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Sustainable aquaculture in Canada: Lost in translation

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ABSTRACT

Canada is a signatory to United Nations conventions on sustainable development and has entrenched sustainability goals in legislation and policies relating to natural resource sectors including aquaculture. Monitoring and measuring progress towards sustainable development requires the development of sustainability indicators (SI) that, when measured, indicate movement towards or away from a stated policy objective, as well as providing the public with a measure of government accountability. This paper examined the SI used by the Canadian government to assess the social, economic and environmental sustainability of aquaculture production in Canada, whether they adequately measure policy outcomes, and whether national-level SI indicators are appropriate to assessing sustainability at the community-level. The analysis reveals that the Canadian government has made virtually no progress towards translating sustainable aquaculture policy aspirations into measurable SI that evaluate policy outcomes. The mismatch between national policy goals and on-the-ground consequences are highlighted in a community case study of finfish aquaculture in Port Mouton Bay (Nova Scotia). Aquaculture SI and sustainability narratives are discussed in relation to emergent governance arrangements (certification programs) and an international development initiative, Blue Growth, for the world's oceans.

1. Introduction

In 1987 a new development paradigm, sustainable development, was introduced to the world in a report from the World Commission on Environment and Development. The report, *Our Common Future*, drew global attention to the limits of economic growth in general and as a solution to global social inequalities [1]. Sustainable development was defined as development that meets the needs of this generation while not diminishing the ability of future generations to meet their own needs [1]. According to the report, the main prerequisite for sustainable development was securing effective citizen participation in decision making [1]. The concept and principles of sustainable development were further developed through four United Nations (UN) conferences: the 1992 Earth Summit in Rio de Janerio; the 2002 World Summit on Sustainable Development in Johannesberg; the 2012 Rio + 20 Conference on Sustainable Development in Rio de Janerio; and the 2015 conference on a 2030 Agenda for Sustainable Development in New York [2–4].

The *Agenda 21* document produced at the 1992 Earth Summit highlighted the need for sustainability indicators (SI) in government decision-making [5]. The document acknowledged that conventional indicators of economic progress and environmental change were inadequate to assess sustainable development and called on countries to "develop systems for monitoring and evaluation of progress towards achieving sustainable development by adopting indicators that measure changes across economic, social and environmental dimensions" [5, section 8.6, p. 67]. This call to action led to a proliferation of research and initiatives on SI. Individual and aggregated SI were developed to measure sustainability at different geographic (local, regional, global) and governance (municipal, provincial, national, international) scales and system levels (individual, population, ecosystems) [6]. Early in the process of SI development, Meadows [7] warned that poorly chosen indicators can create discrepancies between desired goals and perceived goals. For example, "[i]f you manage a national economy to maximize GDP, you get GDP. You do not necessarily get justice or freedom or environmental quality or even, sometimes, real wealth" [7, p.3]. Meadows [7] also identified some common pitfalls associated with the selection of indicators such as over-aggregating data, measuring what is measurable rather than what is important, selection bias in favor of a particular policy objective or sector interest, and using national-level indicators to divert attention from local-level experience. In order for SI to provide meaningful information on policy progress towards sustainability, SI must include a reference value (e.g. target, standard, norm, goal, benchmark) that, when measured, indicate movement

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towards or away from a stated objective, as well as providing the public with a measure of government accountability on policy narratives and initiatives [6–8].

The Canadian government was an early adopter of the sustainable development paradigm outlined in the Brundtland report and a signatory to the UN conventions on sustainable development [9–11]. The government followed up on its commitment to sustainable development by entrenching the concept in a series of federal legislation, such as the *Auditor General Act*,1995, the *Oceans Act* 1997, *Canadian Environmental Protection Act* 1999, and the *Federal Law on Sustainable Development Act* 2008 [10]. Sustainable development evolved to become a government policy imperative in all natural resource sectors (e.g. agriculture, mining, energy, forestry, fisheries), eventually including aquaculture [12].

The global rise of aquaculture in the early 1980s was the impetus for the Canadian government to convene a national aquaculture conference in 1983 to examine the potential for aquaculture development in Canada [13]. Several narratives regarding the role and future of aquaculture in Canada emerged from this conference that would become embedded in federal and provincial economic and sustainable development policy objectives. These early narratives revolved around the role of Canadian aquaculture in feeding a growing world population, reviving rural communities with employment opportunities and replacing declining wild fish stocks [14–16]. Policy narratives on sustainable aquaculture in Canada now also include contributing to global sustainable development by offsetting protein shortages, providing food security and contributing to nutritional well-being [17–19].

Given Canadian's longstanding support and commitment to sustainable development and almost four decades of aquaculture development in Canada, several inter-related questions arise regarding the sustainability of aquaculture in Canada: what sustainability indicators (SI) is the federal government using to assess the social, economic and environmental sustainability of aquaculture production in Canada; do they adequately measure policy outcomes; and are national-level SI indicators appropriate or relevant to assessing sustainability at the community-level? We examine these questions by first providing a brief overview of aquaculture development in Canada and then examining the SI developed by the federal government to assess the sustainability of the aquaculture sector in Canada. We then combine our more than 10 years of research in Port Mouton Bay, Nova Scotia (Canada), with that of other researchers and provincial government data to examine how federal sustainable aquaculture policies and programs have been experienced at the community level. The coastal village of Port Mouton, like many small fishing communities in Atlantic Canada, has been and continues to be dependent on the fisheries resource sector. The extent to which the impacts of finfish aquaculture have been studied in this Bay, compared to other communities and bays in the region, is sufficient to provide a comprehensive social and ecological database for a case study. Lastly, we discuss aquaculture and SI in relation to emergent governance arrangements (certification programs) and the international Blue Growth policy initiative for the world's oceans.

2. Aquaculture development in Canada

In 1995, Canada released its first *Federal Aquaculture Development Strategy* [20]. Although the *Strategy's* initiatives were designed to promote sustainable aquaculture development, the impetus for developing the *Strategy* was a perceived stagnation in the global competitiveness of the Canadian aquaculture industry [20]. Sustainable development as a policy objective for aquaculture was officially declared in the 2002 *DFO's Aquaculture Policy Framework* [21]. The *Framework* established the Department of Fisheries and Oceans (DFO) as a "department of sustainable development" and "both a regulator of the aquaculture industry and an enabler of its development" [21, p 14]. DFO outlined its commitment to supporting sustainability themes that would "foster the development of an aquaculture industry that will be a model of sustainability for the world" [21].

By 2009, Canada's continued low ranking (23rd) among world aquaculture producers triggered DFO to lead a nation-wide consultation with the goal of renewing the policy framework for aquaculture development in Canada [22]. The consultation resulted in the formulation of the *National Aquaculture Strategic Action Plan Initiative (2011–2015)* which, according to the document, was modeled on the principles of sustainable development as defined in the 1987 Brundtland report [22]. The document outlined overall objectives for each of the three pillars (environmental, social, economic) of sustainable development. The environmental pillar was defined as maintaining healthy and productive aquatic ecosystems for aquaculture development. The social pillar was defined in terms of securing social licence and the economic pillar referred to a prosperous aquaculture sector that generated meaningful employment, attracted investment, and advanced sector stability [22].

Canada currently ranks 24th among global aquaculture producers, just ahead of the United Kingdom and behind Malaysia [23]. Despite efforts by the federal government to diversify the species cultivated in Canada [16,22], sea cage-reared Atlantic salmon (*Salmo salar*) is the dominant species in terms of production (63%) and value (76%), with shellfish (mussels and oysters) and trout making up most of the balance of production (20% and 5% respectively) and value (6% and 4% respectively) followed by other finfish (e.g. steelhead trout, halibut) and shellfish (e.g. clams, scallops) species [24].

Globally, farmed salmon represent 4% of world finfish aquaculture production and ranks 9th in production among the major aquaculture finfish species [25]. Since the industry's global rapid rise in the 1980s, salmon farming has changed from a sector once dominated by a large number of small-scale operators to a sector almost exclusively controlled by a small number of multinational corporations [22,26]. Internationally, four companies (Marine Harvest, Mitsubishi, Lerøy Seafood Group, SalMar) controlled 35% (0.83 million mt) of global farmed salmon production (2.38 million mt) in 2015 [23,27]. In Canada Cooke Seafood, a Canadian-based multinational company, dominates production in Atlantic Canada [28]. Farmed salmon production on Canada's west coast (British Columbia) is controlled by two Norwegian-based (Marine Harvest, Grieg) and one Japanese-based (Mitsubishi which acquired Norwegian-based Cermaq) multinational companies [27,28].

The shift from small-to industrial-scale salmon farming has brought with it all the issues characteristic of industrial food-production systems. These include: waste-product pollution (feces, feed) [29], use of chemical and veterinary products (antibiotics, pesticides) [30], environmental quality issues (nutrient and organic loading) [31], off-farm pathogen transmission [32] and farm escapes [33], human health concerns [34], devolution of state-led control to corporate/market-driven governance [26,35–37], and increased control by large-scale processor and retailers (value chain) on seafood systems [38–40]. As a result, the development trajectory of farmed salmon production globally, and in Canada, has been uneven and marked by periods of reduced production due to a range of issues including disease (e.g. infectious salmon anemia, piscine reovirus) and parasite (sea lice) outbreaks, increased global competition, price fluctuations, availability of suitable farm sites, and moratoria [25,26,41].

3. Sustainability indicators in Canadian aquaculture

In 2012, DFO released a report, *Aquaculture Sustainability Reporting Initiative*, announcing its intention to develop sustainability indicators (SI) for aquaculture [19]. The report identified key sustainability issues and potential SI (Table 1) within the aquaculture value chain (from feed manufacturers to consumers) [19]. The process for identifying and ranking potential SI involved participants from the aquaculture industry and their associations, aquaculture feed manufacturers, food marketers and retailers, representatives from federal and provincial government departments, government and university-based

Table 1
Summary of Canadian aquaculture sustainability themes, objectives and indicators as outlined in DFO (2012).

Sustainability Pillar	Themes	Objectives	Potential SI[a]
Environment	Maintaining healthy productive ecosystems	Protecting fish and fish habitat through site allocation processes, managing organic waste, controlling introductions and transfers of fish, escape prevention	Escaped fish Water quality Benthic monitoring
	Using resources efficiently	Feed management, water and energy conservation and production-area optimization	Responsible sourcing of marine raw materials Marine ingredients in aquaculture feed
	Maintaining animal health and welfare	Minimizing stress and reducing disease and pest risks	Disease incidence
Economic	Economically viable and successful sector	Delivering economic growth in rural development, job creation and domestic and international trade	Labour income generated Return on investment
Social	Encouraging social responsibility Ensuring safe and healthy aquaculture products	Respecting local communities, Indigenous and labour rights, safe workplaces Meeting nutritional needs	Employment Value-chain traceability Voluntary certification

[a] All sustainability indicators (SI) identified in the 2012 *Aquaculture Reporting Initiative* were designated as being "under development".

researchers, and Indigenous associations. Absent were representatives from national and regional environmental, fisher, consumer, and social/community development organizations [19]. The selection of potential indicators such as escaped fish, sourcing of fish feed, traceability, and certification (Table 1) is a tacit acknowledgement of the primacy of salmon aquaculture in Canada and the influence of global seafood commodity chains on production.

The following subsections examine the progress made by DFO to further developing and measuring SI within each sustainability pillar.

3.1. Environmental SI

Environmental sustainability indicators identified in the scientific literature for finfish aquaculture operations, such as salmon farms, include the quantity of resources used (e.g. water, energy, space, feed and amount of raw marine ingredients), waste discharges (nitrogen, phosphorus, particulate organic matter, greenhouse gasses, metals), chemicals use (e.g. antibiotics, pesticides, hormones), disease incidence, escaped fish, genetic interactions, and biodiversity impacts [42–46]. To date with two exceptions (antibiotics and drugs), DFO does not publicly report on any of the aforementioned environmental indicators nor does it report on the environmental SI identified in Table 1. Instead, DFO reports on industry's compliance with environmental regulations as an indicator of the sustainability of aquaculture [47,48]. According to the federal department of Environment and Climate Change Canada (ECCC) which reports on SI developed by various federal departments, the rationale behind this choice of indicator was that "regulations are implemented to limit environmental damage caused by human activities" and "the degree to which facilities comply with regulations is an indication of their environmental impact" [49, p. 7]. In 2015, Canada passed its first national aquaculture regulations to protect fish and fish habitat [50]. Compliance with these new regulations means aquaculture operators are now required to report the quantity and frequency of drugs and pesticides use. In 2016 and 2017, marine finfish operators used 16.8 mt and 14.4 mt of antibiotics and 617 mt and 439 mt of pesticides (hydrogen peroxide) respectively [51]. Monitoring sub-lethal, cumulative, and far-field (beyond the farm lease) effects of sequential exposure to antibiotics and pesticides on non-target species is not required. Similarly the new regulations require reporting, on or very near the farm lease site, the benthic sulfide levels in soft-bottom environments and the percentage of the bottom covered by bacterial species, worms and barren substrate in hard- and mixed sea bottoms [50], but monitoring the cumulative and far-field impacts of waste discharges are also not required.

DFO measures compliance rate as a percentage of the farms visited by federal fishery officers where no charges are issued [49]. Currently, there are over 900 finfish and shellfish aquaculture operations in Canada [24] and not all farms are inspected on an annual basis. DFO uses a risk-management approach to determine the frequency of inspection and individual operations may be inspected more than once per year [49]. For 2017–2018, DFO set the compliance indicator target at 90% and, based on 409 inspections, compliance with regulations was reported as 100% in 2017 [47,49]. For 2018–2019, the compliance target is ≥ 90% [48].

3.2. Economic SI

Economic sustainability indicators for aquaculture generally measure the industry's employment characteristics (e.g. full- and part-time employment, salary levels, participation of women, layoff rates) and the economic viability or financial performance of the sector (e.g. profitability, capital efficiency, revenue-investment ratio, internal rate of return) [42–44]. Economic indicators such as employment are also viewed as indicators of social SI for their role in poverty reduction, health and food security [25,52] and, therefore, often reported as a social SI as DFO has done (Table 1). A challenge in developing indicators relating to the economic viability of the aquaculture sector is access to farm-level financial and production data as many farms regard such data as confidential [53].

To date, DFO does not report on the economic SI (labour income, industry's return on investment) suggested in the 2012 report (Table 1). A 2010 socio-economic study prepared for DFO assessed the economic impact of the aquaculture sector [54]. The study acknowledged the challenges inherent in interpreting national-level data based on different provincial and company reporting practices and cautioned that the data should not be taken at face value [54]. One of the data interpretation challenges relates to the study's calculation of economic impact at the community level. The study suggested that for every $10 of direct income generated from expenditure made by aquaculture companies in the community (e.g. hatcheries, grow-out operations, processing facilities and corporate administration), approximately $20 of income is generated at the community level through indirect expenditures (e.g. purchases of feed and grow-out infrastructure such as nets and pens) and spin-off or induced income (spending by employees in the community) [54]. However, of the more than 900 aquaculture (finfish and shellfish) operations in communities across Canada [24], very few communities have hatcheries, processing facilities, corporate administration offices, and net or feed manufacturing operations in addition to grow-out operation [54]. Rather, many of the goods and services associated with grow-out operations (e.g. hatcheries, processing facilities, feed manufacturing) are located within a specific county/region of a province which in turn provides goods and services to operations throughout the province or, in the case of New Brunswick, several provinces [55]. Therefore, measures of direct, indirect and spin-

off labour income identified in the 2010 study are not applicable to every community with a finfish or shellfish farm.

3.3. Social SI

The social dimensions of sustainability are associated with issues of poverty, education, health, culture, governance, equity and social cohesion; with some dimensions (e.g. employment, education) easier to measure than others (e.g. culture, social cohesion) [see reviews in [56,57]]. The social SI identified for aquaculture have largely focused on indicators that are easier to measure such as employment, wages and salary, safety at work, and gender inclusion [42–44].

DFO identified employment in aquaculture as a social SI, but has not developed an employment target. One possible reason may be that the potential for expanding direct employment in aquaculture is continually being undermined by technological improvements that enhance economic efficiencies but reduce the amount of labour needed for production. Between 2007 and 2016, overall Canadian aquaculture production increased 18% but direct employment in the sector dropped 32% [24]. Nowhere is the impact from improved technological efficiencies more evident than in Norway which grows almost ten times (1.33 million tonnes in 2014) more farmed salmon than Canada (134,000 mt) but does so with slightly more than twice the direct labour force (6,300 people) than that of Canada (3,205 people) [23,24]. In addition since the mid-2000s, increased and significant reliance on the Canadian government's Temporary Foreign Worker Program by aquaculture and wild fisheries seafood processing companies, many in high unemployment rural areas [58], also threatens to subvert DFO's social sustainability goal of generating meaningful employment in rural, remote and coastal communities [22,54].

DFO also identified value-chain traceability and voluntary certification as social SI (Table 1). The selection of these indicators reflect DFO's acceptance of industry's role in partnership-based governance arrangements with communities (e.g. social licence initiatives) and civil society (e.g. certification schemes) [19,22]. To date, no targets have been developed for these social SI.

An emerging concept for assessing aquaculture's social sustainability is a 'social licence to operate' (SLO) [59–61]. The phrase or concept of SLO was first invented by extractive and resource-based industries such as mining and oil and gas development in response to the rise of oppositional social movements and empowered communities [see reviews in [62,63]]. SLO is not a legally binding agreement but an undefined process by which an industry attempts to acquire the informal consent of a community to operate in the community [63]. DFO views industry's ability to secure a SLO as a means of establishing more accessible and transparent decision-making processes between industry and the communities in which they operate [22]. The social conditions for meaningful community engagement in SLO negotiations such as knowledge, credibility, power, and trust are key elements in SLO negotiations [59,63–65]. DFO has yet to develop an objective measure or indicator to assess when, and if, SLO has been achieved.

4. Community-level experience with sustainable aquaculture policies: a case study from Port Mouton Bay, Nova Scotia

The role of aquaculture in rural coastal communities has been (and continues to be) a longstanding socioeconomic narrative and sustainable development policy goal for the Canadian government [13,17,20,22]. The following section examines how federal sustainable aquaculture policies have been experienced in a small coastal community (at Port Mouton Bay) in rural Nova Scotia (Canada).

Nova Scotia, one of Canada's four Atlantic provinces, has a long (~7600 km) coastline that is highly indented with hundreds of small embayments [66]. One of those small embayments, Port Mouton Bay (~56 km^2), is located on the temperate southwest coast of Nova Scotia and opens to the northwest Atlantic. Approximately 1100 people live within the watershed area (274 km^2) that drains into the Bay [66] with most residents (~425) living in the coastal village of Port Mouton [68]. Fishing has played (and still plays) a significant part in the social, cultural and economic lives of coastal residents in Atlantic Canada including Port Mouton Bay. The decline of groundfish stocks beginning in the 1980s, culminating in the collapse of cod stocks in the 1990s, resulted in a shift in fishing effort to lower trophic level species such as lobster (*Homarus americanus*) [69,70]. There is now an almost complete reliance for coastal communities on this high-value fishery [71] including in Port Mouton Bay where ~28% of residents depend on the fisheries resource sector and almost every family has some connection with lobster fishing, either past or present [68].

In 1995, a sea-cage fish farm was granted a license to operate in traditional lobster fishing territory in Port Mouton Bay. Initially stocked with Atlantic salmon (*Salmo salar*), the farm was also periodically stocked with rainbow trout (*Oncorhynchus mykiss*) [68]. Information on stocking numbers and monthly feed usage, mortalities, fish harvested, and potential pesticide treatments at the fish farm were proprietary and therefore not publicly available. Data on employment at each farm site are also not publicly available. According to Nova Scotia's Department of Fisheries and Aquaculture, 100 full- and 46 part-time people were employed at approximately 15 finfish farm operations in Nova Scotia in 2017 [72]. These employment levels translate to approximately 3–6 full- and/or part-time individuals working at each marine finfish operation. Most of the fish required for stocking sea-cages, sea-cage infrastructure and fish processing is purchased, produced and/or processed outside of Nova Scotia (in New Brunswick) and therefore outside of the community where the fish are farmed. Although farmed salmon production in Nova Scotia has increased 1000% from 1995 (1120 mt) to 2017 (11546 mt), the number of people employed in finfish aquaculture is the same (100) in 2017 as in 1995 and full-time employment has dropped 86% from 211 in 1995 to 46 in 2017 [72].

Within a year of the fish farm operating in Port Mouton Bay, fishers observed crabs and lobsters migrating towards the finfish farm site, leading them to believe the lobster were attracted to the aquaculture feed settling on the ocean bottom [68]. During the second and subsequent years, fishers were abandoning their traditional fishing areas within the Bay due to low catches [68]. In 2005, residents were informed that a second fish farm was under review for Port Mouton Bay. By then residents and fishers were observing environmental changes to the Bay such as increased occurrence of nuisance green algae fouling beaches and lobster traps, losses of eelgrass (*Zostera marina*) habitat, and declining numbers of lobster, clams, scallops, mussels and periwinkles in the Bay [73]. Although the provincial government required environmental monitoring at fish farms, the results of monitoring were not made public. For both provincial and federal regulatory purposes, dissolved sulfide levels in sediments were (and remain for soft- and mix-bottom environments) the principal environmental parameter reported [50,74,75].

Concerned about the potential environmental impacts from a second fish farm, the citizens and fishers of Port Mouton Bay formed a community network called the Friends of Port Mouton Bay (FPMB) [68]. The FPMB reached out to university and retired scientists and began a series of self-funded studies to examine the changes they were observing in their Bay. One study included applying a decision support system (Marine Finfish Aquaculture Decision Support System, MFADSS) developed by federal government scientists to assist DFO habitat managers in making decisions on farm site location when evaluating finfish lease applications [76]; an evaluation process not applied to the proposed fish farm by either the federal or provincial government. The results indicated that the shallow water depths and low current velocities at both the existing farm and the proposed new lease location, combined with the presence of sills that create depositional basins that retain settled organic waste from sea cages, made both locations in Port Mouton Bay unsuitable for salmon aquaculture [77].

Research by the FPMB in collaboration with university and retired

researchers resulted in the publication of seven peer-reviewed environmental and social science studies and more than two dozen reports [78]. A 11-year lobster study (2007–2017) found that during periods when the Port Mouton Bay fish farm was actively raising fish (a feed period), market lobster catches in Port Mouton Bay on average dropped by 42% and female berried lobster counts dropped on average 56% (with greatest declines in both catches and counts of lobster closest to the fish farm) compared to when the fish farm was not in production (a fallow period) [79]. Eelgrass, a species the federal government (DFO) designated in 2009 as an ecologically significant species but not monitored near fish farms, was found to be impacted by the Port Mouton Bay fish farm [80]. Copper used in fish feed and as antifoulants in nets was being transported from the seabed below the sea cages to the sea surface where concentrations exceeded the level considered safe for the protection of marine life [81] and, overall, the fish farm was the largest source of nitrogen to the Bay compared to all land-based sources [67]. Despite the federal government's long-standing interest in increasing knowledge for regulatory purposes about the impacts of aquaculture operations on wild fish (and shellfish) populations, water quality, and important marine habitat such as eelgrass [82,83], these studies represented the first studies of their kind in Canada.

In the fall of 2012 and in response to requests by individuals and community groups, the NSDFA began publicly releasing previous unavailable historic and current environmental monitoring data on open pen finfish operations. Data for 11 of 16 finfish leases were released including the fish farm in Port Mouton Bay. Environmental monitoring data at the Port Mouton Bay sea-cage operation during finfish production periods (2007–2009; 2013–2014) indicated numerous individual sampling stations had sediment sulfide levels above levels the federal and provincial government consider harmful to fish habitat ($> 3000\,\mu M$) [84,85]. Depending on the production year, sediment sulfides ranged from 5000 to 10000 μM; in 2007 and 2014, mean sediment sulphides were $> 4000\,\mu M$ [85,86].

The proposed farm site was not approved and the existing farm site in Port Mouton Bay has been fallow since 2015. The lease for the site will expire in 2020 [87]. The FPMB have written to the provincial Minister of Fisheries and Aquaculture to share the results of their studies and request the lease not be renewed [88].

5. Discussion: aquaculture SI in certification schemes and global sustainability narratives

Canada's lack of progress on aquaculture SI development can be viewed as part of a broader trend that has governments devolving certain elements of public policy and decision-making to non-state actors [89]. SI development in aquaculture, fisheries, and seafood in general is now largely the domain of certification and labelling schemes administered by industry and a range of non-governmental organizations (NGOs) [36,37,90,91]. Amundsen and Osmundsen [90] examined eight major certifications schemes that are prevalent among farmed salmon producers in three of the world's major salmon producing countries, Norway, Chile and Scotland. These schemes were developed by environmental NGOs (Aquaculture Stewardship Council, Friends of the Sea), retailers (International Featured Standards, BRC Global Standards, Global G.A.P.), industry (e.g. Global Aquaculture Alliance, Scottish Salmon Producers') and an animal rights organization (Royal Society for the Prevention of Cruelty to Animals). Indicators were categorized under four sustainability themes with social sustainability divided into governance and culture. Indicators were not evenly distributed among the eight schemes. Most (96%) of the 2830 indicators categorized in these schemes fell under two sustainability domains, environment (1298) and governance (1427), with fish health and welfare representing 60% of environmental SI and transparency, traceability and food safety accounting for 70% of the governance SI [90, see Table S1 in the Supplement]. The environmental SI identified in these schemes cover more aspects of potential environmental impacts (e.g. waste emissions, energy consumption, greenhouse gas emissions, mitigation measures) [see Table S1 in the Supplement] than the environmental SI identified by DFO (Table 1). The market-orientation in certification schemes is strongly reflected in what certifiers define as key governance issues (e.g. traceability, enforcement, food security) which is similar to the social SI defined by DFO (Table 1). A weakness in both the DFO and certification schemes is the absence (DFO) and the near-absence (certification schemes) of indicators associated with community-level decision-making. Of the 1427 indicators categorized as governance indicators, eight were associated with representation and negotiation (sharing and collaborating with the community), 14 with siting (consideration of protection areas and local ecological knowledge) and 44 indicators with accommodating other local economic activities and conflict resolution [90, see Table S1 in the Supplement]. Even fewer indicators (29) covered social SI such as social learning, equity, community integration, employee interests, and respect for Indigenous culture.

The need for meaningful aquaculture social SI, particularly those relating to governance and decision-making, have emerged over the past few years as one of the most important sustainability issues in aquaculture development because they are entwined with rural and urban community development; the geographic target of most aquaculture development policies formulated at the international, national, regional or state/provincial level [17,25,42,54,91,92]. The most recent international and national sustainable development policy initiative to advance aquaculture is the Blue Growth Initiative [93–96]. The concept of Blue Growth emerged from the 2012 Rio +20 conference on sustainable development and is intended to promote ocean development beyond established industries such as fisheries, shipping, tourism, oil and gas extraction to emerging industries such as offshore renewable energy, deep seabed mining, pharmaceuticals, as well as aquaculture [97].

Within the Blue Growth initiative, aquaculture is framed as increasing food security and future demand for protein, narratives that have persisted in Canada and globally since the 1980s. Until recently, there has been no rigorous evidence-based assessment of these claims but researchers are now examining the role and contribution of aquaculture (and fisheries) in population health and global food supply [98–101]. Béné et al. [99] evaluated 202 scientific articles published between 2003 and 2014 that examined the contribution of fisheries and aquaculture to improving food security, nutrition and poverty in developing and emergent countries using three criteria (rigour, validity and reliability). Their analysis revealed no evidence to support the claim that a higher consumption of fish results in higher nutritional status, that an increased supply of farmed or wild fish had a direct effect on the micronutrient status of households and/or consumers and concluded that the protein contribution of fish to nutritional status was overstated [99]. The share of protein intake derived from plants far exceeds animal protein in general, and fish-protein in particular [102]. The evidence for a link between fisheries/aquaculture and poverty alleviation was ambiguous.

Globally, food production has never been better. World agricultural food production has now outpaced population growth by a significant margin [103,104]. The world now produces more than enough food, including animal protein, to satisfy the dietary needs of the entire global population [105]. At the same time, the global supply of fish (wild and farmed) for human consumption has also outpaced population growth. Between 1961 and 2013, global fish supply increased at an average annual rate of 3.2% while the world's population grew at an average annual rate of 1.6% [25]. Despite this oversupply of food, more than 800 million people suffer from hunger, food insecurity and malnutrition; nowhere more acutely than people living in sub-Saharan Africa [105]. There are many reasons for the disconnect between a surplus of global food and access, key among those reasons is income distribution (the growing gap between rich and poor), protracted conflict and violence, and climate-related disruptions [106]; reasons that

pose significant challenges to aquaculture's potential contribution to global human health, poverty and nutrition [107].

6. Conclusion

Despite decades-long narratives about the sustainability of aquaculture in Canada, the federal department in charge of aquaculture (DFO) has provided very little empirical evidence to support their sustainability claim. Virtually no progress has been made towards translating sustainable aquaculture policy aspirations into measurable SI that evaluate policy outcomes. DFO's single measure of aquaculture's sustainability, compliance with regulations, assumes current regulations adequately address the environmental impacts of aquaculture on fish and fish habitat. However, as the case study of a single fish farm in Port Mouton Bay reveals, Canada's new *Aquaculture Activity Regulations* do not take into account the metal (copper) contamination, nutrient loading, lobster catch decreases and eelgrass loss reported in the Bay. The case study in Port Mouton Bay also highlights the mismatch between national estimates of the economic benefits of aquaculture and community-level reality. Canada's approach to selecting aquaculture SI repeats several of the indicator-selection pitfalls identified two decades earlier such as over-aggregating economic data, measuring what is measurable (compliance with regulations) rather than what is important (e.g. environmental impacts), selection bias in favor of a particular policy objective (global commodity chain), and using national-level indicators to divert attention from local-level experience. In the absence of meaningful measures of global, national and local sustainability, declared aquaculture policy goals risk being reduced to mere political catchphrases.

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Appendix A. Supplementary data

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