salmon and the fourth largest producer worldwide, generating huge annual revenues and employing thousands of people (Dearden & Mitchell, 2009; Fisheries and Oceans Canada [FAO], 2010). However, salmon farming presents a major environmental challenge; although it is an economic powerhouse, the industry uses unsustainable methods and is detrimental to the environment. As an important part of British Columbia's economy and culture, it is imperative that salmon farming methods and their severe environmental consequences be addressed. This paper examines the controversial practices of salmon aquaculture in British Columbia, discusses the industry's environmental impacts, and explores one specific strategy to combat these issues.

The Environmental Challenge:

Salmon farming is an environmental challenge striking passionate debate among British Columbians. The aquaculture industry in B.C. employs some 6,000 people, with numbers expected to grow rapidly in the next 15 years (Dearden & Mitchell, 2009; Fisheries and Oceans Canada [FAO], 2010; Western Economic Diversification Canada [WD], 2014). Moreover, salmon farming brings in large annual revenues and provides social and economic benefits to First

Nations peoples along the coast (FAO, 2010). In 2011, Canada's salmon farming industry was valued at almost $607 million, 72% of which was generated by British Columbia alone (Statistics Canada, 2012). It also benefits consumers because it provides access to nutritious fresh salmon all year round (FAO, 2013).

The environmental aspect of this industry is not as optimistic. A typical salmon farm in British Columbia *(See Figure 1)* consists of 20-30 cages, each 12 or 15 metres square, and contains on average 20,000 fish (Dearden & Mitchell, 2009; Winsby et al., 1996). The cages are made of open nets that allow water to flow through and antibiotics, uneaten food, feces, and chemicals to flow out (Dearden & Mitchell, 2009). These farms are subject to risks posed by weather, temperature, disease, predation and organisms that affect growth (Bureau & Hua, 2010; Monterey Bay Aquarium Foundation, 2014; The Parliament of Canada, 2013). Costs are increased as a result of losses and control efforts (Gillis, 2011). It is also essential to recognize that many of these risks will be exacerbated by climate change (Nguyen & Williams, 2013). The open net method of salmon farming in British Columbia raises several major environmental concerns, such as escapement, disease, parasitism, pollution, and predator control. Furthermore, the salmon farming industry has negative socioeconomic dimensions pertaining to the involvement of multinational corporations,

Figure 1: Types of Aquaculture

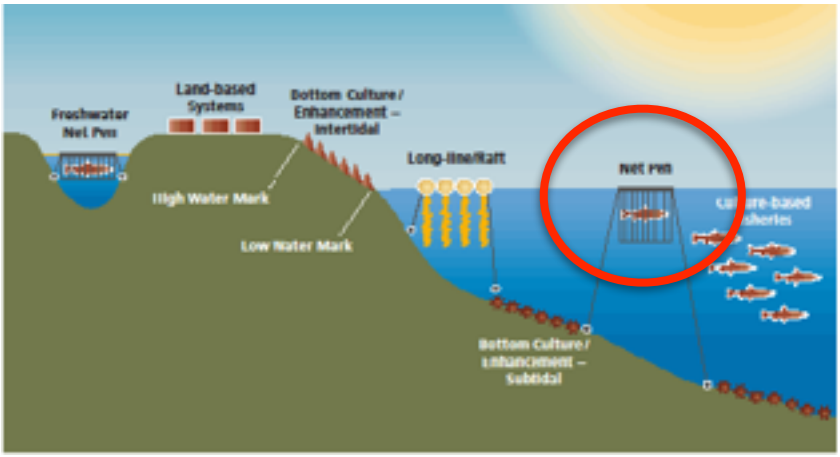

Figure 1 shows Canada's varying aquaculture operations. In British Columbia, salmon aquaculture most commonly uses a "net pen" (FAO, 2013).

overstated future economic growth, and adverse implications for First Nations communities (Dearden & Mitchell, 2009; Monterey Bay Aquarium Foundation, 2014).

Escapement

Most British Columbian farms breed Atlantic salmon, a species not native to the area. Atlantic salmon are in high demand in well-developed markets and have been commonly bred in salmon farms across the globe (Dearden & Mitchell, 2009). The escapement of Atlantic salmon from fish cages into surrounding wild habitat occurs regularly and often in high numbers, most commonly from marine open-net pens (Dearden & Mitchell, 2009; Naylor et al., 2005). In fact, studies have found Atlantic salmon in more than 80 rivers in British Columbia alone, and even found them reproducing in some locations (Dearden & Mitchell, 2009; Volpe, Taylor, Rimmer, & Clickman, 2000). This poses serious potential biological risks to wild salmon populations. The diet and habitat choice of escaped farm salmon overlap with those of wild salmon and of other unrelated species, increasing competition for both food and habitat (Fleming et al., 2000; McGinnity et al., 1997, McGinnity et al., 2003). Also, farmed salmon tend to have a size advantage and higher levels of aggression and thus hold a potential competitive edge over wild salmon (Fleming, Agustsson, Finstad, Johnsson, & Bjornsson, 2002; Fleming et al., 2000; Fleming & Einum, 1997; McGinnity et al., 1997; McGinnity et al., 2003). This enables farmed salmon to displace native fish and severely stress their wild counterparts, even increasing wild salmon mortality (Dearden & Mitchell, 2009; Naylor et al., 2005).

Disease

Another major environmental concern is the transmission of pathogens and disease from farmed salmon to wild salmon. Netted farm areas are stocked with high levels of fish, which promotes a rapid spread of infectious disease and parasites. Some salmon farms are located along

migration routes of wild salmon, which allows diseases and/or parasites to be transmitted from farmed salmon to wild populations (Dearden & Mitchell, 2005; Krkosek et al., 2013; Krkosek, Lewis, & Volpe, 2005). This spread of pathogens is a serious biological risk to wild salmon; a very small number of fish carrying an exotic pathogen may be sufficient to cause severe mortality in wild fish populations (Naylor et al., 2005). Viruses such as infectious salmon anemia (ISA), and infectious hematopoietic necrosis (IHN) have been detected in fish farms across the globe, in countries such as Norway, Canada, Scotland and the United States (Naylor et al., 2005). In 2002, there was a rapid spread of IHN in Clayoquot Sound on the west coast of Vancouver Island. The main aquaculture operator in the region lost about US $5.7 million that year and closed down one of its processing plants (Dearden & Mitchell, 2009; Pendleton et al., 2005). Even the Government of Canada is concerned by potential disease risks in aquaculture; in 2012 its Cohen Commission of Inquiry recognized that "Fraser River [wild] sockeye salmon face some likelihood of harm from disease and pathogens in salmon farms, and that this potential harm is serious or irreversible." (Minister of Public Works and Government Services Canada, 2012, p. 70). The Commission recommended that net pen salmon farms operating along or within proximity of all wild salmon migration routes along the coast be strictly reviewed and/or prohibited (Minister of Public Works and Government Services Canada, 2012; Nguyen & Williams, 2013).

Parasitism

Wild salmon living along the coast of British Columbia are being weakened by excessive parasitic sea lice infestations coming from marine salmon farms near their migration routes. A study published in 2005 suggests that farms may have the potential to raise lice infection levels in wild populations by four orders of magnitude (Krkosek et al., 2005). Exceptionally heavy and

fatal infestations of sea lice have been found in wild salmon populations in Scotland, Norway and British Columbia, and all cases were only found in regions where Atlantic salmon were farmed in net pens (Atlantic Salmon Trust, 2010; Dearden & Mitchell, 2009; Krkosek et al., 2005; Krkosek et al., 2015; Naylor et al., 2005). These parasites have potential to be a significant source of mortality in wild fish populations, particularly because they transfer viruses such as ISA between fish (Krkosek et al., 2013; Naylor et al., 2005). British Columbia may face serious repercussions; if wild fish conservation targets are not being met, parasite-associated mortality may cause the closure of some fisheries in the future (Krkosek et al., 2013).

Predator Control

Seals and sea lions are two main predators of salmon in British Columbia. They are a nuisance to salmon farmers, as they prey on farmed salmon and decrease farms' profits (FAO, 2014). Consequently, farmers are permitted to shoot animals that rip nets open. Fisheries and Oceans Canada reports that between 1996 and 2008, fish farmers killed 3,239 harbour seals and 7,678 Steller sea lions nationally (FAO, 2011). In addition, sometimes the salmon farm nets themselves kill wildlife. In 2007, 51 sea lions got tangled in nets and drowned at a single farm (David Suzuki Foundation, 2014).

Pollution

The salmon farming industry is failing to effectively manage their wastes. These wastes are solid organic wastes, such as fish faeces and uneaten food, and elemental wastes like nitrogen and phosphorus compounds. (Bureau & Hua, 2010). If not properly dealt with, they may result in nutrient enrichment of the receiving environment, which in turn may initiate environmental changes. Some farms are located in relatively protective coves and inlets where waste cannot be readily dispersed, where it will accumulate on the ocean floor. Consequently, oxygen may be

reduced and the production of hydrogen sulphide and methane in the waters surrounding the farm may increase. The changed environment will smother benthic organisms and further impair the existing ecosystem (Bureau & Hua, 2010; Davidson, 1999; Dearden & Mitchell, 2009).

Socioeconomic Dimensions

Sixty years ago there were fifty fish farm companies in British Columbia. Now, five multinational companies control 80% of the aquaculture industry in B.C. (Raincoast Conservation Society, 2004; Dearden & Mitchell, 2009). Even worse, only one of those five multinationals is a Canadian company. Consequently, a large portion of the economic benefits gained from salmon aquaculture are exported out of the province (Raincoast Conservation Society, 2004). Another social dimension concern is the fact that increased mechanization is leading to lower economic figures, implying that employment growth predictions may be overstated. Certainly, economic benefits for local communities relying on salmon farming will be limited (Dearden & Mitchell, 2009). As previously mentioned, parasitic-related mortality of wild salmon may lead to closures of some wild salmon fisheries in the future (Krkosek et al., 2013). Many First Nations are passionately opposed to salmon farming (BC Ministry of Agriculture, Food and Fisheries [MAFF], 2004; The Canadian Press, 2014; Dick, 2014; Raincoast Conservation Society, 2004). Wild salmon is an integral part of First Nations culture, economy, and food supply (Canadian Press, 2014; Davidson, 1999; Dick, 2014). Increased growth of the salmon farming industry further threatens wild stocks, increasing risk of repercussions for the health, economy and lifestyle of communities dependent on wild fish (Dearden & Mitchell, 2009).

The Ideal Outcome:

In an ideal future, British Columbia will expand the salmon farming industry and garner vast economic benefits while protecting, preserving, and enhancing wild salmon, coastal

ecosystems, and coastal communities. Salmon raising will be efficient and environmentally stable, maintaining salmon supply both as an important food source and as a cultural icon (David Suzuki Foundation, 2014; Elderview, 2010; MAFF, 2004) .

Farmed Salmon Impact on Wild Species

Wild salmon and relevant wild species will thrive. Disease and parasite outbreaks will be virtually eliminated (The Parliament of Canada, 2013). No harmful transmission to wild stocks will occur, and related financial losses for both the aquaculture industry and wild salmon industry will be avoided (Boychuk, 2014; The Parliament of Canada, 2013). Additionally, escapes of farmed salmon will be inhibited; food and habitat competition between wild and farmed stock will not occur. Salmon predators' contact with salmon farms will be humanely prevented also (David Suzuki Foundation, 2014; FAO, 2011, 2014b).

Energy and Waste Efficiency

The operation of salmon farms will be energy efficient and emit limited waste. Appropriate technology and processes such as biofiltration will be available to farms to enable this, and these goals will be achievable at an affordable cost to the industry (Boychuk, 2014; Stilts, 2014).

Socio-Economics

In an ideal future, salmon aquaculture will continue to provide economic benefits to British Columbians, particularly to those living in small communities along the coast where farms are located (Stilts, 2014). Salmon aquaculture will continue to expand and correspondingly provide higher employment. First Nations and the salmon farming industry will work in harmony, mutually benefitting from each other (Boychuk, 2014; The Canadian Press, 2014; Stilts, 2014). First Nations' traditional ecological knowledge will be incorporated into salmon farming practices

and planning (FAO, 2010). This more holistic approach to monitoring aquaculture will be more relatable to the general public and help them better understand the industry (Dick, 2014).

The Solution:

The ideal solution to this environmental challenge would simultaneously support salmon aquaculture and conserve the surrounding environment, including wild salmon. Closed containment land-based salmon farms are a solution that promotes the expansion of the salmon farming industry, yet eliminates virtually all risk to wild salmon populations and related wild species. Land-based Recirculating Aquaculture Systems (RAS) are designed to physically separate fish from the external environment. These land-based RAS and similar closed-containment systems have existed for several decades, where they have been used for the aquaculture industry of other species and in salmon hatchery facilities. This technology has been successfully and profitably used at the commercial scale for species such as trout, arctic char, sturgeon, tilapia, Pacific salmon, and Coho salmon (Boychuk, 2014; David Suzuki Foundation, 2005; The Parliament of Canada, 2013; Pendleton et al., 2005).

Protecting the Wild

These systems separate farmed salmon from the external environment; land-based RAS use large, circular concrete tanks arranged in modules on land. Water is pumped into the tanks where it is filtered and treated through various means, including biofiltration, mechanical filtration, UV irradiation, CO_2 strippers and ozone injection. These systems can to reuse up to 99% of their input water (Boychuk, 2014; Monterey Bay Aquarium Foundation, 2014; The Parliament of Canada, 2013; Pendelton et al., 2005; Stilts, 2014). Because water is treated before entering the tanks and no water is released to the natural environment, there are no pathways for disease, pathogens or parasites to transfer between wild and farmed populations (Monteray Bay

Aquarium Foundation, 2014; Stilts 2014; The Parliament of Canada, 2013). These systems offer near complete control over water quality, temperature, oxygenation and other parameters. The separation of salmon from the external environment additionally eliminates virtually all possibility of escape and predator/wildlife mortalities (The Parliament of Canada, 2013; Monterey Bay Aquarium Foundation, 2014).

Waste and Energy Efficiency

Another benefit of land-based RAS is that they manage their waste and use energy efficiently. The solid waste produced by these systems is drained out the bottom of the tank and removed to a separate basin, where it can be treated and used as compost or fertilizer (Bureau & Hua, 2010; Monterey Bay Aquarium Foundation, 2014; The Parliament of Canada, 2013). A land-based RAS raising Pacific Salmon in Agissiz, B.C. operates as a multi-trophic aquaculture site, where the nutrient-rich water produced by salmon tanks is used to grow watercress, wasabi, and garlic. This in turn is used to produce algae and to feed crayfish. This is all done without pesticides, chemical fertilizers, or antibiotics (Gillis, 2011; The Parliament of Canada, 2013). Although electricity requirements are generally greater compared to those of open-net aquaculture, some land-based farms have proved otherwise. For example, The Kuterra salmon farm on Vancouver Island - the first land-based Atlantic salmon farm in North America to produce at a commercial level - reuses heat given off by the bodies of the fish, thereby reducing the amount of power and heating required (Boychuk, 2014; Stilts, 2014; The Parliament of Canada, 2013).

Minimizing Risk and Cost

Although the initial implementation costs are high, land-based RAS have socio-economic benefits in addition to environmental ones. Salmon in these systems grow faster and with less

feed than salmon in open-net marine systems (Boychuk, 2014; Gillis, 2011; Monterey Bay Aquarium Foundation, 2014; The Parliament of Canada, 2013). Furthermore, these systems give farmers the opportunity to reduce business risks and cut losses. Closed-containment systems prevent salmon stocks from being exposed to environmental hazards such as disease, parasites, water quality or pollution issues, escapes or predation (Monterey Bay Aquarium Foundation, 2014; The Parliament of Canada, 2013; Stilts, 2014). An enclosed tank also prevents loss of salmon feed through the nets. These risks and resulting losses main drivers encouraging existing salmon farmers to switch to closed-containment systems (Gillis, 2011). Additionally, land-based RAS can be put in close proximity to urban areas, minimizing transport costs. Although the systems require adequate access to water, they do not necessitate a location near a body of water (Gillis, 2011; The Parliament of Canada, 2013).

First Nations Involvement

First Nations will also benefit from this technology. In fact, First Nations have been among the first interested in developing closed-containment aquaculture technology. They are often best suited to closed-containment methods because of their geographical location, access to land and water, cultural values, history, and experience in fishery (FAO, 2010). Kuterra is an excellent example of a successful land-based RAS salmon farm run by and employing First Nations in British Columbia.

Conclusion:

Aquaculture is a prominent and growing industry in British Columbia and globally, with critical environmental risks that must be addressed. As one of the largest producers of farmed salmon in the world, British Columbia's salmon aquaculture industry generates huge revenues annually and employs thousands of people. However, the environmental defilement inset by the

salmon farming industry is an issue that must be addressed. Escapement of farmed salmon, disease, parasitism, predator control, and pollution are major environmental concerns, particularly because of their adverse impacts on wild salmon and other relevant species. There are also negative socioeconomic implications of salmon aquaculture, particularly regarding multinational corporations' involvement in the industry and salmon farming's impact on First Nations. In an ideal future, salmon farming will invoke no harm on the surrounding environment, and may in actuality improve it. Public participation and First Nations' involvement in the planning and operations of salmon aquaculture will be high, as will employment levels and production values of the industry. As a step towards these goals, land-based Recirculating Aquaculture Systems are an effective and viable solution. With land-based RAS, salmon farming can benefit British Columbia economically, socially, and environmentally. Salmon aquaculture is an important part of British Columbia's economy and culture; therefore it is imperative that its unsustainable methods and severe environmental consequences be addressed.

Map 1: This map shows the location of finfish aquaculture in British Columbia. Many of these are salmon farms (FAO, 2014a).

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