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REGIONAL REVIEW ON STATUS AND TRENDS IN AQUACULTURE DEVELOPMENT IN NORTH AMERICA – 2020

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REGIONAL REVIEW ON STATUS AND TRENDS IN AQUACULTURE DEVELOPMENT IN NORTH AMERICA – 2020

by

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Preparation of this document

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Data used in this global aquaculture overview, as well as in the regional aquaculture reviews, derive mainly from the different FAO fisheries and aquaculture statistics (FishStat), accessible through different tools, including the FAO Yearbook Fishery and Aquaculture Statistics, online query panels and FishStatJ. A discussion of FAO data is included in Appendix 1.

In continuing the global efforts to achieve aquaculture sustainability through dissemination of up-to-date information on the status and trends of the sector, FAO publishes Aquaculture Regional Reviews and a Global Synthesis about every 5 years, starting in 1997. Previous reviews, along with recordings of virtual webinars held 26–29 October 2020, can be found on the dedicated website here: www.fao.org/fishery/regional-aquaculture-reviews/aquaculture-reviews-home/en/

Key words: *aquaculture development, North America, production trends, value, markets, major commodities, consumer preferences, technology developments, external pressures, governance, policies, strategies.*

Abstract

This document summarizes the status and trends of aquaculture development in North America, focusing on Canada and the United States of America, with some discussion on Bermuda, Greenland, and Saint Pierre and Miquelon. Relevant aspects of the social and economic background of each country are followed by a description of current and evolving aquaculture practices and the needs of the industry in terms of resources, services and technologies. Impacts of aquaculture practices on the environment are discussed, followed by a consideration of the response by the industry to market demands and opportunities, and its contribution to social and economic development at regional, national and international levels. External pressures on the sector are described, including climate change and economic events, along with associated changes in governance. The review concludes with an analysis of the contributions of North American aquaculture to the Sustainable Development Goals, the FAO Strategic Objectives, and the FAO Blue Growth Initiative. Throughout the review, outstanding issues and success stories are identified, and a way forward is suggested for each main topic.

Results of this review culminated in eight key findings:

- North America contributes a small and relatively steady level of aquaculture production (600 000 tonnes to 650 000 tonnes annually), but despite the steady production volume, the value of production has continued to rise over the past 25 years.
- Growing global demand for diverse seafood products is probably stimulating local production increases and trade agreements are currently being re-structured and expanded beyond North American parties.
- The increasing value of products over time has been attributed to value-addition initiatives, including branding, eco-certification, processing and packaging so sector growth should continue to embrace such initiatives and to address consumer needs, through further diversification of product lines.
- Growing interest in species diversification has been attributed to challenges associated with environmental sustainability, such as reducing farm impacts, as climate change adaptation strategies, and business risk mitigators in regions affected by fluctuating or uncertain seafood product demand as well as price competition from imported products.
- Technology innovations and their application have contributed to increases in on-farm productivity and decreased production costs.
- Social license, and the negative public perceptions of the aquaculture industry, continue to have an impact on growth, although industry actions to improve its image are becoming increasingly effective.
- With extensive and optimal growing conditions, the region is beginning to embrace the opportunities associated with seaweed aquaculture.
- The regulatory burden for the aquaculture sector has remained high, with sometimes poorly harmonized regulations having an impact on the cost of doing business. Current initiatives in Canada and the United States of America are addressing these constraints to growth.

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Abbreviations and acronyms

AACI	Aboriginal Aquaculture in Canada Initiative
AQUAA	Advancing the Quality and Understanding of American Aquaculture Act of 2020 (United States of America
AMTA	Adjacent Multitrophic Aquaculture
ASC	Aquaculture Stewardship Council
BAP	best aquaculture practices
BGI	Blue Growth Initiative
CAHRC	Canadian Agricultural Human Resource Council
CETA	Comprehensive Economic and Trade Agreement
CFIA	Canadian Food Inspection Agency
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
COVID-19	coronavirus disease 2019
CPGs	consumer-packaged goods
CPTPP	Comprehensive and Progressive Agreement for Trans-Pacific Partnership
DFO	Department of Fisheries and Oceans (Canada)
DHHS	Department of Health and Human Services (United States of America)
ENGO	environmental non-governmental organization
EPA	Environmental Protection Agency (United States of America)
FAO	Food and Agriculture Organization of the United Nations
FDA	Food and Drug Administration (United States of America)
GDP	gross domestic product
GFSI	Global Food Safety Initiative
GMO	genetically modified organism
GSCP	Global Social Compliance Programme
GSSI	Global Sustainable Seafood Initiative
IMTA	Integrated Multitrophic Aquaculture
IPCC	Intergovernmental Panel on Climate Change
ISFA	International Salmon Farmers Association
NAFTA	North American Free Trade Agreement
NOAA	National Oceanic and Atmospheric Administration (United States of America)
PAR	Pacific Aquaculture Regulations (Canada)
RAS	recirculating aquaculture systems
SDGs	Sustainable Development Goals
SEA	Sustainable Ecological Aquaculture

TPP	Trans-Pacific Partnership
USA CB	United States of America Census Bureau
USACE	United States Army Corps of Engineers
USAMC	United States of America–Mexico–Canada Agreement
USDA	United States Department of Agriculture
USDA FAS	United States Department of Agriculture Foreign Agricultural Service
US-EO	Executive Order (United States of America)
UNDESA	United Nations, Department of Economic and Social Affairs, Population Division

EUR	Euro
USD	United States dollar
CO_2	carbon dioxide

1. Social and economic background of the region

1.1 Status and trends

1.1.1 Background

The 2020 regional review of aquaculture in North America is one of a series of regional aquaculture reviews published by the Food and Agriculture Organization of the United Nations (FAO) every five years and focuses on the period between 2015 and 2020 (FAO, 2020a). It is based primarily on FAO information and data compiled from 2015 to 2019 (FAO, 2020b) while additional information was acquired from scientific literature, government statistical reports and industry associations.

The countries and territories included in this review are Bermuda, Canada, Greenland, Saint Pierre and Miquelon and the United States of America. While Bermuda, Greenland and Saint Pierre and Miquelon provide a significant social and demographic contrast to continental North America their reported aquaculture production and future projections do not influence the overall scenario for the region. Mexico is included in the Latin America and Caribbean region for the purpose of these reviews.

1.1.2 Aquaculture status and trends

The North American region continues to make a relatively small contribution to global aquaculture production, providing a relatively steady volume that has fluctuated between 570 thousand tonnes and 660 thousand tonnes over the past eight to ten years (FAO, 2020c; FAO, 2017a). As global aquaculture production has continued to increase, the relative contribution of North American aquaculture has decreased and was 0.8 percent of total global production in 2018 (0.58 percent if aquatic plants are included).

Bermuda and Greenland have not yet generated commercial aquaculture activities despite growing interest in some form of development (FAO, 2017b) while the French territorial islands of Saint Pierre and Miquelon continue to produce very small volumes of aquaculture products (50 tonnes in 2018). Therefore, this review and the associated discussion of status and trends is generally confined to what has occurred in Canada and the United States of America.

The 2015 FAO review of North American aquaculture described environmental impacts, regulatory frameworks, sustainability, partnerships, marketing and access to investment as key influencing factors for aquaculture development in the region (FAO, 2017a). These are still important in 2020 so this review outlines success stories and sector issues that further illustrate these factors.

1.1.3 Population growth

Canada now has the highest annual population growth rate among the G8 countries rising from 0.75 percent in 2014 to a record high of 1.42 percent in 2019, over twice that of the United States of America and bringing the total population of 37.4 million in late 2019. (UNDESA, PD, 2019). Despite having a substantially lower growth rate (0.47 percent), the total population of the United States of America is approximately ten times that of Canada at 329.1 million in 2019 (UNDESA, PD, 2019). More than 80 percent of the population in both countries is concentrated in urban centres, while the rural and expansive coastal areas remain sparsely populated (UNDESA, PD, 2018). The geographic distribution of the population is seen as a concern for long term aquaculture development and sector growth, especially in terms of workforce access to aquaculture sites.

Saint Pierre and Miquelon, lying some 20 km to the south of Newfoundland, has experienced population declines over the decade preceding a census in 2016 and now has approximately 6 000 residents. As the wild capture fishery, primarily Atlantic cod, has declined in recent decades, there has been growing interest in aquaculture, although there are challenging environmental conditions due to high fluctuations in seawater temperatures and large waves, leaving limited options for development.

Greenland, the largest island in the world, is situated between the Arctic and Atlantic oceans and supports an estimated 2019 population of just under 57 000 (World Bank, 2020). The population has grown by 0.12 to 0.17 percent per year over the past five years. However, the population is expected to decline over the next few decades (UNDESA, 2019).

Bermuda is a small island located northeast of Miami in the western Atlantic Ocean off the coast of the United States of America with a 2019 population of 65 441, where the population growth rate (currently 0.2 percent) has been declining since the 1960s (World Bank, 2020). Although Bermuda has a similar population to that of Greenland, it has a much higher population density (1 200 people/km^2) as the total area is only 54 km^2.

1.1.4 Demographics and the aquaculture workforce

Both Canada and the United States of America continue to see a rise in the number of seniors (more than 65 years of age), who make up 17.5 percent of the population in Canada and 16 percent in the United States of America (Statistics Canada, 2019). Although the proportion of seniors in North America is lower than in most G8 countries, for example, the proportion of seniors is 27 percent in Japan and 21 percent in Germany, it is expected that the proportion of seniors will continue to increase between 2020 and 2030, reaching an estimated 22.7 percent by 2031 (UN, 2019).

An aging population will, on its own, have some impact on the available workforce, but the proportion of youth (currently 16 percent between 0 and 14 years of age) will offset this impact to some degree. This assumes that through early introduction to the aquaculture sector and increased training opportunities a sustainable workforce could be generated to support future operations and sector growth. Furthermore, immigration, particularly in Canada, contributes significantly to overall regional population growth and will provide a positive impact on recruitment of workers to this sector.

1.1.5 Incomes, economies and regional trade

Gross Domestic Product (GDP) data for the region is dominated by the United States of America which had a GDP of USD 21 430 billion in 2019, while the GDP of Bermuda was USD 5.6 billion, the GDP of Canada was USD 1 736 billion, the GDP of Greenland was USD 3.1 billion and no data was available for Saint Pierre and Miquelon. (World Bank, 2020).

According to the Canadian 2017 Income Survey, the medium after-tax annual income of Canadian families and unattached individuals rose by 3.3 percent to USD 46 500, following two years without growth (Statistics Canada, 2019). This gain was attributed to a combination of factors, including higher wages among non-senior families (highest income earner less than 65 years of age), and an increase in child benefits. Similarly, a 2.7 percent increase saw non-senior family incomes rise to USD 71 770 in 2017.

In the United States of America, for the same period, the median household income rose approximately 2.6 percent over the previous year to USD 60 336 (USA CB 2017). This was reported as the fifth consecutive year of increases and the first time the national median income exceeded those prior to the global economic downturn of 2008.

In terms of trade agreements, the last few years have seen a number of changes to the North American landscape, the impact of which has yet to be realized. In 2017, the Comprehensive Economic and Trade Agreement (CETA) came into force and in 2018, Canada signed the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP) (Vesselovsky, 2018). In October 2018, Canada, Mexico and the United States of America negotiated the United States of America–Mexico–Canada Agreement (USAMC) to replace the North American Free Trade Agreement (NAFTA).

The United States of America is the largest importer of fish and fishery products in the world with 2018 imports of USD 23.7 billion while exports of fish and fishery products amounted to USD 6 billion, resulting in net imports of USD 17.7 billion (FAO, 2020c).

Canadian farmed seafood exports were valued at USD 689.8 million in 2018, with approximately 70 percent of these exports going to the United States of America (Statistics Canada, 2018). Although aquaculture remains a small percentage of overall agricultural output in both countries, as noted in the 2015 FAO regional review (FAO, 2017a) there is a marked and well-established regional distribution of production. For example, farmed salmon remains the largest agrifood export from the Canadian coastal province of British Columbia and comprises more than 50 percent of Canadian total farmed fish production.

1.2 Salient issues

The social and economic perspectives and status of North American countries and territories will jointly affect how and to what degree the aquatic food sector, and farmed production in particular, develops and performs in the future. The economies of Canada and the United States of America have fully recovered from the global economic downturn of 2008, and the economic climate up until spring 2020 would appear to have positioned the region to support and continue to facilitate growth in the technology-based aquaculture sector. However, the economic impacts resulting from the coronavirus disease (COVID-19) global pandemic starting in early 2020 mean that the expected growth for this region is likely to be delayed.

As noted in the 2015 review (FAO, 2017a), the ageing population of North America may represent a significant challenge to the ability of the aquaculture sector to meet labour needs. For example, in a 2016 study conducted by the Canadian Agricultural Human Resource Council (CAHRC, 2016), the increasing product demand seen in aquaculture sector will require an estimated 4.2 percent annual increase in production by 2025. This increase would represent an additional 1 300 workers, bringing the total to 5 800. The study identifies the “rural nature” of aquaculture as the most significant challenge to worker recruitment and retention, with declines in rural community populations making it increasingly difficult for aquaculture operators to source labour so immigration and seasonal workers may be key sources for the required labour force.

Although most aquaculture operations in North America are situated in remote coastal communities, the sector strives to provide good living conditions, competitive wages and benefits, and reasonable access to urban centres. The demographic for those entering the aquaculture industry in this region (Statistica, 2019) is best described as “young, educated and mobile”. It may also include those First Nations communities that reside in these areas who have traditionally relied upon seafood.

While the projected needs for aquaculture sector labour may raise some concerns, given the anticipated growth in production, a few trends and aspects of the sector provide cause for optimism. First, most industry participants are under 40 years of age (CAHRC, 2016), so retirement will not be an issue in the near future. Second, an increase in immigration (particularly in Canada; Statistics Canada, 2019) may help offset the challenges of attracting and retaining labour in communities that support farming operations. Migrant workers may also continue to support seasonal activities for aquatic food production sectors. Third, the aquaculture industry in North America is considered intensive and increasingly technology-based, reducing cost of production with operational efficiencies including process automation, robotics, machine learning, and virtual or augmented reality solutions. An educated workforce for maintaining and improving these systems will still be needed, albeit fewer will be required in regions with less intensive aquaculture. The educational levels in Canada and the United States of America continue to increase, which can provide this work force. In the United States of America, for example, the percentage of adults who have received at least a bachelor's degree was more than 20.6 percent in 2018 (USA CB, 2019), and of those, 52.3 percent were female. Nevertheless, there is a need for increased aquaculture training and a need to replace the serious loss of expertise resulting from the retirement of pioneering professionals (Jensen *et al.*, 2016). The loss of human capital and institutional capacity is an issue that will affect aquaculture sustainability and growth in the United States of America in the near future and one that will certainly apply to the other North American jurisdictions.

1.3 The way forward

While Canada and the United States of America remain one of the most successful trading partnerships in the world, their trade agreements have undergone recent changes that may impact future seafood market opportunities. The challenge for North America in the coming decades will be to maintain the significant cross-border trade that was successfully developed through the 1994 North American Free Trade Agreement (NAFTA) which generally provided a balanced economic climate for collaborative and sustainable regional growth.

With a re-negotiated NAFTA, the United States of America-Mexico-Canada Agreement and new international trade agreements such as the Trans Pacific Partnership (TPP), an opportunity exists for expansion into new and growing seafood markets such those in Asia and the Pacific. The 2015 FAO review anticipated imminent signing of the TPP, but the new administration in the United States of America a few months later issued a directive to withdraw from the TPP making it unclear how this might affect the historically strong Canada-United States of America trade relationship (FAO, 2017a).

At a minimum, an expansion of seafood trade partners, particularly in the Asia-Pacific area where increases in demand are readily apparent, may reduce availability of production, traditionally destined for the North American partners. The added challenge going forward will require a focused effort on the maintenance of a working relationship between these neighbouring nations, which will ultimately facilitate North American aquaculture sector development and growth. With inherent limits to production and stagnation in production within North America, available product must seek and satisfy the most profitable marketplace. Reliance on a single trade partnership may result in additional risk to the individual sector partners, so diversification in markets becomes appealing.

2. General characteristics of the sector

2.1 Status and trends

2.1.1 Overall production trends

The aquaculture sector in North America continues to support domestic and international markets with a variety of aquatic products from marine, estuarine and freshwater systems. The increasing global consumer demand for high quality aquatic food, coupled with the inability of wild stocks alone to support this demand, provides an opportunity for aquaculture production to fill this gap (Cross, Flaherty and Byrne, 2016).

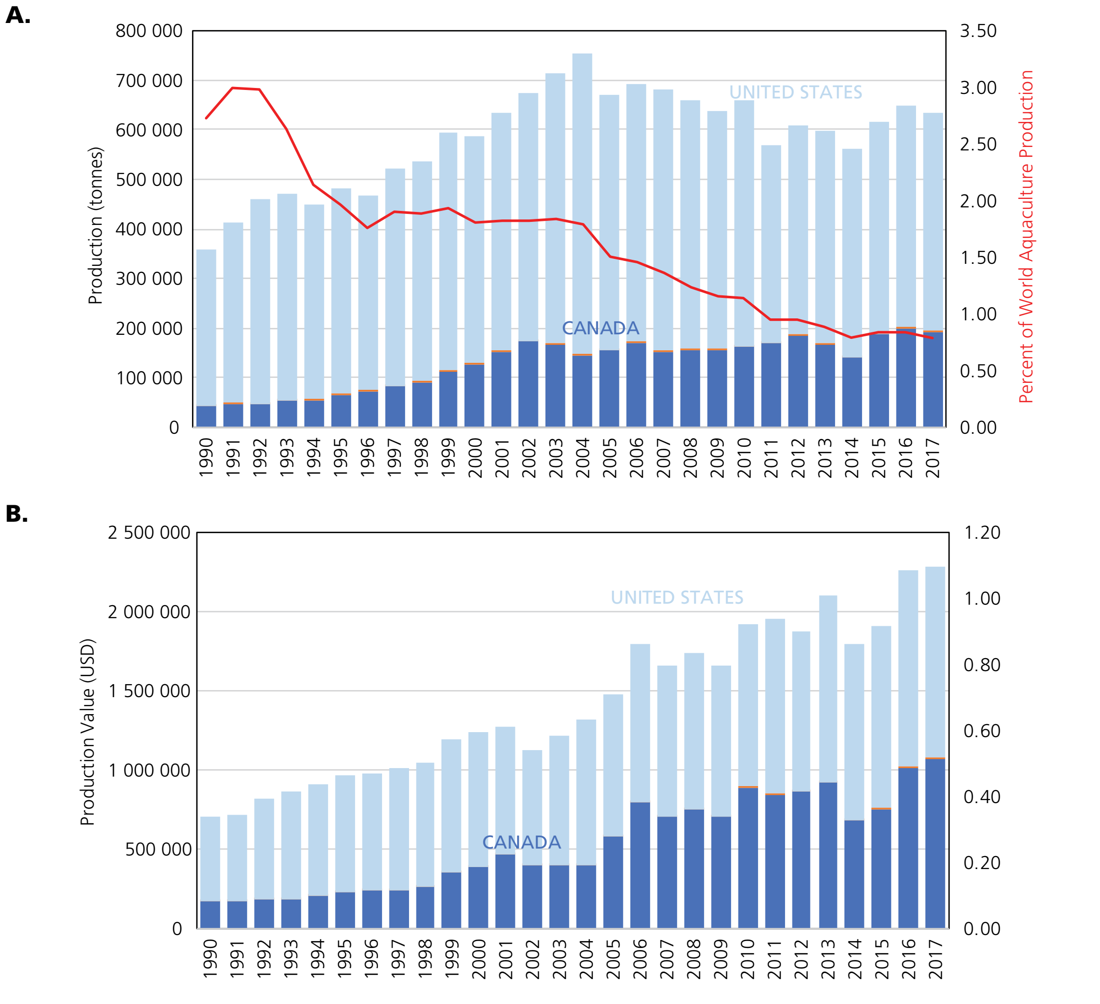
Increasing demand for aquatic food continues to stimulate growth in aquaculture globally, but growth in North America is generally lagging behind the rapid expansion seen elsewhere, largely due to a high governance burden and, in many areas of the continent, environmental activism (Cross, Flaherty and Byrne, 2016). Figure 1A shows the aquaculture production trend for Canada and the United States of America from 1990 to 2018 (FAO, 2020c). Aquaculture production in 2018 was approximately 468 185 tonnes in the United States of America and 191 323 tonnes in Canada. While slow and steady growth in production occurred between 1990 and 2003 to 2004, annual production has plateaued, if not declined over the last 15 years. As a result, the North American share of global production, has continued to drop and is now well below one percent (trend line in red, Figure 1A). However, although North American aquaculture only contributed less than one percent to the global total, Canada is ranked as the fourth largest salmon producer.

Figure 1B shows the annual value of total aquaculture production for Canada and the United States of America since 1990 (FAO, 2020c). The 2018 value of aquaculture production was approximately USD 1.1 billion in Canada and USD 1.23 billion in the United States of America. Despite production volume stalling since 2002-2003, the value of aquaculture products has continued to rise. Industry has responded to the constraints (outlined in subsequent sections of this report) that have limited production increases through a variety of value-added approaches. These value-added approaches have included new product development (rather than simply whole-product sales), custom processing and packaging, third-party certification of farm operations and new, effective branding and product marketing.

Despite the slowing overall production trend, the North American aquaculture industry has continued to diversify and innovate, driven by three main factors; economic and livelihood opportunities, social license and eco-ethical consumer demands and changing environmental conditions. Growing market demand for value-added products created in response to these conditions has provided opportunities to significantly increase the value of aquaculture products despite the levelling of annual production.

While Canadian aquaculture production volume was between 33 percent and 45 percent of that in the United States of America over the period 2014 to 2018, the production value for Canadian aquaculture products rose steadily over the period. The value of aquaculture production from the United States of America remained between USD 1.1 billion and USD 1.2 billion from 2014 to 2018 and Canadian aquaculture production value grew from USD 0.7 billion to USD 1.1 billion. This dramatic difference in production value is most likely attributable to the Canadian focus on high-value marine species, such as salmon, which accounted for approximately 85 percent of the total production value, as well as recent efforts to develop value-added products, particularly for finfish.

FIGURE 1. Annual aquaculture production from 1990 to 2018 in Canada (light bars) and the United States of America (dark bars) in volume (A) (tonnes) and value (B) ('000 USD). Red line shows proportion (as a percentage) of total global production



2.1.2 Canadian production and value

Canadian finfish and shellfish aquaculture production volumes (2014–2018) and associated farm-gate values are shown in Table 1 (FAO, 2020c). These data represent Canada as a whole, although regional differences in production focus have remained similar to previous reporting periods (FAO, 2017a; FAO, 2011), with western Canada having the largest share of finfish production (mainly salmon), eastern Canada dominating in terms of shellfish (mainly mussels), and central Canada (Ontario) leading freshwater production (mainly trout).

Total Canadian production volume has fluctuated over this period with a low point of 139 732 tonnes in 2014 due to salmon production dropping from 116 thousand tonnes in 2012 to only 86 000 tonnes. Salmon production recovered in 2015 but has not increased since then and total aquaculture production has ranged from 187 000 tonnes to 201 000 tonnes. However, the value of total aquaculture production has risen steadily, increasing from USD 0.7 billion in 2014 to USD 1.1 billion in 2018.

Canadian finfish represents the largest proportion of total production and by far the highest value of aquaculture products generated in the country (Table 1). The top three finfish species, representing the majority of production, are Atlantic salmon (*Salmo salar*), freshwater rainbow trout (*Oncorhynchus mykiss*), and steelhead trout (*Oncorhynchus mykiss*), the sea run, or

TABLE 1. Canadian aquaculture production (tonnes) and farm-gate value ('000 USD) from 2014 to 2018

USD x 1 000		2014	2015	2016	2017	2018
Finfish	Salmon	492 592	519869	769 978	812 741	855 206
	Trout	33 824	31 305	42392	41 094	43 614
	Steelhead	5 321	1 940	0	7 643	416
	Other	11 506	11 200	11 077	13757	11 136
	Total	**584 480**	**682 519**	**948 953**	**1 000 025**	**1 017 000**
Shellfish	Clams	5 763	7 122	5330	5700	5884
	Oysters	26 601	28 415	29901	34724	38452
	Mussels	40 549	33 698	28427	27815	31900
	Scallops	588	244	295	476	393
	Other	1 524	173	2 035	2 905	4 968
	Total	**75 025**	**69 652**	**65 989**	**71 620**	**81 597**
TOTAL AQUACULTURE		**659 505**	**752 170**	**1 014 942**	**1 071 645**	**1 098 597**

Tonnes Produced		2014	2015	2016	2017	2018
Finfish	Salmon	78 979	121 926	123 522	120 553	123 184
	Trout	6 698	7 062	9 507	9 126	9 323
	Steelhead	790	718	0	1072	65
	Other	1 209	1 177	1 237	1 304	1 280
	Total	**93 656**	**151 031**	**160 054**	**151 342**	**149 418**
Shellfish	Clams	1 626	2 402	1 962	1 624	1 681
	Oysters	12 604	11 153	13 824	13 800	14 614
	Mussels	25 464	22 725	24 584	24 448	24 918
	Scallops	114	31	38	75	94
	Other	119	32	103	127	110
	Total	**39 927**	**36 343**	**40 511**	**40 074**	**41 841**
TOTAL AQUACULTURE		**133 583**	**187 374**	**200 565**	**191 416**	**191 259**

Source: Government of Canada, 2019a; FAO, 2020c.

saltwater form of this anadromous species. Small amounts of two Pacific salmon species, coho (*Oncorhynchus kisutch*) and chinook (*Oncorhynchus tshawytscha*) are also cultured using the same husbandry methods as Atlantic salmon.

The intensive farming approach for each of these finfish species is similar, with most farm companies maintaining their own broodstock facility with a genetic selection programme, a hatchery for spawning and juvenile production and a standardized net-cage system for on-growing in either marine or freshwater environments. Ongoing development and commercial-scale testing of land-based production systems supplements these coastal facilities but most of these are currently used to increase fingerling or smolt size prior to placing them in net pens.

The annual production of salmon has remained relatively steady since 2015, at 120 000 tonnes to 123 000 tonnes (Table 1). Production in 2014 was at a decadal low among most of the cultured species, but rebounded in 2015, forming the basis for consistent annual production thereafter. Atlantic salmon is the dominant cultured species, although some coho and chinook salmon are produced on the west coast. The value of salmon produced in Canada represents over 85.4 percent of all the finfish, and 78.8 percent of all aquaculture production (fish and shellfish). As the 2018 salmon production value was USD 0.9 billion, the significance of the aquaculture sector to the country is clear.

Of particular note is the Creative Salmon Company which is the first Canadian salmon farm certified for organic production, located on the west coast of Vancouver Island and is farming Chinook salmon. It is a good example of how companies have used certification, coupled with customer engagement through social media, to increase production value. Most of the other west coast companies have achieved Best Aquaculture Practices (BAP) certification and are working to achieve Aquaculture Stewardship Council (ASC) certification. This is especially important for companies where the potential for expanding production, for example by opening new sites or intensifying production, is limited by regulations or social license.

Rainbow trout production in Canada is conducted in freshwater ponds in a number of provinces, although Ontario (Central Canada) continues to produce over 50 percent of the national total. Annual trout production increased between 2014 and 2016 and has since stabilized at between 9 400 tonnes and 10 200 tonnes (FAO, 2020c). The value of trout production has also remained steady and was around USD 96 million in 2018 (FAO, 2020c).

Other finfish species, including sablefish (*Anoplopoma fimbria*) and arctic charr (*Salvelinus alpinus*), contribute approximately 1 200 tonnes to total annual production, which has remained steady over the past five years. Most of this relatively small component is currently provided by sablefish, a marine finfish species that is cultured only on the west coast of North America (British Colombia Salmon Farmers Association, personal communication), although in the United States of America only experimentally in Washington State at this time. This high-value species is marketed directly to high-end restaurants in major North American cities and to Tokyo and Hong Kong. Despite the low annual production, the value generated by this species was more than USD 11.26 million in 2018.

The Canadian shellfish aquaculture sector includes a number of species and, as with finfish, the regional focus differs in terms of production. Mussels, oysters, clams and scallops are the primary cultured species, with blue mussels (*Mytilus edulis*) dominant on the east coast and Pacific cupped oysters (*Crassostrea gigas*) on the west coast. British Columbia is the major clam producing province in Canada with the aquaculture industry farming Japanese carpet shell (*Ruditapes philippinarum*), varnish clam (*Nuttallia obscurata*), littleneck clam (*Protothaca staminea*) and geoduck (*Panopea generosa*). Clam culture is also important in Eastern Canada, where there are quahog (*Mercenaria mercenaria*) and soft-shell clam (*Mya arenaria*) farms on Prince Edward Island and in Nova Scotia. In British Columbia, the primary species of scallop farmed is a Japanese/weathervane hybrid scallop (*Patinopecten caurinus x yessoensis*) known as the Pacific or Qualicum scallop. In Eastern Canada, the giant or sea scallop (*Placopecten magellanicus*) and the Northern Bay scallop (*Argopecten irradians irradians*) are the primary species farmed.

With the exception of clams, which are produced on beaches, bivalve shellfish aquaculture in Canada has developed a variety of production methods to support suspended culture on surface or subsurface longlines, or on rafts. The intensive culture of shellfish includes shellfish hatcheries, dedicated juvenile production systems including floating upwelling systems, and on-growing rafts or longline infrastructure to support nets and trays.

Total shellfish production in Canada has remained static in recent years, fluctuating between 39 927 tonnes and 41 841 tonnes from 2014 to 2018 (Table 1) with a slight decline in production to 36 343 tonnes in 2015.

In Eastern Canada and particularly Prince Edward Island, shellfish farms produce around 25 000 tonnes per year primarily of blue mussels, which represents approximately 60 percent of total national shellfish production. The production value has not changed significantly over the past five years and was estimated at USD 34.4 million in 2018.

On the west coast, Pacific cupped oyster dominates shellfish production with an annual output of approximately 7 200 tonnes in 2018 (FAO 2020a) while farms east coast produced about 7 400 tonnes of the Atlantic oyster (*Crassostrea virginica*). The combined oyster production represents about 35 percent of total Canadian shellfish production. The value of both species of oyster, has increased significantly over the past few years, bringing the total value from USD 22.9 million in 2014 to USD 38.8 million in 2018. This significant increase in value, despite the modest increase in production volume can be attributed to increasing sales in the half-shell market (oysters sold raw and served live or fresh in restaurants) while oyster branding, with specialized names, farm location and product labelling has also added value.

Scallops are produced on both coasts and continue to represent a small contribution to overall shellfish production in Canada. British Columbia produces over 85 percent of the Canadian scallops, but these high-value species are also grown in Nova Scotia, New Brunswick and Quebec. Despite the potential for these species, both in terms of growing conditions (suitable farm sites) and unit value for the resulting products (for example, west coast scallops can have a farmgate value of USD 5.13 per kg), annual production over the past five years has been very low and has fluctuated considerably (Table 1). This may in part be due to ocean acidification and disease (Shore, 2014). The most recent production statistics indicate a volume of approximately 94 tonnes in 2018, with a reported farm-gate value of USD 395 000.

Other shellfish species (Table 1) account for fluctuating annual levels of production that are greater than those reported for scallops with annual production typically around 100 tonnes and values of between USD 173 210 to USD 4.97 million, over the last five years. While species-level detail is not reported with these figures, trials of potential aquaculture candidates can contribute to this production category and may include sea cucumbers (*Apostichopus* (*Parastichopus*) *californicus*), green sea urchin (*Strongylocentrotus droebachiensis*), signal crayfish (*Pacifastacus leniusculus*), and other invertebrates.

2.1.3 United States of America production and value

Aquaculture production statistics for the United States of America from 2014 to 2018 are shown in Table 2 (FAO, 2020c). These data represent the status for the United States of America as a whole, recognizing that, as in Canada, production is divided between marine (coastal) and inland (freshwater) operations. Compared to Canada, the species diversity within the United States of America aquaculture industry is quite high, largely as a result of the significant latitudinal differences that determine growing conditions influencing temperature, salinity and primary productivity. North-eastern states support similar coastal aquaculture species to Eastern Canada while north-western states and Alaska, are similar to Western

TABLE 2. United States of America aquaculture production volume (tonnes) and value ('000 USD) from 2014 to 2018

Tonnes Produced		2014	2015	2016	2017	2018
Inland	Crustacea	60 925	63 757	67 659	63 693	72 709
	Finfish	176 372	179 705	183 124	185 752	191 789
	Sub-Total	**237 297**	**243 462**	**250 783**	**249 445**	**264 498**
Marine	Crustacea	2 209	1 805	1 633	1 633	2 035
	Shellfish	160 464	159 516	174 035	171 864	181 228
	Finfish	21 219	21 219	18 228	16 728	20 424
	Sub-Total	**183 892**	**182 540**	**193 896**	**190 225**	**203 687**
TOTAL AQUACULTURE		**421 189**	**426 002**	**444 679**	**439 670**	**468 185**
TOTAL VALUE (USD `000)		**1 108 087**	**1 149 678**	**1 243 018**	**1 212 480**	**1 212 480**

Source: FAO, 2020c.

Canada. In addition, the United States of America supports aquaculture in the warm coastal waters of the Gulf of Mexico. Freshwater production also spans a range of warm and cold-water species, providing further diversity.

Total production remained relatively steady over the period, with slight inter-annual variations between 420 000 tonnes and 470 000 tonnes (Table 2). Freshwater production remained consistently higher than marine production, and accounted for about 56 percent of total aquaculture production in 2018.

Finfish aquaculture in the United States of America is dominated by freshwater production, with total annual freshwater production showing moderate but steady growth from 176 372 tonnes in 2014 to 191 789 tonnes in 2018. The primary species is channel catfish (*Ictalurus punctatus*), which accounted for 159 423 tonnes or 83 percent of total freshwater finfish production in 2018, nearly eight times the production of the entire marine finfish production. Channel catfish is a relatively low-value species (farm gate value around USD 1.5 per kg) and is sold exclusively to domestic markets.

Marine finfish aquaculture contributes about 20 thousand tonnes per year, with production dominated by Atlantic salmon. Total Atlantic salmon production in 2018 was 16 107 tonnes and the majority of farms are located in Maine (northeaster United States of America) by companies affiliated with major Canadian salmon producers. A small proportion of farmed salmon production was from Washington State (north-western United States of America), although following a large fish escape into Puget Sound in 2017, authorities banned the culture of Atlantic salmon in state waters in March 2018 (Britten, 2018). Marine culture of native steelhead trout, in a joint venture with a First Nation, has recently been approved as a substitute (Dawson, 2020). Troutlodge, the largest trout hatchery in the world that has supplied trout to over 60 countries since 1945, is also based in Washington State.

The production of channel catfish and rainbow trout takes place in inland systems including channels, raceways, tanks and ponds, relying on centralized hatcheries to produce juveniles for local farmers. Few companies are completely vertically integrated within this sector. Marine farms are similar to those described for the Canadian industry, where companies typically invest in broodstock selection programmes to ensure optimal performance in their growing areas and use floating cage systems for grow-out.

In the inland, freshwater environments of the United States of America, shellfish aquaculture production is dominated by crustacean culture, which has remained relatively steady over the past few years, generating an annual production of 72 709 tonnes in 2018). This freshwater sector is comprised of two species – the giant freshwater prawn (*Macrobrachium rosenbergii*) and the red swamp crayfish (also called crawfish), (*Procambarus clarkii*). Both are grown in shallow earthen ponds, often with a rotation of agricultural crops such as rice.

Shellfish is by far the most productive marine aquaculture sector in the United States of America, contributing approximately 39 percent of total marine and freshwater production and occurs in farms located in the north-eastern and north-western states, as well as the Gulf of Mexico. This includes the Pacific cupped oyster and American cupped oyster (*Crassostrea gigas* and *Crassostrea virginica*), clams (*Mercenaria mercenaria*, *Venerupis philippinarum* and *Panopea generosa*), as well as blue mussels and Mediterranean mussels (*Mytilus edulis and M. galloprovincialis*) that jointly contributed 242 192 tonnes to total aquaculture production in 2018 (Table 2). Production of shellfish has remained relatively steady over the reporting period, although a 20 000 tonne increase between 2015 and 2016 may reflect a positive trend for the sector.

2.1.4 Aquaculture in other North America countries

Saint Pierre and Miquelon has seen fluctuating aquaculture production between 3 tonnes and 88 tonnes since 2015, with 48 tonnes of mostly mussels and scallops produced in 2018 (FAO, 2018).

Greenland does not presently support an aquaculture sector but small coastal fishing communities continue to rely on wild capture fisheries. Although production trials have been conducted for Atlantic cod (*Gadus morhua*) and blue mussels, results have not been encouraging because of low growth rates and the impacts of very cold winters. Greenland remains interested in developing aquaculture and researchers have recently begun exploring seaweed production, a relatively low-maintenance crop that would be seasonal in nature (Kreissig and Hansen, 2017).

There is currently no aquaculture production in Bermuda, but the government recognises the ongoing interest in the production of farmed freshwater and brackish water fish on land and is developing a robust regulatory regime that can capitalize on this interest and ensure the production of high-quality products with minimal detrimental impact on sensitive island environments (Government of Bermuda, 2019).

2.2 Salient issues

The constraints on North American aquaculture operations have hindered the expansion of operations, restrained production increases and slowed diversification into new systems and species. This is a serious issue for the sector and one that continues to limit the contribution of the region to global aquatic food production. There are substantial opportunities for industry growth across North America, not only in the remote coastal areas of British Columbia and southern Alaska that offer high species diversity, optimal growing conditions and pristine marine environments, but also in the significant freshwater systems of the interior provinces and states. Despite its enviable resource position, the North American aquaculture sector has yet to move forward and take advantage of this opportunity.

The greatest challenge facing the North American aquaculture sector is social license, an issue that first arose in the mid-1990s and is still the main development constraint for expansion of production areas in this region. Environmental issues associated with aquaculture are described and discussed in chapter 4 of this report.

Although initially associated with marine cage culture, the limited social acceptance of aquaculture extends to other production environments and methods as well. As all forms of aquaculture require some alteration of natural ecosystems through factors such as increased stocking densities, controlled seed production with genetic management or selection and aquaculture infrastructure, there are concerns about environmental impact and site contamination, at times reinforced by garbage, noise, traffic and accidents. While these issues continue to be addressed by the industry through appropriate technology and science-based operational improvements, these largely environmental issues over the past few decades have created a perception of poor environmental performance and socio-economic barriers, limiting the ability of the sector to capitalize on the growing business opportunities provided by rapidly increasing seafood demand.

Ocean acidification appears to be particularly advanced in some areas of the Pacific Northwest, affecting oyster hatcheries and scallop production (Shore, 2014; Stiffler, 2017). Oyster growers in Puget Sound are working on technical solutions (Shore, 2014) and raising spat in Hawaii (see section 3.1.3). British Columbia growers are now importing oyster seed from Chile (Dodd, 2015), representing up to 80 percent of the supply in 2020 (N. Sahli, personal communication), as well as searching for genetically resilient farmed types (Kingdon and Daley, 2017; R. Saunders, personal communication).

The North American aquaculture industry has generally continued to improve its operational practices, reduce its environmental impact and make strides in shifting public opinion with respect to aquatic food production, particularly regarding the net cage-based, finfish production sector. However, campaigns led by environmental non-governmental organizations (ENGO) in the last two decades have influenced public perception and political perspectives, and decision-makers have shown reluctance to support industry growth, restricting access to new sites and increasing the regulatory requirements. While ENGO campaigns were initially based upon undisputed environmental impacts of fish farm start-ups in the early 1980s, many of the environmental problems of this period have arguably now been mitigated through science-based approaches, while at the same time increasing profitability and sustainability through holistic and longer term views of corporate risk. Nevertheless, controversy on the topic persists and continues to influence policy.

Certification programmes have become increasingly popular within the industry and are recognized as an approach to provide sustainable operational protocols for farms to address the environmental risks and public concerns regarding the industry, as well as retaining and building their customer base. Programmes such as the Monterey Bay Seafood Watch Programme and Ocean Wise, provide consumers with recommendations, offering a sustainability-based classification of products, in part measured by the level of compliance with certification programmes incorporating specific operational standards including Aquaculture Stewardship Council (ASC), Best Aquaculture Practices (BAP) and the ISO-9000 (Quality) and ISO-14000 (Environmental) Management Standards. In Canada, certified organic standards were ratified for aquaculture by the Canadian General Standards Board in 2012, and producers can use the Canadian organic logo if they meet the requirements of these standards. North American companies have also been very active in development of the Global Sustainable Seafood Initiative (GSSI), a benchmarking tool for third party certification schemes based on international certification standards from FAO, ISO, ISEAL (FAO, 2011). The 2013-2015 GSSI project, financed by the German government and private industry was a public-private partnership on seafood sustainability involving more than 90 industry-wide stakeholders. The GSSI aligns global efforts and resources to address seafood sustainability challenges. It provides a standard for the certification standards, promoting a common baseline for the proliferation of aquaculture certifications. Governed by a steering board representing the full seafood value chain, companies, non-governmental organizations, governments and international organizations including the FAO, GSSI promotes sector-wide collaboration to drive forward more sustainable seafood for everyone (GSSI, 2019).

The widespread acceptance by industry of third-party certification, which requires acceptance of and compliance with best practices that address environmental, social and health risks, coupled with new and effective product branding and target marketing, has improved operational practices in the North American aquaculture sector. However, many consumers do not recognize these certifications and the issue of social acceptance remains so further consumer awareness initiatives are required.

2.3 The way forward

North American aquaculture production has been influenced by a variety of drivers that have in many ways determined its options for regional growth. The lack of social license, and resultant limits on sector growth, have resulted in an industry focus on operational efficiency and production increases in existing farms. Furthermore, this situation has created increased diversification of aquaculture production and the development of specialized and high-value products that provide further choice to a demanding seafood marketplace.

Although annual aquaculture production volume in North America is not increasing, the opportunities for growth and diversification are substantial and represent a major opportunity for this industry. The constraints that have limited opportunities in the past are becoming increasingly clear. New initiatives that directly address public acceptance including social license, enabling legislation and governance, while meeting the demands of a growing aquatic food consumer base, are beginning to open doors that will facilitate change and support growth.

3. Resources and technologies

3.1 Status and trends

3.1.1 Background

The focus of this section is natural resources and the application of technology in the ongoing development of the North American aquaculture sector. This sector is best described as a technology-based, intensive production model. The industry structure and the production approaches used to increase operational efficiencies and sector competitiveness, are what differentiates North America from many other global aquaculture regions.

3.1.2 Land and water

The challenges associated with access to aquatic resources have generally remained the same since the 2015 North American aquaculture review (FAO, 2017a). While the United States of America is primarily based on freshwater production, with its affiliated culture systems, this very much limits growth for the sector, given the finite nature of freshwater resources and competition among multiple stakeholders for its use.

In contrast, Canada's extensive coastlines and the focus on saltwater production systems represents a significant opportunity for aquaculture growth (Advisory Council for Economic Growth, 2017). The physiographic characteristics including the range of tidal flows, salinity and temperature regimes, water depth and primary productivity of the province of British Columbia alone provide both the space and optimal growing conditions not only for expansion of existing production of species such as oysters and salmon, but also a wealth of opportunities for native species diversification including marine fish, invertebrates, and seaweeds given the rich biodiversity of the region. For example, since 1985, the Province of British Columbia has identified over 80 species that have historically supported small regional fisheries, but also represent candidates for commercial aquaculture production. In terms of seaweeds, this area has over 630 species making it one of the richest areas in the world for seaweeds (Gabrielson *et al.*, 2000). In the United States of America, NOAA has identified Aquaculture Opportunity Areas, providing the foundation for appropriate coastal zone management, as one of the tools under its Marine Aquaculture Policy and Executive Order 13921, "Promoting American Seafood Competitiveness and Economic Growth" (NOAA, 2020).

Despite the clear opportunities available for aquaculture growth in various areas of North America, social acceptance issues continue to have an impact on how and where farms can be sited and operated. In western Canada, the Cohen Inquiry, which assessed potential risks associated with farmed and wild salmon interactions, recommended a suite of restrictions on salmon farm positioning with respect to wild population migratory routes (Government of Canada, 2016a). This inquiry provided substantial scientific evidence including a review and summary of wild and farmed disease interactions, facilitating a measured approach intended to support both farming and wild harvest activities along the coast. Nevertheless, this controversy has recently led to the mandated removal of fish farms from the migratory fish route in the Discovery Islands by 2022 (Dawson, 2020) and a continuing expressed commitment by the Canadian government to move salmon aquaculture into land-based systems.

3.1.3 Production diversification

The diversification of aquaculture in North America has been stimulated by social, economic and environmental drivers. The movement towards a more diverse aquatic food production sector is reflected in the variety of species cultured, as well as the research, development and innovations associated with production system improvements. Additional species have been selected as an integral part of multi-species ecological system designs, such as Integrated Multi-Trophic Aquaculture (IMTA) or Sustainable Ecological Aquaculture (SEA) systems (Chopin *et al.*, 2012; Cross, 2012). This approach to species diversification can make a positive contribution to social license, with new species improving how aquatic seafood is produced through integration with the ecosystem. Alternatively, technical innovations allow for greater separation of culture systems from sensitive ecosystems including land-based recirculation systems (for example, Kimta Farms) and off-shore cage-based systems (for example, Ocean Era, Hawaii, United States of America). Diversification can therefore support both economic and business improvements, as well as addressing the environmental challenges.

Production diversification is now being considered in both the finfish and shellfish sectors, typically in response to market demand but also as a business response to climate change impacts that are occurring or have been forecast for the near future. Examples of diversification can be found in all geographic regions of North America and the following examples are provided mainly from the Pacific Northwest (Alaska and Washington States, United States of America; British Columbia, Canada).

Diversification in clam production has been stimulated by increasing demand, increasing product value, technical advances, and opportunities to supplement and increase existing farm-level production (co-culture) with additional species (Cross, *et al.*, 2016). For beach production, the addition of geoduck (*Panopea generosa*) to the lower intertidal and shallow subtidal regions is seen as a high-value option that complements Manila clam (*Ruditapes philippinarum*) or beach oyster operations. In deepwater farms, where rafts are typically used to support oyster production, a unique opportunity to add native cockle (*Clinocardium nuttallii*) is under consideration as this is the only clam species so far that shows potential to be cultured in suspended trays in the absence of beach substrate (Dunham *et al.*, 2013).

Although North American finfish aquaculture is well established and comprised of a few major production species, there is ongoing interest in diversifying production to satisfy both domestic and export market demands. In Canada, halibut (*Hippoglossus* spp., rockfish (various species), wolf eel (*Anarrhichthys ocellatus*) and sablefish (*Anoplopoma fimbria*) are relatively new and could be considered to be in the pre-commercialization stage. The production of small (plate-size) fish, especially rockfish, is a new opportunity for a growing Asia-Pacific market. In the United States of America, white seabass (*Atractoscion nobilis*), burbot (*Lota lota*), and halibut are also included as species in the pre-commercialization stage of development and with most of the basic research completed, they will soon be ready for production.

Sea cucumbers (various species) are a high-value delicacy in China and demand has increased dramatically as China's middle class has grown while the global supply has failed to meet demand. As an epibenthic detritivore, the sea cucumber has potential as a co-culture species with shellfish (Paltzat *et al.*, 2008) and as an organic waste extractive species with finfish in an IMTA/SEA multi-species system configuration (Cross, 2012; Chopin *et al.*, 2012; Hannah *et al.*, 2013; Van Dam-Bates, *et al.*, 2016). Regional challenges with sea cucumbers include cost of production if containment is required and the present regulatory restrictions that prevent an ocean ranching approach. Current research by the industry and governments is addressing each of these constraints.

3.1.4 Production technologies

With inherent strengths in technological innovation and a focus on its uses across the aquaculture sector, North America offers examples of a variety of production technologies.

Ongoing research and innovation has been supported to increase sustainability of the sector and to provide industry with increased operational efficiencies, decreased cost of production and thus increased global competitiveness.

Over the past three or four decades, innovations in farm design and practices have introduced technologies that in many cases, have become standard across the various aquaculture production sectors. Automated feed delivery systems, cameras for monitoring feed uptake, new net materials, antifoulant compounds, cage and production system designs (offshore, IMTA), fish harvest uplift systems, shellfish suspended culture systems and on-site shellfish depuration systems all continue to be assessed and upgraded. The sector is also incorporating and adapting new technologies such as artificial intelligence, robotics, sensor integration, the internet of things, and virtual or augmented reality applications.

Recirculation aquaculture systems (RAS) continue to be of interest in North America, not only as a relatively new approach for fish production, but also in response to pressures to move coastal production to land-based facilities. In March 2019, the Government of Canada announced a study to examine land-based and ocean-based closed containment technologies to reduce cultured salmon interactions with the environment or wild salmon, as well as options for offshore aquaculture production systems (Salmon Business, 2019). However, the report from this study has not yet been released.

As with the adoption of any new practice or technology, tradeoffs must be considered. For on-shore RAS culture, the increased energy, land, and freshwater requirements, are expected to lead to higher operating costs and associated negative externalities including increased greenhouse gas emissions, with the International Salmon Farmers Association (ISFA, 2019) estimating a three-fold increase compared to marine cage culture. These costs and impacts would need to be assessed and balanced against other options to provide evidence-based decision-making support for policymakers and the private sector. Several other pilot projects are initiating salmon culture in RAS systems including Kuterra, a pilot, land-based salmon farm owned by the Namgis First Nation in British Columbia, in expectation of an eventual exclusion of cage-based aquaculture in that region (Kuterra, 2020). These pilots, in North America and other parts of the world, will provide information on the costs and overall feasibility of this approach.

Recirculation systems are also being explored for other species. In central Canada, a few smaller Ontario growers have developed RAS-based operations for the production of Asian sea bass (barramundi, *Lates calcarifer*), shrimp (for example, Good4uShrimp Inc.), and tilapia. Proximity to a large local market such as the Greater Toronto area is a major benefit to these operations.

The development of new seed production protocols has been a necessity as species diversity in aquaculture production increases. The production of seed is a critical stage in the life cycle, and the lessons learned from developments in many of the pioneer species (such as oysters, mussels, shrimp, catfish, trout and salmon) are now being applied to new species in a process that can expedite commercialization. Interestingly, Taylor Shellfish, the largest oyster grower in the United States of America, transports oyster and clam seed from a nursery in Hawaii to Puget Sound for grow-out, taking advantage of Hawaiian productive water, climate and lack of seasons. This has also helped to mitigate impacts of ocean acidification that is particularly affecting the American northwest (Stiffler, 2017).

Ongoing research continues to focus on optimal diets for broodstock and the various early life stages of seed production, as feeding is integral to the development of healthy seed and ensuring greater survival through the on-growing phase of production (Cheng *et al.*, 2020).

In terms of juvenile fish production, many hatchery facilities are now based on RAS, offering high levels of control over environmental parameters. Increased survival of fingerlings and smolts has been achieved by increasing the length of time spent in the hatchery, resulting in larger juveniles for final on-growing in net pens or other production systems. Survival, health and growth of individuals is enhanced through this approach.

Genetic techniques are helping the aquaculture sector enhance production, particularly through the development of selective breeding programmes for fish, invertebrates and seaweeds. These tools are helping to identify and develop farmed types adapted to environmental conditions that are particularly important in light of the rapid changes caused by climate change. These tools also enable a greater understanding of diseases and parasites, and the relationship between environmental stressors and aquatic animal health, in addition to the development of disease-resistant farmed types.

Genetic techniques can be further leveraged for more productive and competitive industry growth, while protecting wild stocks and ecosystems. Effective genetic management and improvement can provide aquaculture with the tools to support strong, competitive growth based on product quality and security, technological soundness, economic viability, environmental integrity and social license. MacKenzie and Jentoft (2016) describe current advances within the field of genomics and their applications to aquaculture, providing a review of key genomic tools ranging from genome sequencing, to transcriptomics and proteomics with the potential to enhance production performance and add value to traditional approaches such as selective breeding. Many of the current aquaculture species under commercial production in North America are considered in this review including rainbow trout, channel catfish, tilapia, Atlantic cod, salmon, carp and molluscan shellfish. Genomics has also produced the world's first transgenic salmon in North America, which is now proceeding into RAS-based production.

Aquaculture currently uses 70 percent of global supplies of fishmeal and fish oil, making it the largest consumer of these commodities (FAO, 2017a; Chauton *et al.*, 2015). It is projected that demand for these aquafeed components, extracted from wild fisheries such as sardine, herring and anchovy, will exceed global supply by 2040. Development of new and sustainable aquafeeds has necessitated finding alternatives to fishmeal and fish oil for environmental, food security, and financial reasons. Terrestrial-sourced ingredients such as soya, is one option, but this also presents sustainability challenges, including competitive use of a limited resource, climate change, environmental impacts and quality of the resulting feed formulations such as compromised fatty acid profiles and reduced palatability.

There is promising ongoing research into alternative aquafeeds on the use of marine microalgae, which are excellent sources of essential amino acids, minerals, vitamins and omega-3 fatty acids, all of which are needed to the nutritional requirements of fish. A new aquafeed has replaced fish oil with microalgal oil based on the inclusion of whole *Schizochytrium* sp. cells and replaced fishmeal protein with leftover biomass from another oil-extracted marine microalga, *Nannochloropsis oculata*, a protein-rich waste product from commercial omega-3 dietary supplement production. Initial feed trials show increased performance including higher weight gains, improved feed conversion and product quality (Chauton *et al.*, 2015). As marine microalgae do not require fresh water or a terrestrial base, there is significant potential in generating sustainable commercial aquafeeds that eliminate the challenges identified with agri-based alternatives.

3.2 Salient issues

ENGOs continue to push for stricter environmental regulation and standards for salmon aquaculture, including moving all open net cage aquaculture to land-based facilities. Disease outbreaks and large escapes of non-native Atlantic salmon have contributed to legislation banning ocean rearing of this species in Washington State (Mapes, 2019), while the current Canadian government, following an election promise, recently mandated Fisheries and Oceans to create a responsible plan to transition from open net-pen salmon farming to entirely land-based production systems in coastal British Columbia waters by 2025 and begin work to introduce Canada's first-ever Aquaculture Act (DFO, 2020). Both the British Columbia provincial and Canadian federal government have policies to move salmon farming on-shore. While the aquaculture industry has not been enthusiastic about this, it welcomes the prospect of a new Aquaculture Act.

Atlantic salmon is the first genetically modified (GMO) fish to enter the market and one of the first GMO animals to be used in agriculture. AquaBounty Technologies Inc., which has farms in the United States of America (Indiana) and Canada (Prince Edward Island), also grows conventional Atlantic salmon as well as bioengineered salmon in RAS facilities. These Atlantic salmon contain transgenes from the Pacific Chinook salmon and a promoter from the ocean pout (*Zoarces americanus*) which regulate growth hormone production, specifically allowing for year-long growth in colder temperatures. The AquAdvantage fish are made triploid and thus sterile, to reduce risk of interbreeding with wild fish, should an escape occur. Following a lengthy process over more than 15 years, AquaBounty (2020) received approval for commercial production and sale of their fish from the Food and Drug Administration (United States of America) in 2015, and from Environment and Climate Change Canada, Health Canada and the Canadian Food Inspection Agency in 2019. The product has been deemed safe for consumption after extended scientific reviews in both countries. However, the commercialisation of this GMO remains contentious in the United States of America and several court challenges have been launched to block the import of genetically modified salmon, with more anticipated.

The integration of land-based technology into the aquaculture sector serves as an effective way to make existing forms of production more efficient and more profitable. For example, hatchery facilities for both finfish and shellfish, which have been land-based for decades, are now using state-of-the-art technologies. These seed production facilities integrate sophisticated sensor arrays, automated water treatment systems and electronics controllers which are fully programmable to operate the facility within very narrow specifications. They can also compensate for acidification of ocean-sourced waters.

The use of advanced technologies is also applied in farm systems. For example, automated feeding systems including robotics and machine learning software in finfish farms and computer-controlled oyster grading offer total control of critical components of the seafood production cycle. Processing plants are now equipped with fully automated process lines, where fish are sized, measured, cleaned and assigned boxes for subsequent processing.

Interest is growing for production using both land-based and off-shore systems. Salmon Business summarizes projects in production or under construction in Canada and the United States of America including four producers of 72 tonnes to 600 tonnes, all with plans to expand (Evans, 2019). The largest of these is Atlantic Sapphire, currently producing 3 000 tonnes per year of Atlantic salmon is constructing a 220 000 tonne facility in Miami intended to enter full production capacity by 2031 (Evans, 2019). Nordic Aquafarms is also planning two projects to produce over 16 000 tonnes per year of Atlantic salmon and possibly steelhead trout in Maine and California (Owens, 2019). In addition to Nordic, Maine has two other companies with land-based aquaculture plans; a Dutch company, Kingfish Zeeland, planning to raise yellowtail (*Seriola lalandi lalandi)* for the sushi market and a second company raising Atlantic salmon and also planning a processing facility. The two Atlantic salmon projects planned for Maine are industry partners with Superior Fresh, a commercial aquaponics producer in Wisconsin, in receipt of a large capacity-building grant from Maryland Sea Grant with a goal to help identify the limits to producing market-sized salmon in recirculating systems (Salmon Business, 2019).

As noted previously, coastal British Columbia, Washington and Alaska comprise some of the richest areas in the world for seaweeds. Although there is a growing interest in commercial cultivation of seaweeds in this area, current development is limited primarily to a number of brown and red species, although there has been some recent interest in green taxa. Economically, kelps and rockweeds are harvested, and can be produced through aquaculture, with their raw form used for food products, cosmetic and luxury spa items, and fertilizers. Through processing, cellular components such as alginic acids and polysaccharides can be extracted and used as emulsifiers, anticoagulants, and in the production of textiles and rubbers.

Kelps and seaweeds represent only a small percentage of current aquaculture production along the north-eastern seaboard, but support some targeted fisheries and have huge potential for expansion. Until relatively recently, seaweed and kelp has been wild-harvested only. Irish moss (*Chondrus crispus*) is now cultured in land-based tanks in Nova Scotia, and the brown seaweeds *Saccharina latissima* (sugar kelp) and *Alaria esculenta* (winged kelp) have been cultured alongside Atlantic salmon and blue mussels at an IMTA system in New Brunswick and at sea sites in Maine. Horsetail kelp (*Laminaria digitata*) is also cultured commercially in Maine. Research, development and early commercialization of dulse (*Palmaria palmata*) and nori (*Porphyra* spp.) is ongoing in Atlantic Canada and New England.

3.3 The way forward

Despite the potential for aquaculture growth in North America, environmental issues that have tainted social acceptance of the sector continue to create barriers to expansion. As an intensive technology-based industry, efforts to increase production within the constraints of the current regulatory burden have focused on the development of new production technologies, diversification of production in support of new sustainable production models and exploring options for entirely new production sectors such as seaweeds. All focus on ways to address environmental and sustainability issues of the sector. The science-based approach taken in each of these approaches is gaining support from the public and resulted in recent policy changes, and it is expected that the aquaculture industry will see more rapid development in the coming years.

4. Aquaculture and environmental integrity

4.1 Status and Trends

Many aspects of North American aquaculture are linked to and influenced by the overarching issue of social license, as has already discussed in chapter 2 of this report. This continues to be a critical issue that is influencing decision-makers, increasing the regulatory burden, prohibiting access to resources, and deterring sector investment. The ultimate result is a negative impact on growth of the sector and overall unrealized potential. However, there is evidence that the industry is exploring opportunities that address the environmental issues which may therefore have positive effects on social license.

This section of the review provides a summary of the environmental performance issues of the aquaculture industry as practised in North America and then, through a focused success story, looks at one of these issues (organic/inorganic waste discharges) and an initiative that is being implemented to mitigate these impacts while diversifying production and increasing social acceptance.

4.2 Salient Issues

The 2015 North America Aquaculture Review (FAO, 2017a) provided a synopsis of the key environmental issues associated with the aquaculture sector. While there are environmental interactions with all types of aquaculture, the impacts of fed aquaculture operations such as finfish and shrimp are seen as more substantial than those associated with non-fed aquaculture facilities such as shellfish and seaweeds.

The 2015 review described five issues associated with coastal finfish aquaculture, the sector representing the greatest production and value in North America. The first is the transmission of disease from farmed to wild stocks including parasites, such as sea lice and the treatments used to control these. This is related to the issue of drug and chemical usage and impacts of residues in the food chain as well as systemic impacts of anti-microbial resistance. Disease is also linked to the issue of fish welfare, as is on-farm husbandry conditions.

The second set of issues is competition between sectors. Coastal marine farming can compete with other users of waterways and coastal zones, such as tourism, fishing, recreational activities, and navigation. There are also concerns about the use of non-native species, including the risk of accidental introductions and invasion. Meanwhile, even with native species there is a risk of genetic erosion if a farmed-type escapes and breeds with wild native stocks, and public opinion surrounding genetically modified organisms further adds to this debate.

All of these issues are concerning to consumers and the wider public, and influence aquaculture development as a whole, despite the fact that scientific evidence may still be inconclusive. For example, the ability for sea lice to be transferred from farmed fish to migrating wild stocks has an extensive scientific literature base, but consensus is lacking (Cubitt, Butterworth and McKinley, 2008). This type of uncertainty, or science-based disagreement, can be seen in a number of other issues, including disease transmission, production of GMOs and offshore farming.

These issues are nonetheless highly recognized by the public and remain major concerns that continue to be argued as reasons to avoid farmed fish. However, these issues are less relevant to the farmed shellfish sub-sector and while agricultural production has many comparable issues, the lack of acceptance of aquatic food under similar production scenarios continues to plague the industry.

Surprisingly, the contribution of organic wastes from aquatic farm installations, and the resulting impacts on local habitats and species is sometimes omitted from the debate over the environmental sustainability of aquaculture despite irrefutable impacts that these wastes can cause (Cross, 2012; Chopin *et al.*, 2012). However, the impacts of organic wastes have been measurably less over the past few decades as feeding techniques have become more efficient, feed formulations have improved and feed conversion ratios dropped. Despite this, little acknowledgement has occurred of the systematic approach to environmental interaction taken by industry.

The integration of species that extract organic waste, such as scallops and sea cucumbers, and inorganic waste such as aquatic plants and seaweeds together with fed species has been studied extensively for the past 15 years. Researchers continue to look to integrated multi-trophic aquaculture (IMTA) as an environmental solution to the issue of finfish aquaculture waste discharges (Chopin *et al.*, 2012). However, IMTA has yet to be fully developed commercially and as stated by Cross (2012) this multi-species approach is not likely to be adopted by the salmon farming industry due to the nature of their business, the infrastructure re-configuration challenges associated with proper IMTA design and component orientation and the fact that the sites selected for salmon are not necessarily optimal for the suite of extractive species required. IMTA development will require new policies, new infrastructure design and site selection for water circulation and quality that meets the requirements of all the species involved.

A pilot Adjacent Multitrophic Aquaculture (AMTA) design was developed recently in British Columbia as a more feasible option for salmon farmers than IMTA. Developed by Cross (2004), this approach examines the addition of shellfish and seaweed production components to a fish production site. Unlike an IMTA design, these nutrient extractive components need not be immediately adjacent to the fish and thus not in a position to interfere with fish production. This configuration takes full advantage of the unused space within the aquatic tenure area, in this case, the water column above the anchor lines, allowing on-farm diversification, economic benefits, nutrient extraction and improved environmental performance. The use of native species addresses social concerns over the use of non-native species in aquaculture.

Bearing in mind the real constraints (biophysical and business) that have constrained uptake of the IMTA model in Canada and by other finfish production jurisdictions globally, this study focused on an approach that circumvents many of the issues. In doing so, real benefits can be realized by the farm including revenue generation through production diversification, but also by the public who see the environmental benefits of the extractive component, the use of local aquatic species that are not fed (invertebrates and seaweeds), and the socio-economic benefits to rural coastal communities such as associated jobs, operational partnerships with fish farm companies, service sector opportunities and co-culture sector growth.

The AMTA approach has recently been embraced by a new seaweed company in British Columbia (Cascadia Seaweeds Corp) and this company is engaging both First Nation communities and salmon farmers to produce sugar kelp at a number of salmon farms along the coast. The production and profitability evaluations have been successfully demonstrated and partnership agreements and scale-up plans are currently underway.

Aquaponics uses nutrient-rich water from RAS fish culture to fertilize terrestrial plants. Aquaponic operations have historically struggled with profitability at commercial scale, but several commercialized systems exist in Canada and the United States of America, with most focusing on high-value vegetable crops.

Channel catfish production in the southern United States of America is exploring the use of split-pond systems to increase farm production while supporting a biological within-system waste treatment component. Typically designed with a 20 percent production pond area connected to an 80 percent treatment area, water is circulated between the two sides to allow for natural organic and inorganic waste treatment (water quality enhancement) and thus improved growing conditions for the catfish. Ongoing research is refining system design to optimize performance (Jescovitch, Boyd and Whitis, 2017).

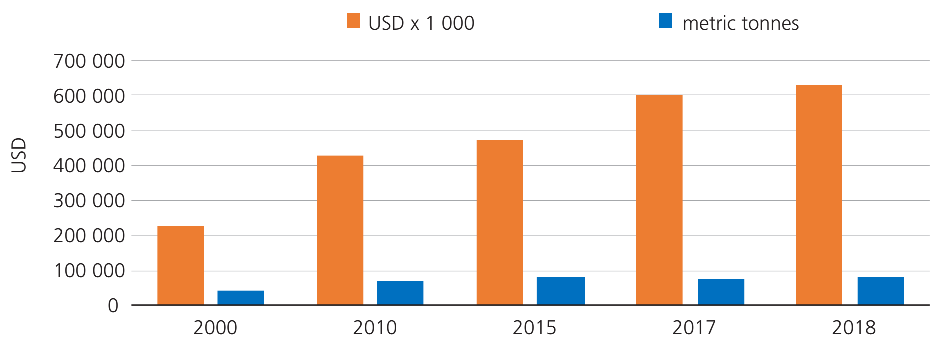
4.3 The way forward

Developing solutions that provide advantages to the farm operation while addressing issues that have caused the loss of social confidence in aquaculture across North America can create a pathway that will support industry expansion and growth across all production sectors. Taking a fresh approach that features innovation and diversification in a context of environmental improvement will help move the aquaculture industry forward in North America.

Industry, academic researchers and regulators will need to work together to provide science-based options for moving industry forward in a sustainable and competitive manner. Collaborative initiatives that address and provide solutions for existing issues, whether they represent environmental or socio-economic constraints to the aquaculture sector, will certainly help to support messaging that will inform a public that has been sceptical regarding farmed seafood products. Industry should build on their progress and develop a stronger and more broadly-based communication strategy that will help educate and dilute persistent, negative views of the sector.

Bringing all stakeholders together in a continual improvement process will certainly help to address issues and move this industry sector forward. Recognition of an issue or a negative perception, supporting proactive governance and industry self-regulation to mitigate risks, supporting applied research where and as needed and facilitating public awareness are critical pieces of this process.

FIGURE 2. Total Canadian exports of farmed Atlantic salmon in volume (tonnes) and value ('000 USD) from 2008 to 2019



Source: Statistics Canada, 2020.

5. Markets and trade

5.1 Status and trends

5.1.1 Background

The following sections provide a review, with selected commentary and examples, of the status of aquaculture markets and trade within North America and between North America and other regions.

5.1.2 Canada

The United States of America is Canada's largest trading partner and export market, and the top export destination for Canadian aquaculture products. Total merchandise trade between Canada and the United States of America has more than doubled since the signing of the North American Free Trade Agreement (Government of Canada, 2020a) and the new USMC (United States of America, Mexico and Canada) version is anticipated to maintain this positive relationship and facilitate trade in aquaculture products among the three countries. Canada continues to maintain a growing global trade balance in fish and fishery products (Table 3). Except for a few species, Canada does not differentiate between seafood sourced from capture fisheries and aquaculture in the trade statistics.

TABLE 3. Canadian total trade balance of fish and fish products ('000 USD)

Country	2000	2010	2015	2017	2018
Total exports (incl. re-exports)	259 605	479 785	504 613	636 380	664 980
Total imports	**34 255**	**65 042**	**36 640**	**56 942**	**71 385**
Trade balance	**225 350**	**414 743**	**467 973**	**579 438**	**593 595**

Source: FAO. 2020b.

In 2018 and 2019, 61 percent of Canadian exports of fish and fish products were to the United States of America, and 17 percent to China (Statistics Canada, 2018). China is the second largest recipient of Canadian seafood exports, of which about eight percent was shellfish, including squid and other cephalopods. The largest growth in Canadian seafood exports between 2014 and 2018 was a 91 percent increase in value to China and a 139 percent increase in value to the Republic of Korea.

On average, 70 percent of Canadian farmed Atlantic salmon was exported between 2014 and 2018 (Statistics Canada, 2020). Atlantic salmon exports were relatively stable, between 70 000 tonnes and 90 000 tonnes with the exception of 2014. However, total value has increased in recent years (Figure 2).

The United States of America used to receive almost all (averaging 98 percent between 2009 and 2015) of Canadian Atlantic salmon exports. However, this has decreased by about 7 percent between 2015 and 2018. Data suggest that competition from Chilean exports to the United States of America may be contributing to this reduction (Government of the United States of America, 2020).

Approximately 65 percent of farmed salmon are produced in western Canada (Statistics Canada, 2020). Production of Atlantic salmon and some steelhead trout in Newfoundland was 70 percent higher in 2018 than 2008. However, during 2013 and 2014 there were significant production declines due to infectious salmon anaemia and super-chill. This explains the significant drop in Canada's exports in Figure 2 and was noted in the last FAO North American regional report (FAO, 2017a).

Shellfish production in Canada has increased by 35 percent over ten years (2008-2018), mainly as a result of increased oyster production in British Columbia, New Brunswick and Prince Edward Island, and mussel production in Prince Edward Island (Statistics Canada, 2020). The United States of America remains the largest recipient of Canadian shellfish, which has remained relatively stable at approximately USD 60.5 million annually for the last three years (Government of Canada, 2018a). However, there is recent growth in exports to the Asian market, particularly Singapore and China which saw a 13 percent increase in imports of Canadian shellfish each year for the last two years (Statistics Canada, 2020).

Canada remains the largest foreign exporter of live, fresh or chilled mussels and oysters to the United States of America with 12 829 tonnes of mussels and 2 635 tonnes of oysters in 2018. Compared to its two other major exporters, the United States of America pays a lower unit price for Canadian blue mussels (approximately USD 1.21/kg) compared to mussels from New Zealand (USD 3.85/kg) and Chile (USD 2.18/kg) (Government of the United States, 2019a). For example, although the weight imported is less, and the product is frozen (on the half shell), the average value of mussels per weight imported from New Zealand in 2015 and 2016 was twice as high as that for Canadian blue mussels (Government of the United States, 2019a).

5.1.3 United States of America

The United States of America produced 468 200 tonnes of farmed seafood in 2018, valued at USD 1.1 billion, ranking 18th in global production volume (excluding aquatic plants).

Channel catfish remains the dominant cultured finfish in the United States of America. Both sales and production have been quite stable between 2013 and 2018, averaging USD 366.4 million (Government of the United States, 2018a, Government of the United States, 2018b). This is in the order of three times the total value of trout sales over the same time period (Government of the United States, 2018a) and five times the value of Atlantic salmon production (FishWatch, 2019). In 2018, the value of channel catfish was USD 341.2 million with an average unit value of USD 2.1 *per* kg, for rainbow trout it was USD 95.7 million (unit value USD 4.3/kg) and for Atlantic salmon it was USD 67.3 million with a unit value of USD 4.2/kg (FAO 2020c).

Channel catfish production peaked at 300 056 tonnes in 2003, but experienced a decline that settled at 139 479 tonnes in 2014. Production has increased slightly since then, reaching 159 423 tonnes in 2018 (FAO, 2020c). Mixed catfish species imports (*Pangasius* spp., *Ictalurus* spp., *Silurus* spp.) from the two largest global exporters, China and Viet Nam, surpassed sales of domestically produced catfish in 2017. This increase continued in 2018 such that domestic catfish sales were 40 percent of the value of total fresh and frozen catfish from China and Viet Nam (Government of the United States, 2019a). Earlier analyses identified factors that influenced the drop in market share and production, including the increased cost of production of catfish due to increased feed costs and the lower prices of Asian-produced frozen catfish fillets. Li *et al.* (2018) refer to four phases of catfish production in China, the first being the "golden period" of 2004–2009 with a large increase in exports to the United States of America. However, the fourth phase (2010–2013) has been relatively stable in terms of production. Chinese domestic factors include the high cost of raw fish processing, increased domestic demand and resultant increases in unit price.

Several Congressional and Administrative actions taken to assist the United States of America catfish industry have been summarized by the Congressional Research Service (CRS, 2015). These included excluding Vietnamese species from being labelled as catfish, inspections of non-Ictalurid species, and the imposition of antidumping duties on some frozen fillets from Viet Nam in 2003 and upheld in 2009 and 2014. Despite this intervention, United States catfish producers saw production fall by nearly 54 percent between 2003 and 2014. Viet Nam filed a dispute with the World Trade Organization in 2018 arguing that Pangasius imports had been unfairly targeted for trade restrictions (WTO, 2018)

Trout total sales have increased slightly since 2013. However, this was due to an increase in unit price, and since then production has fluctuated, with a recent 2016 to 2018 increase of approximately 10 percent (Government of the United States, 2018a; FAO, 2020c). Less than five percent of total sales were associated with exported fresh and frozen product in 2016, with the two following years realizing an increase of trout exports by just over 50 percent and 80 percent, respectively, in both weight and value (Government of the United States, 2018c; Government of the United States, 2020).

The three top marine species produced in 2018, in terms of value, were oysters, clams, and Atlantic salmon at USD 192 million, USD 139 million and USD 68 million, respectively.

The United States of America is the leading global importer of fish and fishery products, resulting in a trade deficit of USD 18 billion in 2018. Almost 85 percent by value of the aquatic food eaten in the United States of America comes from abroad and over half of it from aquaculture (Government of the United States, 2019b). Annual salmon consumption in the United States of America trails shrimp and canned tuna by about one kg per person, which has remained stable for most of the last decade, and two-thirds of this salmon is comprised of imported farmed product (Sea Grant Delaware, 2020).

There is no clear trend in the total value of major aquaculture exports, or in combined freshwater and marine production, between 2014 and 2018 (Government of the United States of America, 2020). Exports of farmed Atlantic salmon and mussels have fluctuated over the same time period, showing no clear trend. Oyster and scallop exports have declined in value, while mussels have increased (Government of the United States of America, 2020).

Atlantic salmon export sales have increased by 34 percent since 2014 to USD 77 million in 2018. Atlantic salmon experienced a large drop in export revenues between 2016 and 2017. This drop was also seen in many marine exported species including commercially fished species and may be connected to the high value of the United States dollar during that period. A recovery of sales in 2018 did not reach the levels seen in 2016 (Government of the United States, 2020).

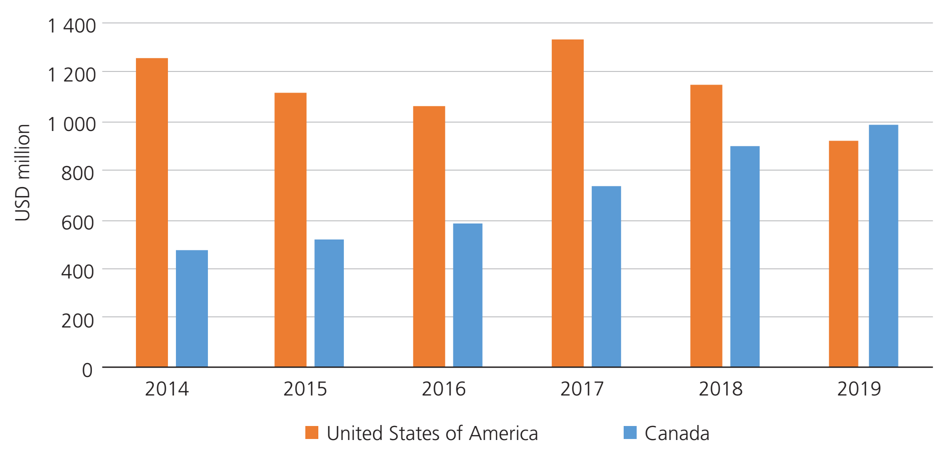
The United States of America has a diverse export network, providing shellfish products to Central American countries, Canada, China, the Middle East, and to European Union Members. Total sales of molluscs reached USD 469.3 million in 2018, a decline of seven percent since 2013 (Government of the United States, 2018a). Mussel and scallop exports have generally decreased in both volume and value over the period from 2014 to 2018, and while the weight of exported clams also decreased, its export value increased, most of which can be attributed to a domestic sales increase because the value of exports has not increased. During the same period, shellfish imports of these same species have stayed relatively stable with the exception of scallops, which has declined.

Recent census data show that geoducks represented ten percent of total mollusc sales in 2018 (Government of the United States, 2018a), a 62 percent increase over the past six years. Most geoduck is likely exported. However, it is currently not singled out in the Cumulative Trade Data from the United States of America National Oceanographic and Atmospheric Administration (NOAA).

5.1.4 Trade relations

The seafood trade imbalance in the United States of America is ongoing (Government of the United States, 2016c). However, a 370 percent increase in fish and seafood exports to China over the last decade is of particular interest and is soon expected to exceed exports to the European Union (FAO, 2017a). This trend continued through 2017 (Figure 3), with high-value seafood including fillets and portions and frozen whole fish some of the best seafood export prospects to China (Government of the United States, 2019d). However, the uncertain status of the United States and China trade relationship negatively impacted exports in the last quarter of 2018 (Government of the United States, 2019d).

FIGURE 3. Fish and fish product exports to China from Canada and the United States of America



Source: USDA FAS, 2020.

North America's diplomatic and trade relations with China remain volatile. In 2018, the United States of America imposed tariffs on some Chinese products, with China retaliating. By July 2019, Chinese tariffs of 25 percent appeared to have resulted in a 35 percent reduction of United States of America seafood imports by China, worth USD 340 million, based on Chinese customs data (Harkell, 2019). In 2019, United States of America exports of fish and fish products were USD 922 million, declining from the USD 1.3 billion in 2017 (Figure 3). Tariffs affecting lobster resulted in a relatively favourable price for Canadian lobster (Gunn, 2019).

Canada has at least 15 free trade agreements with countries and regions around the world, including the Canada European Union Trade Agreement (CETA) in place since 2017 (Government of Canada, 2018c) and the recent Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP), which is coming into force according to the timelines of various countries. The CPTPP is between Canada and ten other countries in the Asia-Pacific region, including Japan, but it does not include China or the United States of America. These agreements are expected to benefit Canadian seafood exports through the removal of tariffs. CETA will help with access to the European Union, which, in 2018, was the largest importer of fish and seafood products at USD 33 billion, or just over one quarter of global imports (Government of Canada, 2018d, Government of Canada, 2020b).

Although the United States of America is largely a seafood importer, it has 20 international Free Trade Agreements, eleven of which are with Central and South America countries. Additional agreements with Australia, Bahrain, Canada, Israel, Jordan, Korea, Morocco, Oman, and Singapore exist and may offer opportunities for future export growth from the United States of America.

5.1.5 Innovation – new products, species and markets

Considerable room for aquaculture production expansion exists in North America, as well as market development and the integration of technology. Production of such well-established species as Atlantic salmon and oysters could be increased, and new markets could be found to expand exports to feed growing middle classes in China, Latin America and Southeast Asia (Government of Canada, 2018b; FAO, 2020a. For example, the Government of Canada (2018b) identified the category of Chinese mollusc imports as the fastest growing. Frozen, dried, salted or brined molluscs (compound annual growth rate of 52 percent from 2012 to 2016) could represent a diversification of traditional product lines and an opportunity to expand or grow export markets for North American producers.

FAO (2020b) notes the general increased demand for pre-packaged and convenience products applicable for salmon and all cultured species. Innovations in marketing and value-added production are needed in order to respond. Financial assistance to the aquaculture sector in both Canada and the United States of America is necessary to support this innovation through market research and product development. Blue mussels in Canada could potentially benefit from this approach in order to raise the value of exports to its principal market in the United States of America and better compete with the higher-priced New Zealand frozen product.

A recent article from the Institute of Food Technologists summarizes research on recent food trends including the increase in sales of frozen foods, consumers describing themselves as “foodies” who are interested in all trends and novel approaches to prepare and enjoy food, the trend to eat restaurant-purchased meals at home and the shift to purchasing food based on health benefits rather than on brand and form (Sloan, 2019). These trends highlight the need for the creation of value-added aquaculture products that are convenient and emphasize their relative contribution to health. They also bode well for new niche markets, including restaurants. For example, farm-raised catfish in northern North America to compete with fried chicken.

Similarly, recent upward trends in fresh and frozen trout in the United States of America, both domestic and exported, suggest that demand may exist for expanded trout production in both sectors, including exports to new countries.

Canadian oyster production could increase its export opportunities with the United States of America with a focus on fresh (live) half-shell, which commands a significantly higher price (Government of the United States, 2020) than the historically common shucked or ‘frozen/dried/salted/brine’ products.

Efforts are being made on species diversification, for example, recent research on sea cucumber culture (Walker, 2017). The government of Canada notes the “keen interest by industry and investors” and the need for additional research. The price paid to harvesters has more than tripled over the period 2008 to 2018 (Government of Canada, 2019c), while in addition to sea cucumber and geoduck, the Canadian Aquaculture Industry Alliance (2018) lists 12 other species with commercial potential including two species of wolf eel, sea urchins, and halibut. Arctic charr (*Salvelinus alpinus*) continues to be of interest, as does burbot in the Pacific Northwest.

Strategic financing through partnerships between government, universities and the private sector could be explored in order to support scientific research on reproduction, hatchery rearing, grow-out and extension to pilot farms, as well as food science research to develop new seafood products from North American cultured species.

5.2 Salient issues

North American consumers have expressed concerns about aquaculture products, primarily related to the environmental and operational issues associated with fed aquaculture systems including finfish or shrimp production. Specifically, the need for third-party certification that addresses sustainability and traceability forms part of the overall social license issue and was discussed in chapter 2 of this report. As with any food production sector, customer concerns will have a direct influence on marketability of products and sector growth.

The book "Tracing the evolution of organic and sustainable agriculture" connects sustainability to the protection of "the ecological and human resources that a viable food production system relies on" (Gold and Gates, 2007). Noting that a concern for sustainability has existed for centuries, these authors place organic farming under the "sustainable agriculture umbrella". Concerns about sustainability have grown and are reflected by the many products that identify as being sustainably produced. Within aquaculture (FAO, 2011), consumer concerns may include how aquaculture species are raised, the environmental impacts of their production on surrounding water quality or the seabed, whether chemicals (including antibiotics) are used in production, the source of feed (wild fish or plant-based) and the well-being of human communities impacted by their production.

Certifications and traceability are not only intended to improve the state of the environment, ensure seafood safety and facilitate social acceptance of the sector, but also to obtain higher revenue for aquaculture producers through increased prices, demand or amounts sold (Roebuck and Wristen, 2018). However, more relevant than possible price premiums, certifications are important for producers to access guaranteed markets and secure long-term business-to-business contracts. In North America this is especially important as those without certification are locked out from the major buyers and this is especially a concern for developing countries that export to North America. The evidence of consumer demand for certified product is more the result of non-certified products being locked out of the market by these large retailers.

In addressing consumer concerns and the industry impacts of the lack of *social license*, a range of production standards varying from guiding principles to criteria with strict thresholds have been developed and may be promoted through seafood wholesalers, retailers and ENGOs such as the Monterey Bay Aquarium's Seafood Watch and Ocean Wise recommendation programmes. The Aquaculture Stewardship Council is a programme with global reach that parallels the Marine Stewardship Council for capture fisheries. Its logo is said to give the consumer "reassurance that the seafood comes from a farm which uses responsible farming methods that minimise (negative) environmental and social impacts." Currently, Canada has 35 certified Atlantic salmon farms with nine under assessment (Aquaculture Stewardship Council, 2019) and the sector has made a 100 percent commitment to this programme.

Best Aquaculture Practices (BAP) is the only third-party aquaculture certification programme that encompasses compliance with the Global Food Safety Initiative (GFSI), Global Social Compliance Programme (GSCP) and Global Sustainable Seafood Initiative (GSSI). Chain of custody is also a part of certification. BAP is a global programme that certifies processors, farms, hatcheries, and feed mills. It currently has a massive database of certified producers (over 2 300) with others in process (Best Aquaculture Practices, 2019).

The Canadian Organic Aquaculture Standard has existed since 2012 and a number of products are currently certified including Chinook salmon grown by Creative Salmon, sturgeon caviar from Northern Divine and most recently, coho salmon, grown in an aquaponic system (Hicks, 2015; Habitat Craft Cannabis Ltd., 2019). No such standard exists in the United States of America. Nichols (2019) notes that the United States Department of Agriculture (USDA) does not currently certify organic aquaculture production. The agency maintains that the National

Organic Programme is in the process of developing organic practice standards for aquaculture. However, no progress has been made since 2016.

The Government of Canada is also developing "boat-to-plate" and "farm-to-plate" traceability programmes to help Canadian fishers market their high-quality products (CFIA, 2020).

While certification is being widely adopted by farmers, actual data on the commercial benefits of certification are difficult to find. A news story reported premium prices for ASC certified salmon of between EUR 0.60/kg to 0.70/kg higher than for non-certified salmon (Seaman, 2016). The global retail value of eco-certified seafood was estimated to be USD 11.5 billion in 2015 (Pott *et al*., 2016) and USD 12.7 billion in 2017 (Coherent Market Insights, 2018). This increase in value is supported by a recent United States of America study on consumer-packaged goods (CPGs) with sustainability labelling. New York University's Stern's Center for Sustainable Business found that purchases of "sustainably-marketed" CPGs by consumers in the United States of America grew 50 percent more and 5.6 times faster than goods that were not certified (Whelan and Kronthal-Sacco, 2019). Similar studies for the aquaculture sector would be beneficial.

5.3 The way forward

As stated in previous chapters, the lack of growth in the North American aquaculture sector is most likely due to a combination of factors, including competition with other food sectors, price and tariff issues with seafood imports, cumbersome regulatory frameworks and a loss in public confidence in the farmed production of aquatic foods as a result of farm impacts. The result is a stagnation in growth and diversification of the entire aquaculture industry. This, coupled with the marketplace impacts of less-expensive imported seafood products, complicates the economic climate and further exacerbates conditions that constrain growth (Carter and Goldstein, 2019).

Third-party certification programmes have been well received across the aquaculture industry, and these sustainability initiatives continue to augment public and consumer awareness. This is providing a slow but increasingly positive understanding of how farmed aquatic food is produced so that the methods, use of materials and environmental interactions meet the highest standards. It is with these ongoing and expanded efforts to keep the consumer engaged that future growth of aquaculture production in this region will be realized.

In moving forward, the communication of industry efforts to address sustainability challenges and mitigate environmental impacts is essential. While third-party certification and consumer recommendation programmes such as Monterey Bay's Seafood Watch and Vancouver's Ocean Wise will play a pivotal role, education, promotions and marketing tools such as product branding and targeted advertisements will certainly support these initiatives.

6. Contribution of aquaculture to food security, social and economic development

6.1 Status and trends

6.1.1 Background

As in many other regions of the world, North American aquaculture continues to evolve in the wake of declining or threatened capture fisheries. Aquaculture is generally seen as a way to offset the shortfalls in fish supply and declining fishery-based, coastal community livelihoods and economic opportunities. As such, aquaculture has primarily followed in the shadow of reduced coastal fisheries and their established markets, with little effort placed on developing new aquaculture species and methods.

6.1.2 Food security

The ongoing global development and growth of aquaculture has been apparent in the North American region and while this has slowed in recent years, the region recognizes that the development of aquatic food or an increased reliance on imports is essential to meet the needs of a growing population.

Food security has several dimensions (FAO, 2006): availability - food of sufficient quantity and quality that meets nutritional and physiological needs; access and utilization - people need to be able to access food and be healthy and knowledgeable enough to utilize it, generally through purchasing it or having it provided to them, or in some cases through subsistence farming, harvesting, barter, and trade; stability - food must be accessible on a regular or stable basis.

Canada and the United States of America have relatively large middle classes with the resources to purchase aquaculture products that are more expensive than local capture fisheries and other sources of protein (FAO, 2017a; Love *et al*., 2015). However, there are still segments of the population who are not able to do so, given poverty, lack of access and uneven pricing in different parts of the region, for example, because of higher prices in remote communities.

Nutritional guidelines of both Canada and the United States of America include recommended amounts of fish or seafood to provide nutrients such as essential fatty acids and vitamins (Government of Canada, 2020c). These nutrients have been shown to be particularly important in early development and for pregnant women. Lack of access to seafood could further contribute to disparities and impact health. Even if prices are affordable, consumers may prefer not to eat fish and seafood due to risks associated with environmental contaminants such as polychlorinated biphenyls (PCBs) or mercury (Love *et al*., 2015). In addition, familiarity plays a role; many consumers may not know how to prepare and cook aquatic foods and only eat it in restaurants.

The complexity of this issue in the United States of America is addressed by Love *et al*. (2015), who argue that in order to achieve food security, health and fisheries policies need to be explicitly aligned. For example, "federal health policy does not mention the goal to support sustainable domestic fisheries and aquaculture or include language that indicates how food systems are linked to healthy fisheries". These authors examine federal and state programmes that supply food to people in need and show how strengthening linkages between federal agencies could increase access to fish, whether supplied by wild fisheries or aquaculture. Recommendations included:

- Move toward a national food policy that recognizes how fisheries and agriculture policy can support human health and the environment.
- Link seafood to the "Local Foods, Local Places" initiative, which connects multiple agencies around farmed products.
- Take advantage of the purchasing power of federal agencies and large institutions such as hospitals and universities.
- Explore how the federal government can support seafood consumption in large federal entitlement programmes such as Supplemental Nutrition Assistance Programme (commonly known as food stamps), The Nutrition Programme for Women, Infants, and Children, and the National School Lunch Programme, all of which make money available for food or directly supply food to over 80 million Americans.

Access to fish or seafood in coastal and rural areas can occur through subsistence fishing of wild species, or purchase of affordable commercially caught or farm-raised species. In rural areas, aquaculture contributes to food security through the provision of much-needed employment. This in turn allows rural families to purchase healthy foods including seafood, some of which may be farm-raised.

The United States of America leads the world in the importation of fish and fishery products, resulting in a 2018 trade deficit of USD 18 billion while nearly 90 percent of the value of seafood eaten in the United States of America comes from abroad and over half of it from aquaculture (NOAA, 2018). The demand for fresh and sustainably produced seafood continues to grow, yet the absence of domestic supply represents a lost opportunity for food security and for economic growth. Expansion of domestic seafood production could promote significant economic development and job creation, and aquaculture rather than capture fisheries, has been suggested as the only realistic option to achieve this goal (Costello *et al.*, 2016). In addition, wastage of edible seafood accounts for as much as 40 percent of production while approximately 36 percent of this volume could address the gap between actual and recommended seafood consumption in the United States of America (Love *et al.*, 2015).

6.1.3 Aquaculture as an employer

Employment data for aquaculture are incomplete, requiring extrapolation from sources including census information and labour statistics. For example, in the United States of America, aquaculture employment statistics are included with animal husbandry in the national occupational census (FAO, 2017a).

Given the size of the economy of the United States of America, aquaculture plays a relatively minor role in employment. However, in a recent study, Lipton, Parker and Duberg (2019) detail the challenges of determining the total economic contribution "due to a lack of current, sufficiently detailed and standardized production budgets for major aquaculture species." They estimate total employment in marine aquaculture in the United States of America in 2015 to be 53 355 jobs, with a total economic impact of USD 5.1 billion. Details of their findings include first sales of USD 394 million and final sales value to consumers of over USD 1.7 billion through processing and distribution as well as indirect effects of USD 1.13 billion and induced effects of USD 2.0 billion. The employment estimates were 33 429 jobs directly related to the production, processing, distribution and final sales of marine aquaculture products as well as 9 925 jobs through indirect and induced effects.

Lipton, Parker and Duberg (2019) lacked the data to extrapolate from the values measured in their study to the full impact of aquaculture in the United States of America. However, they noted that total aquaculture first-sale value was USD 1.4 billion in 2015, and that this value had risen from USD 1.2 billion estimated in 2017 (FAO, 2017a) to USD 1.5 billion in 2018, an

TABLE 4. Selected aquaculture sector economic statistics for Canada, 2014–2018. Examples illustrate annual indirect sector benefits (revenues/expenses) associated with services, sales, and non-operational expenses associated with the supply chain

Indirect Components ('000 USD)	2014	2015	2016	2017	2018	2014-2018 Increase (%)
Sales of aqua products and services	701 254	721 916	1 024 836	1 077 821	1 121 980	87
Other goods and services, not specified	16 825	15 270	19 398	16 281	30 431	112
Goods transportation and storage	27 500	35 714	33 673	31 803	40 152	71
Processing services	20 089	20 930	19 258	17 239	20 905	22
Rental and leasing expenses	9 537	12 700	11 544	18 231	23 799	192
Maintenance and repairs	36 722	38 960	44 758	54 129	61 145	95
Professional services	15 315	13 820	16 415	19 678	20 897	60
Other operating expenses, not specified	69 532	92 860	99 512	116 500	121 435	105
Salaries and wages	95 881	85 835	87 030	93 693	95 045	16

Source: Government of Canada, 2016b.

overall ten percent increase from 2013 according to the United States of America Aquaculture Census (Government of the United States, 2019e). Thus, aquaculture has significant and growing economic impacts, including employment. In comparison, FAO (2018) estimated that the United States of America supports 5 903 direct jobs in aquaculture.

In Canada, direct employment in aquaculture has varied from approximately 3 600 persons to 3 900 persons between 2014 and 2018 according to Labour Statistics (Government of Canada. 2020d). However, these data did not include processing and a range of other services and economic benefits associated with aquaculture, some of which are listed in Table 4.

Fisheries and Oceans Canada lists aquaculture employment figures that are based on 2010 data, previously reported by FAO (2017a). Although it is unclear how the values were estimated, they reported that the industry provided approximately 14 000 direct and indirect jobs, 95 percent of them in rural or coastal areas. Of this total, employment on farms, in hatcheries and in processing plants accounted for around 5 800 jobs; goods and services industries for 5 600 and 2 600 in other retail businesses.

As explained in Chapter 2 of this report, total aquaculture production and value fluctuated between 2012 and 2018 but not by a significant amount, so it is assumed that the earlier reported employment numbers may still be relevant. Although there has been no significant trend in salaries and wages paid by the aquaculture industry in Canada between 2010 and 2014 (Government of Canada, 2016b; Government of Canada, 2016c), there has been an increase in aquaculture salaries and wages of 16 percent between 2014 and 2018. In addition, much higher increases in many key economic statistics suggest considerable gains in economic benefits including additional employment (Table 4) (Government of Canada, 2020d).

The Canadian Aquaculture Industry Alliance (2018) reported that farming and fish processing activities alone generated an estimated USD 4.16 billion in economic activity, USD 1.69 billion in GDP, and full-time jobs for more than 26 000 Canadians earning an estimated USD 0.92 billion in wages in 2017[2]. They also evaluated the full value chain of economic activity involved in farmed seafood production including wholesale and distribution, retail and food services for an estimate of 56 600 workers. Ninety percent of this economic activity is attributed to salmon farming (British Columbia Salmon Farmers Association, 2020).

[2] Current USD values calculated from average 2017 currency exchange (1.2994)

Regardless of national-level statistics, in both Canada and the United States of America, aquaculture is an important employer in rural and coastal areas where job opportunities may be limited (FAO, 2017a). Remote coastal areas such as coastal British Columbia and Newfoundland have particularly benefited from aquaculture. In British Columbia, about 20 percent of salmon farming jobs are held by people of First Nations' heritage (British Columbia Salmon Farmers Association, 2019a). The economy and people of Newfoundland suffered from overfishing of Atlantic cod and a resulting moratorium on cod fishing in 1992. A total of 30 000 people lost their jobs, increased out-migration occurred, and a 10 percent drop in population occurred over the ten years following the moratorium (Higgins, 2008). Now, over 90 percent of the jobs in the salmon culture industry in Newfoundland are full time (2016 data) and offer young people "challenging, full-time work in their own communities" (Newfoundland Aquaculture Industry Association, 2020). Total employment impacts were estimated to be 872 person years in 2013, compared to approximately 225 person years in 2003 (Government of Newfoundland and Labrador, 2014).

Similarly, in coastal states of the United States of America, communities have realized significant social and economic benefits from aquaculture. For example, in Maine, the total economic impact of aquaculture has almost tripled to USD 137 million dollars in seven years. Maine's aquaculture sector was estimated to provide almost 600 direct and 1 000 indirect jobs, including multiplier effects (Aquaculture Research Institute, 2016).

Two of the four largest aquaculture production states in the United States of America, Mississippi and Louisiana (Government of the United States, 2019e) have the highest poverty rates of mainland states, at just under 20 percent (Government of the United States, 2017). This emphasizes the importance of aquaculture as an employer in these areas. In Mississippi, the largest producer of catfish in the southern states, catfish farming played an important role in replacing lost manufacturing jobs in the 1960s and 1970s. Even after a large decrease in production, it has stabilized in recent years and is still an important employer (Soergel, 2018; Hanson, Dean and Spurlock, 2004) with estimated employment in 2001 at about 6 600 direct jobs and 10 670 indirect jobs. Hanson concluded that by 2015, the large loss of production and sales had reduced total employment by 5 000 jobs (Hanson, 2018). Lipton, Parker and Duberg (2019) did not include catfish in their study due to a lack of recent and readily available cost and returns data.

The majority of freshwater crayfish are raised in Louisiana. Crayfish has had the most reliable production, estimated in 2015 as having a total economic impact of USD 2.6 billion and providing over 25 000 jobs (Lipton, Parker and Duberg, 2019). Given the lack of growth in recent years, these numbers have most likely not changed.

6.1.4 Participation of Aboriginal Communities in Aquaculture

As reported in the 2015 North American aquaculture review (FAO, 2017a), the Department of Fisheries and Oceans of the Canadian government initiated the British Columbia (AACI) in April 2013 which ran until March 2018. It facilitated increased participation of indigenous communities in the aquaculture sector, allocating funds that provided technical business expertise for developing viable aquaculture business development plans.

By the end of the AACI the funding, which was matched by other agencies and the private sector had been invested in 19 aquaculture pilot projects, 12 feasibility studies, 35 early-stage business development projects and 24 equity investments in indigenous aquaculture venture projects. This development effort has resulted in 148 jobs in indigenous aquaculture ventures and six in regional business development teams.

Although there remains persistent scepticism within some First Nation communities about salmon aquaculture due to ongoing concerns about environmental impacts and risks to traditional fishing grounds and habitats, there is growing interest in participating in other forms of aquatic food production with communities realizing the socio-economic benefits of participating in the sector. Shellfish production, including oysters, scallops, clams, sea cucumbers and sea urchins, continue to be targets for First Nation aquaculture development. More recently the business opportunities offered by farming native seaweeds is especially intriguing to these coastal communities, particularly given the traditional use of many of these aquatic plants.

Coastal British Columbia is one of the richest areas in the world for seaweeds. Interest in commercial production of seaweeds in British Columbia is mostly limited to a number of brown and red species, although there has been some recent interest in green taxa. Nevertheless, many First Nations have expressed interest in aquaculture opportunities for seaweeds. A few of these communities have suggested that farming would even be a better option than the reliance on wild harvests, stating that an aquaculture approach would not negatively impact valued wild seaweed resources while providing control of production volume, biomass and quality. It would also allow for controlled growth and production diversification as markets developed and provide stable employment opportunities within the community.

6.2 Salient issues

In Canada, most of the area available for aquaculture expansion is located along the coast and these coastal areas fall almost entirely within the traditional territories of indigenous peoples so the support of these nations is required in order to move forward with any form of farm operations. In fact, recent court cases in Canada have found that First Nation communities must be consulted regarding any form of coastal development within their traditional territory, approving all aspects of the proposed facility. As such, stakeholder consultation, approval, participation and ownership are essential for further aquaculture development. Therefore, the questions of social license in these communities is especially important, and so far the overall negative perception has resulted in a slow and measured approach to aquaculture development.

A good example is the Cascadia Seaweed Corporation which was launched in the spring of 2019 and has been actively seeking seaweed aquaculture partnerships with First Nation communities in coastal British Columbia. The company has finalized an agreement with Nuu-chah-nulth Seafood LP and has initiated seaweed production at two farm sites on the west coast of Vancouver Island, with initial harvest planned for June 2020.

Interest continues to grow among the coastal nations, and Cascadia Seaweeds has a number of new partnerships under negotiation. Furthermore, the partnership model is now extending to salmon farm companies, providing a three-way opportunity that offers socio-economic benefits, ecosystem services (nutrient extraction and absorption for the fish farming companies), along with continued growth and profitability for Cascadia Seaweeds. The real success in this partnership model is the ability to concurrently address a number of environmental and socio-economic issues thereby securing support for continued improvement in the perception of the aquaculture industry by addressing the concerns of the public and of the consumer.

First Nation partnerships provide an inherent benefit to both the community and to the aquaculture company seeking to establish operations within the nation's territory. This has become readily apparent in many of the Canadian production regions, including Ontario (trout farms), Nova Scotia and other maritime provinces (salmon farms), and in coastal British Columbia (shellfish and salmon farming). Companies have become increasingly successful in developing working partnerships with First Nation communities, providing these remote communities with valued jobs and associated economic benefits. Many such partnership agreements include partial, and in some cases complete, ownership of the corporate entities established and structured for these partnership ventures.

6.3 The way forward

The continued development of aquaculture in North America provides a valuable and significant economic impact by creating a broad spectrum of direct and indirect jobs. Aquaculture production in North America results in internationally traded products, and as such comprises a complex supply chain, further increasing the number of jobs associated with the industry. Direct employment in aquaculture includes farm staff, environmental and health technicians, processing and packaging technicians, and management personnel. Secondary jobs can provide a variety of opportunities including equipment suppliers, specialized services (for example, divers, and environmental consultants) and professionals such as accountants, lawyers and marketing services. The broader impact of all of these positions, most of which reside in the remote coastal or rural communities that support the farm operations, is felt through housing, community growth and associated public services and business.

Despite its comparatively minor role in global aquaculture production, North America plays a significant role in global aquaculture development through investment, applied research and innovation (knowledge and technology exports) and through foreign aid and international development agencies and programmes such as the United States Agency for International Development and Canada's International Development Research Centre. These technological contributions will most likely continue, and both Canada and the United States of America will, as a result, be well positioned to respond to their own sector growth in the future.

Continued engagement of indigenous and other coastal and rural communities in aquaculture will reflect the sustainable nature of the aquaculture industry and further support the much-needed growth in the North American sector.

7. External pressures on the aquaculture sector

7.1 Status and trends

7.1.1 Background

There are three main categories of external pressures that impact the aquaculture sector in North America: environment, society and the economy. Together these external pressures dictate the success of the sector through the response and performance of its individual members, the farming companies and individuals.

Various environmental and socio-economic factors have a profound impact on the North American aquaculture sector. These factors, acting through individual or combined events, will dictate the sectoral and company responses and determine the outcome of such actions. Previous sections of this review have illustrated how and why the North American aquaculture sector has stalled in terms of overall production and the present section outlines the key external pressures and how sector response is addressing them.

In general, the North American industry response to external pressures that impact production embraces a science-based approach to find solutions, as well as a willingness to move towards increased diversification and production innovation. Cross, Flaherty and Byrne (2016) suggested that the response of the aquaculture industry has been stimulated by three drivers: economic and livelihood opportunities; social license and eco-ethical consumer demands; and as an adaptive response to changing environmental conditions.

The following sections provide a description of the types of environmental and socio-economic external pressures that currently affect the aquaculture industry in North America and examples of how it has been responding to these pressures.

7.1.2 External environmental pressures

External environmental pressures include a variety of factors that may change the conditions under which aquatic farms, both marine and freshwater, operate. These environmental changes may or may not be predictable, may be short-term, long-term or permanent, and the magnitude of the change may be minor or severe with consequent impacts on the species being cultured.

The direct impacts of climate change are considered as the most significant and disruptive external environmental pressures at this time (Barange *et al.*, 2018). For example, projected sea level rise due to loss of polar ice caps will have a devastating effect on intertidal aquaculture (for example, clam farming on beaches) given that tidal elevations will change and substrate exposure times will be altered (Jose, 2016). Changes in marine and freshwater temperatures will have direct impacts on species performance, including growth, quality and survival, particularly if outside tolerance levels for the cultured species.

Increasing atmospheric carbon dioxide (CO_2) lowers the pH of seawater due to the formation of carbonic acid and causes the equilibration of carbonate ions to bicarbonate, thereby lowering the availability of carbonate ions for calcifying organisms (Waldbusser *et al.*, 2011). In the past decade, extreme losses have been reported in the shellfish industry affecting multiple species around the world (Barton *et al.*, 2012). Most losses have been reported on ocean farms (Gruber *et al.*, 2012), but hatchery failures and reductions in natural seed production are also problematic, especially in British Columbia (Waldbusser and Salisbury, 2014). While multiple factors are likely involved, elevated water temperatures, ocean acidity and emerging diseases are considered primary factors (Cook *et al.*, 1998).

A socio-economic vulnerability analysis (Cooley and Doney, 2009) examined nutritional and economic dependencies of shellfish production, the adaptability of aqua-food producing nations and time until a significant change occurs in seawater chemistry. For Canada and the north-western United States of America, they projected this transition will occur by 2029, leaving little time to develop and implement appropriate adaptive strategies.

Despite the projected timeline for changing seawater conditions, recent events have caused concern that this process is either occurring faster than anticipated or that subtle changes are having an indirect and equally disconcerting impact on shellfish production. In many coastal areas, impacts of increased seawater acidity are already being felt due to enhanced upwelling of deep, saline, high-CO_2 water (Feely et. al, 2008). In Western Canada, hatcheries were among the first to notice these changes in coastal acidity, which coincided with difficulties in maintaining hatchery production across Washington State and British Columbia, with particular impacts on oyster and scallop production (Barton *et al.*, 2012). Hatcheries now apply chemical corrections for pCO_2 and aragonite levels. Despite improved performance they are still experiencing large fluctuations in cohort survival that were rare 5 to 7 years ago and have led to seed shortages in recent years. Pathogens may also be involved through unknown mechanisms.

In October 2018 the International Panel on Climate Change released a special report on the impacts of global warming by 1.5°C (IPCC, 2018). The report notes that human-induced global warming has caused ocean warming and acidification, which is expected to impact a wide range of marine organisms, ecosystems and sectors such as aquaculture and fisheries. Developing adaptive strategies to meet the challenges of a rapidly changing farming environment has been identified as a critical global need by FAO (Cross, Flaherty and Byrne, 2016).

Other climate impacts include the increase in severe weather events or patterns, affecting both marine and freshwater systems. Increased rainfall in traditional growing areas could have an impact on sea surface salinity, affecting species performance as well as temperatures (Barange *et al.*, 2018). Indirect impacts of extreme and shifting weather patterns could result in a significant input of terrigenous materials, including silt and nutrients, impacting freshwater as well as coastal systems. While the former may have a direct impact on species performance, nutrient inputs could result in an indirect stimulation of phytoplankton growth, facilitate the range extensions of aquatic predators and diseases and even perpetuate harmful algal blooms, which already have serious impacts on both finfish aquaculture through increased mortality and shellfish aquaculture through toxin accumulation affecting product safety.

In addition to the environmental pressures associated with climate change, other unpredictable impacts such as pollution due to microplastics will continue to represent risks to farm operations, with potential effects on product quality and safety.

7.1.3 External societal pressures

This review earlier discussed the aquaculture workforce noting an aging population in the region, the impact of immigration and the future needs for workers trained for highly technical jobs. These external pressures are critical in supporting sector growth, particularly in the North America region where aquaculture has such a strong relationship to technology.

Societal perceptions of the industry, in terms of environmental performance, have also seriously impacted social acceptance and will continue to have a constraining effect on industry unless decisive and proactive actions are taken to address such concerns. The perception that farmed fish contain antibiotics and high levels of pollutants, that the flesh is dyed for market purposes and that these fish are all genetically modified are just a few of such misconceptions.

Societal pressures also include consumer critiques and demand. These pressures are common to all businesses and essentially provide feedback on consumer preferences including product portioning, packaging and processing as well as information on sustainable farm practices and traceability. This form of feedback informs industry on all aspects of consumer need and with an appropriate and timely response, will increase customer satisfaction.

7.1.4 External economic pressures

The global economic down-turn of 2008 had a serious impact on aquaculture development in North America, largely in terms of operational financing and investment. The novel coronavirus virus disease (COVID-19*)* pandemic is another such disruptive event and this too may have devastating global economic impacts. In a quarterly survey in March 2020 by Virginia Agricultural Research & Extension Centre, researchers analyzed the impacts of COVID-19 on aquaculture, aquaponics and allied businesses in the United States of America (Senten, Smith and Engle, 2020). An estimated 18 percent of the companies responded and results indicated that 90 percent of companies said they had already been impacted by the COVID-19 pandemic, with 80 percent having lost sales contracts. Losses ranged from more than USD 1 thousand to USD 5 million. Despite still being at the early stages of the pandemic, the respondents reported employee layoffs as high as 329. Many companies also noted that they were unlikely to be able to survive beyond three months (six months maximum), without some form of financial assistance. This information will need to be updated as the pandemic progresses but it is very likely that the sector will incur negative impacts.

While major events such as the 2008 economic downturn and the 2020 COVID-19 pandemic are rare, other regional factors can have more frequent influences on production and sales, particularly to the export marketplace (Engle and Stone, 2013). For example, currency exchange rates play a key role in the trade of aquaculture products between Canada and the United States of America. The relative value of the Canadian and United States of America dollar is a routine and important consideration for any industry trading across the border. Currency exchange rates differed by about 28 percent between 2011 and 2020 and this affects product pricing and thus competitiveness, depending on which country the value favours. A large margin can have significant impacts on farm profitability and provide opportunities for investment in operational improvements and growth.

Other external economic pressures include international trade arrangements, including, tariffs, quotas, import and export regulations and international trade agreements. These issues were discussed in the markets and trade chapter of this review.

7.2 Salient issues

The impacts of many of these environmental and socio-economic pressures can be substantial, are usually unpredictable and pose a great deal of uncertainty for farm operations. The consequences of rapidly changing climate and aquatic growing conditions require a responsive adaptive strategy to ensure resilience in the aquaculture sector. The major issue resulting from this global situation is higher levels of uncertainty and risk for the investment community

However, there are many examples of how innovation and diversification of production, in terms of both species and production methods, have provided environmental and socio-economic benefits to the aquaculture industry. Cross, Flaherty and Byrne (2016) provided a variety of examples from across North America including for oyster culture in the Pacific Northwest.

Pacific oyster production is a well-established technology with proven value (Statistics Canada, 2018). It has experienced significant diversification over the past few decades in terms of production methods, from beach culture to suspended longline culture to raft culture. These changes have also represented a transition from bulk production of a shucked product using beach and longline methods to the higher value single oyster produced on rafts which generates small, fresh half-shell, "cocktail" products for the restaurant market. The pursuit of higher farm-gate prices for half-shell oysters has most recently been associated with product branding and various system innovations including automatic grading and tumbling protocols as well as packaging to differentiate oyster products.

In addition to ongoing production improvements and associated product differentiation for the introduced Pacific oyster there has also been recent interest in looking at new oyster species to further support the growing demand. In particular, the introduction of the native west coast oyster (*Ostrea lurida*) into culture would support a species that was almost harvested to extinction a century ago. It has been classified as a species of special concern in Canada since 2001 by Committee on the Status of Endangered Wildlife in Canada (COSEWIC, 2011). The oyster industry views this as an opportunity to not only re-establish an endangered native species, but to capitalize on its marketability given its history on the west coast.

7.3 The way forward

Social acceptance of aquaculture could be considered the root cause that has slowed or halted growth in the North America aquaculture sector. However, the opportunities for growth and for production diversification are substantial and represent a major opportunity. New initiatives that directly address public acceptance while engaging a growing seafood consumer base are beginning to facilitate change and support sector growth. This is not to say that competitive seafood imports do not have an impact on the North American aquaculture sector but, given the growing consumer interest in foods that are grown locally, are of high quality and are diligently regulated with clear product traceability, there could be an increase in domestic sales if consumer confidence were boosted.

The uncertainty associated with external environmental pressures will continue to represent significant threats to the aquaculture industry. Climate change will necessarily require an effective adaptation strategy, one which may include pivoting to completely new species or genetic strains that respond positively to these environmental changes. The aquatic farming community will need to embrace monitoring technologies and become well-versed in the application of genomics and other tools.

8. Governance and management of the sector

8.1 Status and trends

8.1.1 Background

An appropriate and effective governance and management framework for the aquaculture sector will play a pivotal role in facilitating industry growth in North America. Regulatory burden, environmental assessment, planning, and social license have been discussed in other chapters of this review as issues that currently constrain sector growth. In developing an enabling environment for future developments, the following considerations ideally need to be incorporated into the governance and management discussion:

- Incorporate and implement an aquaculture strategy, including policies, plans, laws and regulations, and monitoring of the sector.
- Provide economic incentives that encourage and support better management practices for example, aquaculture certifications.
- Provide an effective and transparent environmental, risk assessment and strategic environmental assessment approach for developing and monitoring aquaculture operations.
- Develop effective biosecurity frameworks for the sector.
- Consider a regulatory framework embracing an ecosystem approach to the sector (Ecosystem Approach to Aquaculture), including spatial planning, carrying capacity estimates for farms and for watersheds, coastal zones, measures to integrate aquaculture with other coastal users, activities and the use of sustainability indicators.
- Support and enforce self-regulating management codes and promotion of sustainability-conducive production systems.

The management of aquaculture in North America continues to be based generally on supporting socio-economic sustainability while ensuring environmental protection (FAO 2017a). In both of the major aquaculture-producing countries, aquaculture is regulated by a combination of national or federal and state or provincial regulations. While little has changed in the United States of America in the last decade with respect to the aquaculture regulatory framework, the changes in management responsibility that have occurred in Canada over this same period have stabilized and some feedback on regional performance is available.

8.1.2 United States of America

Aquaculture in the United States of America is regulated through several federal agencies, including the Environmental Protection Agency (EPA), Department of Agriculture (USDA), Food and Drug Administration (FDA), the Department of Health and Human Services (DHHS), the Army Corps of Engineers (USACE), the National Oceanic and Atmospheric Administration (NOAA), as well as through local state agencies. A comprehensive listing and analysis of the United States of America policy and regulatory framework is provided by FAO (2020a).

The federal legislative mandate is typically supplemented with regional (state) operational regulations for the industry. State-directed regulations address many of the regionally specific issues associated with aquaculture management, such as resource use conflicts and the significant differences in climate and water conditions between the various production states. However, in moving to integrate an offshore component with the current aquatic food production industry, the obvious increased role of the foundational national legislation, combined with the disparity in management approaches among states, will provide a challenge (Cicin-Sain, et.al., 2001).

The National Oceanic and Atmospheric Administration (NOAA), through its Office of Aquaculture, addresses regulatory and policy issues as they relate to marine aquaculture in the United States of America. NOAA is responsible for enabling marine aquaculture while protecting the marine environment and balancing the resource use needs of coastal stakeholders (FAO, 2006-2020). They consult with state and other federal agencies and departments and issue permits for aquaculture in federal marine waters.

The continental United States of America does not have the physiographical coastal environments that can provide the productive cold-water aquaculture sites that are characteristic of the Canadian coasts, which are comparable to Norway and Chile. However, it has smaller areas of tropical, subtropical, temperate and arctic environments that support a greater diversity of seafood production. With a need for additional space, the move to offshore aquaculture continues to remain of interest, but comes with issues of zoning, multi-stakeholder conflicts and environmental impacts. New and cost-effective production systems for offshore environments that consider the impact of sea conditions and depth are key technical challenges for offshore development (Kapetsky, Aguilar-Manjarrez and Jenness, 2013).

In May 2020 the United States administration announced, through an Executive Order (US-EO, 2020), a pathway for the approval of ocean aquaculture in federal waters, a controversial departure from existing policy and one that could reshape seafood production in the country. The order set in motion a multi-institutional process for assessing and approving aquaculture projects in federal waters, including science-based planning to identify Aquaculture Opportunity Areas to find appropriate space in the marine environment for aquaculture production (Lester et.al, 2013,2018). The NOAA, is tasked with coordinating these projects, with the aim of harmonizing and streamlining the regulatory environment, and expanding overall seafood production.

Separately, a United States Senate bill, "Advancing the Quality and Understanding of American Aquaculture (AQUAA) Act of 2020" was introduced to the 116th Congress, along with a companion bill in the House of Representatives. The AQUAA Act intended to establish national standards for sustainable offshore aquaculture, arguing that this would create jobs and meet the growing regional and global demand for seafood. The bill would have designated the NOAA as the lead federal agency for marine aquaculture. The legislation would have also directed NOAA to harmonize the permitting system for offshore aquaculture for farms in federal waters and direct the agency to lead a research and development grant programme to spur innovation. However, the AQUAA Act did not receive a vote and therefore died as the Congressional session terminated in January 2021.

The proposed AQUAA Act was envisioned to uphold existing environmental standards while providing regulatory certainty and clarity to the industry, include a set of national standards to guide development of offshore aquaculture and aquaculture management plans that implement those standards on a regional scale and include a national coastal zone management plan to identify and establish areas particularly suited to aquaculture. An Office of Marine Aquaculture was to be established within NOAA, charged with coordinating the federal permitting process that would give farm operators the security of tenure necessary to secure financing for an aquaculture operation. It would also support the economic development needs of the sector by facilitating a variety of financial instruments and processes and fund research, extension services and loans to support innovation and the growth of aquaculture in the United States of America.

The future of this or similar legislation will have significant impact on the offshore aquaculture in the United States of America.

8.1.3 Canada

In Canada, most of the coastal aquaculture production and the potential for significant future growth, resides in coastal British Columbia. Management of the aquaculture industry in this region changed significantly in 2010 due to a British Columbia Supreme Court decision that aquaculture was legally considered a fishery, and as such falls within federal jurisdiction. As a result, all aquaculture except for aquatic plants (seaweeds) is now regulated by the Department of Fisheries and Oceans (DFO). The DFO manages the aquaculture sector using two relevant provisions of the Fisheries Act; habitat protection and pollution prevention. The Department conducts analysis and approves site selection for new operations, issues operational licenses for facilities and assesses sector performance through a comprehensive environmental compliance programme which forms the Pacific Aquaculture Regulations (PAR).

The compliance of any farm with PAR environmental standards is used as the metric of performance and a quantitative indicator of how well the operators of an aquaculture facility meet environmental protection standards. The 2018 compliance report for the industry (Environment and Climate Change Canada, 2019) indicated that of the 141 farms inspected, 76 percent had no violations and 20 percent had only minor non-compliance issues, none of which resulted in any charges under the Fisheries Act.

The British Columbia Provincial government assumes responsibility for issuing farm tenures, managing coastal zone planning, multi-stakeholder conflicts and First Nation consultation. In addition, the province retains overall management of the seaweed sector, which includes site selection and approvals, licensing, and compliance monitoring. As this sector is gaining considerable interest this may represent a significant change to regional government involvement in the sector.

8.2 Salient issues

A common theme in the current North American review is the influence of public perception of the industry. As the negative views of aquaculture have evolved primarily from marine finfish aquaculture and associated environmental impacts, the development of comprehensive environmental and farm operational regulations and performance standards provides an additional level of transparency for the public and supports the gradual transition to broad acceptance of the sector. It should be noted that despite the shift from regional to national jurisdiction over aquaculture, the approach used for site-specific management has remained largely unchanged. However, a national consultation in Canada has recently been initiated to support the development of a Canadian Aquaculture Act, embracing a new regulatory framework which would not be encumbered by the conflicting mandates of the legislation under which the sector currently is managed.

The involvement of indigenous communities in aquaculture is growing, especially in western Canada. Partnerships in a variety of farm operations are under development. In addition, the inclusion of First Nations in coastal zone planning and in new farm operational reviews provides an additional component to the management framework. As noted above, the inclusion of strong regulations and broad community engagement in the industry will continue to support the acceptance and eventual growth in the region.

8.3 The way forward

The structure of aquaculture governance will play a pivotal role in determining how readily the aquaculture sector will be able to expand in North America, facilitating an increase in production and an associated diversification of aquatic foods. Canada and the United States of America are following different trajectories to achieve this goal, determined by the availability and extent of their respective resources, and as such face different regulatory challenges. As discussed earlier in this review, the focus of both countries is on production for both domestic and export markets. Whether export remains concentrated between the neighbouring nations or expands to include new and extensive Asia-Pacific export markets, an enabling governance and management framework and complementary international trade agreements will provide certainty and open the opportunities that typically attract the investment community. All of these developments will support growth in the sector.

Had the AQUAA Act been enacted, it would have enabled the expansion of aquaculture opportunities by opening suitable federal waters for sustainable aquaculture growth, creating new jobs, stimulating economic growth in coastal communities, and ensuring the coasts and offshore waters are responsibly managed. Similarly, development of a Canadian Aquaculture Act would also address the regulatory constraints and challenges for aquaculture management and future growth of the sector. This type of legislation is envisioned to enable sustainable aquaculture development, including research and innovation, coastal zone management for site selection and approvals, a streamlined regulatory path and security of operational permits for the farmer (British Columbia Salmon Farmers Association, 2019b). The next five years of aquaculture development in North America may see significant changes in regional production capacity as a result of these governance efforts and the region may join other jurisdictions to address the global demand for seafood.

9. Contribution of aquaculture to the FAO strategic objectives, the Sustainable Development Goals, and the Blue Growth Initiative

9.1 Sustainable Development Goals

The 17 Sustainable Development Goals (SDGs) are designed to be a "blueprint to achieve a better and more sustainable future for all". They were established in 2015 by the United Nations General Assembly and intended to be achieved by the year 2030, and aim to "create conditions for sustainable, inclusive and sustained economic growth, shared prosperity and decent work for all, taking into account different levels of national development and capacities" (FAO, 2017c).

The SDGs are:

1. No Poverty: End poverty in all its forms everywhere.

2. Zero Hunger: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture and aquaculture.

3. Good Health and Well-being: Ensure healthy lives and promote well-being for all at all ages.

4. Quality Education: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.

5. Gender Equality: Achieve gender equality and empower all women and girls.

6. Clean Water and Sanitation: Ensure availability and sustainable management of water and sanitation for all.

7. Affordable and Clean Energy: Ensure access to affordable, reliable, sustainable and modern energy for all.

8. Decent Work and Economic Growth: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.

9. Industry, Innovation and Infrastructure: Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation.

10. Reducing Inequalities: Reduce income inequality within and among countries.

11. Sustainable Cities and Communities: Make cities and human settlements inclusive, safe, resilient, and sustainable.

12. Responsible Consumption and Production: Ensure sustainable consumption and production patterns.

13. Climate Action: Take urgent action to combat climate change and its impacts by regulating emissions and promoting developments in renewable energy.

14. Life Below Water: Conserve and sustainably use the oceans, seas and marine resources for sustainable development.

15. Life On Land: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

16. Peace, Justice, and Strong Institutions: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.

17. Partnerships for the Goals: Strengthen the means of implementation and revitalize the global partnership for sustainable development.

The North American aquaculture sector addresses a number of the SDGs, particularly with respect to the proposed changes that will facilitate growth and improve consumer confidence in aquaculture products and seafood production processes. For example, SDG 2 encourages sustainable agrifood practices and production that is nutritionally beneficial. SDG 5 embraces gender equality and the aquaculture workforce in North America attracts both men and women to the sector. As the sector becomes increasingly technology-based, the opportunities for both men and women have been growing, attracting individuals with higher education and with specialized areas of expertise. SDG 8 ensures that all farm operations provide full and decent work for all employed, and the corporate goals focus on economic growth, stability and profitability to support the sustainability of the operation. SDG 13, in calling for an urgent response to climate change, is reflected in the growing focus on species diversification as an adaptive response to changing ocean conditions, but also an expressed interest in opportunities for co-culture of species that may in fact sequester carbon (for example seaweed uptake of CO_2). SDG 14 recognizes the need for sustainable use of the oceans and the North American model for environmental monitoring, site selection and coastal zone planning is an approach that can meet this goal. Finally, SDG 17 looks to partnerships to meet the SDGs, and the example of First Nation community involvement in aquaculture development provides a positive example.

9.2 FAO strategy and Blue Growth Initiative

The FAO Blue Growth Initiative (BGI) seeks to maximise economic and social benefits while minimizing environmental degradation across sectors related to fisheries and aquaculture and is closely aligned with the SDGs (FAO, 2017d). This includes significantly growing global aquaculture to meet the increasing need for aquatic food projected over the next few decades in a socially, economically and environmentally sustainable manner.

Within the North America region the following examples illustrate alignment with the BGI goals:

Increasing decent work opportunities and fostering healthy, resilient and inclusive communities.

The BGI seeks to promote the development of a sustainable aquaculture sector through a balance of economic and social benefits for local communities, including those of indigenous peoples. As noted in this review, coastal First Nation communities are actively exploring opportunities for developing aquaculture ventures and many who are already directly or indirectly involved in aquaculture are now looking to integrate traditional knowledge and practices as stewards of the ecosystems in which they live. The examples provided from coastal British Columbia show that these communities are also engaged in decision-making processes that affect them, supporting or denying access to their traditional lands and territories and encouraging the preservation of their cultural heritage through sustainable aquaculture management.

Increasing financial and technical innovation.

North American production facilities are typically vertically integrated and are becoming increasingly technology-intensive. The ongoing commercial-scale testing of Recirculation Aquaculture Systems (RAS), developed from sophisticated hatchery technology, offers the opportunity to control environmental conditions, capture and remove organic and inorganic wastes, as well as move entire production facilities closer to markets (Kuterra, 2020). New production systems that allow offshore aquaculture to develop, including single-tether mooring systems, subsurface cage structures and autonomous (free floating) cages all provide opportunities for producing aquatic food in open, potentially harsh, oceanic conditions. These technology innovations will facilitate sector growth and allow for significant increases in farmed seafood, particularly in continental United States of America where inshore siting is limited.

Sustainably managing the environment and its resources and minimizing degradation.

As discussed in chapter 8, a comprehensive regulatory and management framework in North America provides metrics of sustainability that allow the entire aquaculture sector to be concurrently assessed, with farm-based environmental performance graded against a series of standards. This type of approach offers public scrutiny and transparency of farm operations, with a time series of performance that can offer evidence on sustainability. Similarly, thorough site selection and evaluation criteria provide pre-installation assurances that proposed aquaculture facilities will not exceed environmental carrying capacity, will not negatively impact valued habitat, but will consider and support social sensitivities such as the traditional knowledge and practises of indigenous peoples.

Reducing food loss and waste for efficient resource use and increasing energy efficiency to reduce the carbon footprint of aquaculture.

North American aquaculture seeks continual improvement. For example, over the past few decades, research on the nutritional requirements of fish has resulted in feeds that have dramatically increased food conversion efficiencies and thereby reduced the output of organic and inorganic wastes and the environmental impacts associated with these discharges. Development and commercial-scale testing of integrated multi-trophic aquaculture (IMTA) systems goes further by intercepting wastes and using them for production of secondary and tertiary species like shellfish and seaweeds. IMTA may provide environmental as well as socio-economic benefits for North American aquaculture, supporting environmental sustainability as well as allowing for production diversification and increases.

The current interest in seaweed aquaculture in Alaska and western Canada offers several environmental benefits. Sequestration of carbon through the physiological processes of macrophytes, will reduce the carbon footprint of a farm whether the seaweed is grown in monoculture or as part of a co-culture or IMTA system. This extraction capacity can be substantial, and estimates suggest that coastal production of seaweeds at a large scale would provide significant sequestration if the seaweed is removed from the environment and incorporated into soil for medium to long term storage.

In terms of seafood waste, Love *et al.* (2015) noted that as much as 40 percent of wild harvested fish and aquaculture production goes uneaten. The authors further estimated that 36 percent of this volume could fill the gap between current seafood consumption and the recommended consumption rate to convey health benefits to consumers in the United States of America.

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Annex 1. FAO statistical data

Data used in this regional aquaculture review, derive mainly from the different FAO fisheries and aquaculture statistics (FishStat), accessible through different tools, including the FAO Yearbook Fishery and Aquaculture Statistics, online query panels and FishStatJ[2] (FAO, 2020a; FAO, 2020b; FAO, 2020c). These tools provide free access to fisheries and aquaculture data, including production, trade, consumption and employment for over 245 countries and territories from 1950 to the most recent year available. FAO represents the only global source of fisheries and aquaculture statistics, which are mainly compiled from data submitted by member countries. Statistics received are validated by FAO through adequate quality controls and, in the absence of official reporting, FAO estimates the missing data based on information obtained from alternative sources or standard estimation methods. Estimates also involve disaggregating some of the data received by FAO in aggregated form by species and, in the case of production, also by culture environment.

FAO highlights that data received from countries show different levels of quality in terms of coverage of species, environment and overall national reporting. Inconsistencies may occur in data reported or data are not reported at all. For example, in the case of aquaculture production, FAO has noted that not all the countries have adequate and effective data collection systems set in place. Many countries still do not have a systematically established framework aligned with internationally and regionally accepted standards for data collection from fish farms. In addition, in several countries, the staff responsible for reporting aquaculture production lack the relevant knowledge, support or relevant mechanisms such as specifically designed databases to develop accurate production estimates and improve monitoring and control of the industry. Production data are often estimated through extrapolation by multiplying the area under fish culture by an estimate of average productivity, with adjustments according to advice from key contacts in the industry. Improvements to this problem could, for example, be found by resolving issues related to the fish farm licensing process and devising a system for direct reporting of production, coupled with validation through sample survey by trained enumerators.

Problems occur as well for other typologies of aquaculture statistics. Only a very limited number of countries have a breakdown for farmed vs wild species in their trade statistics and, in addition, many farmed species are often reported in an aggregated form under miscellaneous entries as other fish. The lack of accurate trade data on farmed fish and fish products implies the impossibility to calculate separate consumption statistics on farmed species, with no clear assessment of the nutritional role of farmed species in the countries. In addition, not all the countries have a good collection of employment data in the primary and secondary aquaculture sectors, including insufficient detail on the role of women in the sector, which is captured mainly by ensuring employment data is sex-disaggregated and that all types (part time, full time, occasional time use) are all collected and reported . These data are essential to better assess dependency on the sector and other relevant indicators.

Due to the key role that accurate and timely data play in the management and policy formulation for sustainable aquaculture development, FAO remarks the urgent need for national capacity development in aquaculture statistics systems at several levels, including:

- the legal status, institutionalization and resource allocation;
- development of national statistical standards in line with international standards;

[2] http://www.fao.org/fishery/statistics/en

- adequate and stable staffing plus an effective mechanism for data collection, compilation, storage, dissemination and reporting; (FAO, 2020d)
- improvement in the coverage of farmed species in trade statistics, with the clear separation of farmed vs wild species; and,
- improvement in the coverage and accuracy of employment data, disaggregated by sex, occupational status and age.

In continuing the global efforts to achieve aquaculture sustainability through dissemination of up-to-date information on the status and trends of the sector, FAO publishes Aquaculture Regional Reviews and a Global Synthesis about every 5 years, starting in 1997. This review paper summarizes the status and trends of aquaculture development in North America.

Relevant aspects of the social and economic background of the region are followed by a description of current and evolving aquaculture practices and the needs of the industry in terms of resources, services and technologies. Impacts of aquaculture practices on the environment are discussed, followed by a consideration of the response by the industry to market demands and opportunities, and its contribution to social and economic development at regional, national and international levels. External pressures on the sector are described, including climate change and economic events, along with associated changes in governance.

The review concludes with an analysis of the contributions of aquaculture to the Sustainable Development Goals, the FAO Strategic Objectives, and the FAO Blue Growth Initiative. Throughout the review, outstanding issues and success stories are identified, and a way forward is suggested for each main topic.

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