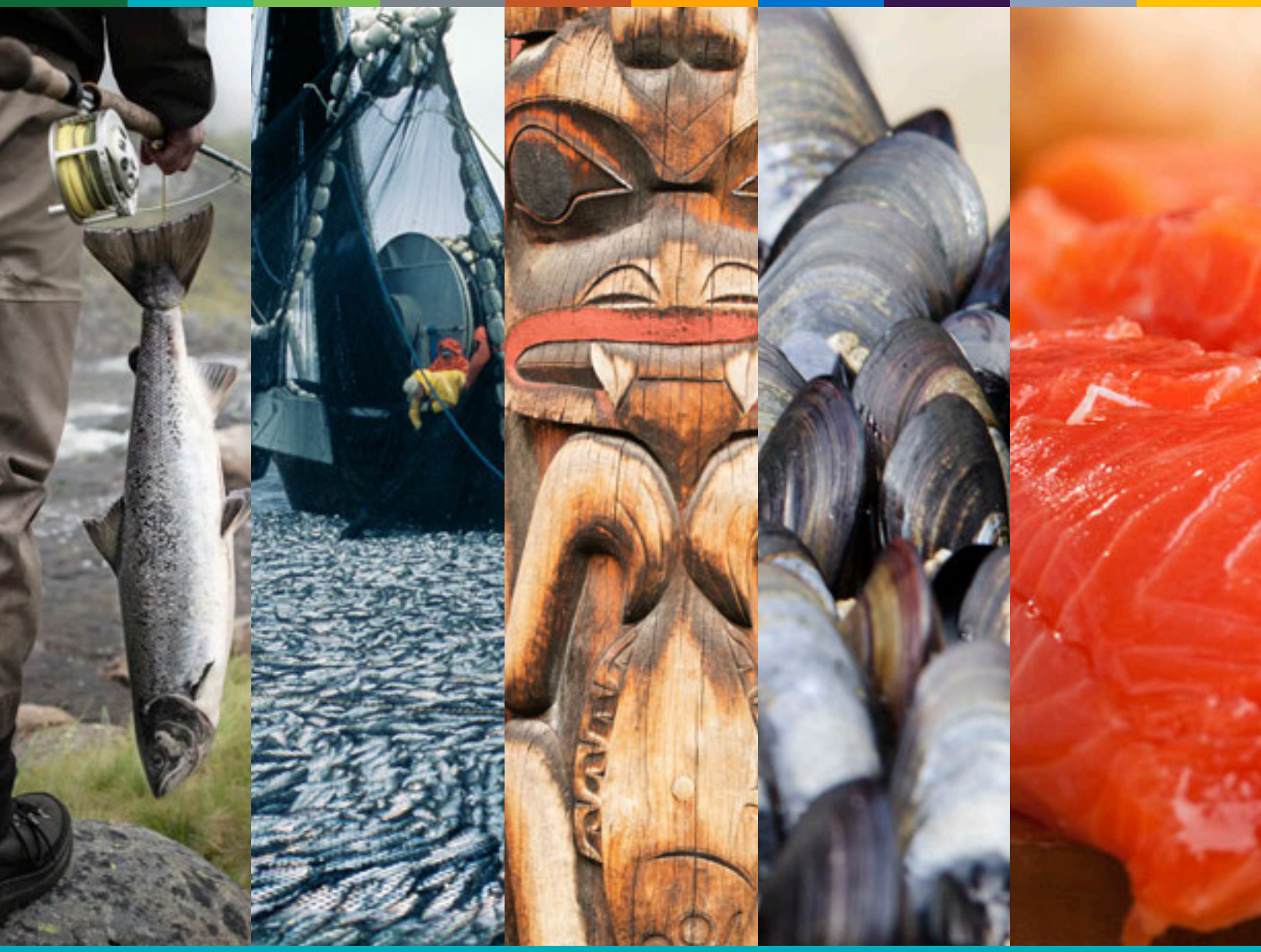


A GENOMICS STRATEGY FOR BRITISH COLUMBIA'S

FISHERIES & AQUACULTURE SECTOR

Genome BritishColumbia

Leading ▸ Investing ▸ Connecting

2019

Contents

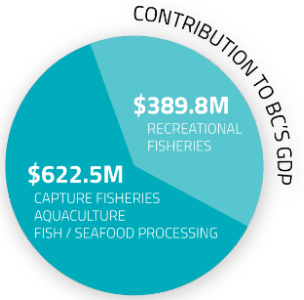
1. Importance of the sector to the BC economy 3
2. Current state of the sector 4
3. Sector challenges and opportunities 6
4. The role of genomics in addressing sector challenges 8
5. Approach 11
6. Conclusions 11
7. References 11

1. Importance of the sector to the BC economy

The fisheries and aquaculture sector is an integral part of BC's history, culture and community and one of the economic engines of the province. More than 100 distinct species of fish, shellfish, and marine plants are currently commercially harvested from BC's waters. In 2017, provincial harvests of primary seafood, including capture fisheries and aquaculture, totaled 279,400 tonnes with a landed value of $1.178 billion. Of this, 180,996 tonnes of processed seafood was shipped to 73 markets with a total export value of $ 1.288 billion[1].

The fisheries and aquaculture sector comprise

- capture fisheries
- aquaculture
- fish and seafood processing
- recreational fisheries






A report prepared by BCStats[2] compared the GDP contributions of all four sub-sectors in 2016; while recreational fisheries had the highest GDP ($389.8 million), the combined GDP of the other three sub-sectors listed above was much higher ($622.5 million). The fisheries and aquaculture sector employ approximately 15,000 people[2] mainly in coastal and First Nations communities.

First Nations are involved in marine resource management and environmental stewardship in addition to being employed by this sector. While First Nations are constitutionally recognized as distinct aboriginal peoples who hold specific aboriginal rights and title including fishing for food, social and ceremonial purposes, there is also a growing interest in aquaculture as an opportunity for economic development among Indigenous communities.

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2. Current state of the sector

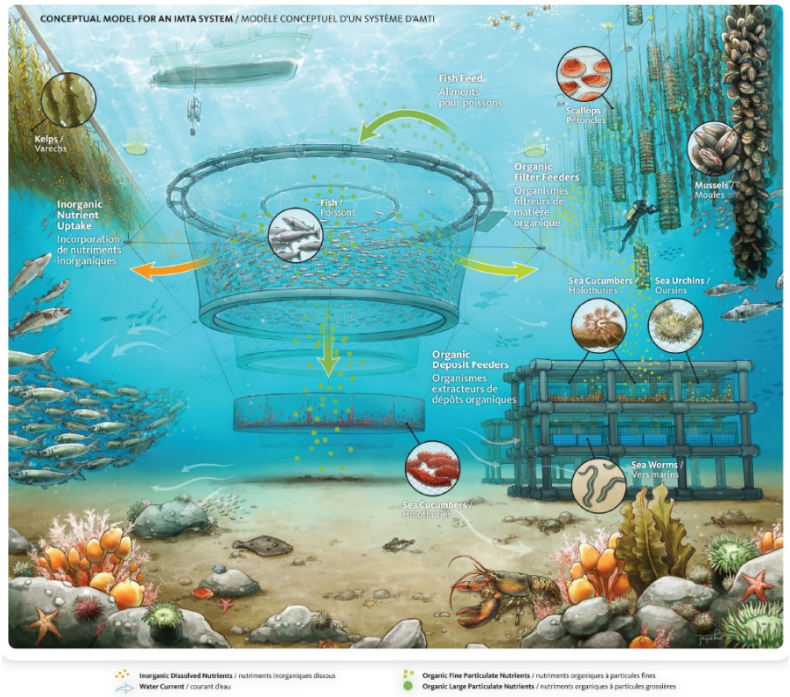
Capture fisheries

BC's capture fisheries harvested 182,900 tonnes (landed value $410.2 million)[1] in 2017. Groundfish including hake, rockfish and flounder (126,600 tonnes) represent most of the BC capture harvest, followed by herring (i.e. whole fish, roe herring, spawn on kelp; 27,900 tonnes) and Pacific salmon (13,700 tonnes) and shellfish (12,100 tonnes)[1]. However, species such as halibut, crab, geoduck and prawn make a significant economic contribution to this segment of the sector although their harvest volume is small *(see table below)*.

Species	Landed value ($ million)[1]	Harvest (tonnes)[1]
Halibut	58.9	3,800
Crab	51.1	3,800
Geoduck	50.2	1,400
Prawn	29.5	1,100
Herring (whole fish, roe herring, spawn on kelp)	27.5	27,900
Rockfish	24.1	16,800
Chum	21.9	7,000
Hake	19.3	85,000
Chinook	17.1	1,200
Arrowtooth flounder	10.0	10,100
Coho	8.4	1,300
Sockeye	4.7	500
Pink	3.3	3,700

Aquaculture

In 2017, BC produced 85,700 tonnes of farmed salmon with a landed value of $728.6 million[1]. Atlantic salmon is the primary cultured species with a harvest of 83,100 tonnes and is BC's largest agricultural export commodity with a value of $512.3 million[1].



Currently, open ocean net pens are the most common form of commercially operating aquaculture systems in BC. To mitigate challenges such as risk of pathogen transfer and fish escape, innovative technologies such as closed and semi-closed contained systems, offshore fish farms as well as land based

recirculating systems are currently being tested. Diversification of aquaculture species and systems has been identified as a promising approach to meet increasing global seafood demand[3]. An example of alternative seafood production systems is Integrated Multi-Trophic Aquaculture (IMTA). It mimics a natural ecosystem by farming multiple, complementary species from different trophic levels such as fish, shellfish and seaweeds.

Shellfish, including oyster, mussel, geoduck and other clams are also produced in BC and contributed with a landed value of $21.8 million[1] to BC's economy in 2017. The shellfish aquaculture sector may expand in the future as there is growing demand from local and international markets, in particular, Asia. Furthermore, BC offers very favorable conditions for shellfish production and some First Nations are becoming increasingly involved in growing shellfish commercially, in addition to traditional sustenance harvesting. Other species including trout, tilapia, sablefish, sturgeon, Arctic char and marine plants are also grown commercially in BC and contributed with a landed value of $17.8 million in 2017[1].

Marine plants are among many aquaculture species grown commercially in BC.

Fish and seafood processing

Fish and seafood processing are integral to the fisheries and aquaculture sector and generated about 23% of the fisheries and aquaculture's GDP ($232.8 million) in 2016[2]. Since fish and seafood processing is dependent on the input of capture fisheries and aquaculture, fluctuations of the GDP are linked to variations in these sub-sectors. Despite a decline in capture fisheries the GDP in the fish and seafood processing has increased 23.2% since 1990 [2].

Recreational fisheries

BC's recreational fisheries occur in marine and freshwater environments. While the concept of "landed value" does not easily apply to recreational fisheries, approximately 330,000 and 360,000 licenses for marine and freshwater recreational fishing, respectively, were sold in 2016 and 2017, with a combined value of $17.86 million (marine: $6.75 million, freshwater: $11.11 million).[5,6] However, the total economic impact of the recreational fishery is much greater than this as it includes indirect revenues such as spending by local and visiting anglers for travel, hotels, food and drink, gear, guide services, etc. The most recent BC Stats assessment[2] noted that GDP associated with recreational fishing activities increased during the past five years indicating that recreational fishing is a growing sector in the province. Pacific salmon, primarily chinook and coho, constitute most of the marine recreational fisheries. While rainbow

trout is the cornerstone of freshwater recreational species other popular freshwater species include cutthroat trout, Sockeye/kokanee and steelhead.

3. Sector challenges and opportunities

As with all the natural resources sectors, there are several challenges facing BC's fisheries and aquaculture sector. The overarching challenge is sustainability, specifically to provide opportunities to catch, harvest and produce aquatic animals and plants while preserving the integrity and productivity of aquatic ecosystems. Significant challenges include:

Climate change and environmental impacts

Climate change has already had a significant impact on fisheries and aquaculture worldwide. Changes in water temperature and chemistry affect ocean ecosystems, food chains, and the ability of fish, shellfish and marine plants to thrive. Extreme weather events such as floods, fires, and drought, will occur with greater frequency and intensity and the sector requires adaptation and mitigation strategies to ensure sustainability of wild populations and productivity of aquatic ecosystems. In addition to climate change challenges, a range of societal impacts may further bring immediate or long term changes to aquatic habitats and associated biodiversity.

Animal health and product safety

The health of aquatic organisms is paramount for wild and farmed stocks alike. While several bacteria, viruses and parasites have been identified the impact of most of these potential pathogens on wild and farmed aquatic species requires further investigation. Finfish health is challenged by the limited availability of therapeutics and vaccines for bacterial infections such as *Tenacibaculum maritimum* (causes rotten fins and skin lesions), *Piscirickettsia salmonis* (causes heavy mortality) as well as sea lice, and shortage of affordable, sensitive and rapid diagnostics for parasites such as *Kudoa thyrsites* (causes muscle tissue dissolution). Furthermore, pathogens such as norovirus and *Vibrio parahaemolyticus* as well as marine biotoxins produced by microalgae accumulate in shellfish. While this is not harmful to shellfish it is a significant threat to human health, which highlights the need for improved diagnostics, monitoring and traceability.

The impact of potential pathogens on wild and farmed aquatic species requires further investigation.

Wild fish stock monitoring and management

Conservation of wild stocks is the foundation of sustainable harvest of aquatic resources. The assessment of fish stocks and their activities within the vast and dynamic environment of BC's extensive lakes and coastal waters is difficult and expensive. Available data on stock size, structure and distribution as well as migration patterns of populations is rarely complete or comprehensive, but it is crucial for generating models to inform fisheries and conservation management. This situation is further complicated by the presence of several hundred genetically distinct Pacific salmon stocks in BC that fall within seven species, not to mention the challenge of addressing by-catch issues. Moreover, fisheries often harvest multiple fish populations with unknown origins. These mixed stock fisheries may lead to overharvest of weak populations or lost opportunities to catch abundant populations.

Hatcheries

While wild stocks are the base for capture as well as recreational fisheries, more than 30 hatcheries as well as spawning channels throughout BC operated by the Department of Fisheries and Oceans Canada (DFO-MPO), First Nations or community groups, significantly support these fisheries. Every year, hundreds of millions (in 2017: 368 million[8]) of juvenile Pacific salmon are released from hatcheries and spawning channels (about 50% of the released fish[8]) into the wild and it is estimated that 10-20% of all salmon harvested in BC are derived from hatcheries and spawning channels[13]. However, the beneficial role of hatcheries in enhancing and restoring wild stocks is still uncertain due to evidence for reduced fitness and maladaptation of hatchery fish when released into the wild, and hatchery fish may negatively impact wild fish of the same species through genetic, ecological and disease interactions.

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Social license, risk and uncertainty

Concerns regarding the risk of disease and pathogen transfer from farmed to wild salmon and associated moratoria imposed by both the provincial and federal governments in the recent past have limited the growth of the aquaculture sector in BC. Thus, in 2015 the BC government convened an Advisory Council (Minister of Agriculture's Advisory Council on Finfish Aquaculture, MAACFA) "to provide strategic advice and policy guidance to the Minister of Agriculture about the future of, and issuance of new Crown land tenures for, marine based salmon aquaculture in B.C"[7]. After consultation, the council agreed on six strategic recommendations[7]. Some of these recommendations will have implications for the aquaculture sector in BC in the near term. These implications come at a

time when consumers' awareness of food sources increase and thus the demand for sustainably reared or caught products. Traceability will become more important to avoid food fraud, as will the use of sustainable feed in meeting the anticipated increased production.

While the production of shellfish in BC has slowly increased in recent years, the industry remains small and is built around several small companies and family holdings with more than 500 shellfish tenures on the BC coast. Some of the contributing factors for the small size of the industry may be related to the lack of capacity among regulatory agencies creating uncertainties for the sector; for example, lengthy approval timeframes hamper profitability and further investments. In addition, lack of locally adapted seed supply may affect growth of this industry.

Improved collaboration between private and public research partners will be key to overcoming current challenges as described above and positioning end users to increase global market share and to compete internationally.

Product development and infrastructure

In order to remain globally competitive in the long term, it is imperative for the sector to develop and adopt innovative technologies that utilize marine resources economically and in a socially responsible manner. To undertake product development, research or testing, current capacity of wet labs, quarantine facilities as well as qualified personnel is limited in BC, posing a significant challenge to the growth of the sector. Expanded research capacity and infrastructure, as well as improved collaboration between private and public research partners will be key to overcoming current challenges as described above and positioning end users to increase global market share and to compete internationally.

4. The role of genomics in addressing sector challenges

Genome BC has been strategically investing in opportunities to advance the application of genomics in BC's fisheries and aquaculture sector. Since inception in 2000, Genome BC has invested $66.3 million directly into 21 genomics research projects associated with the fisheries and aquaculture sector.

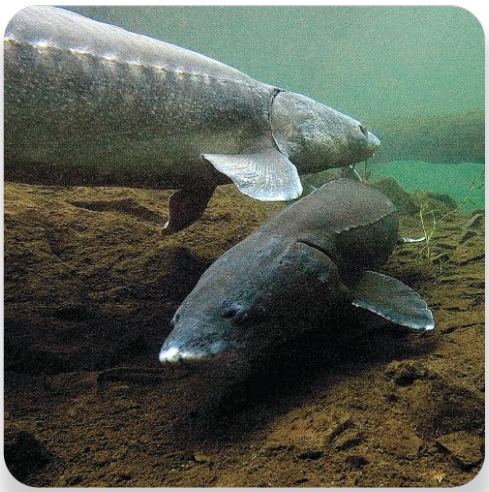
Success stories

The International Cooperation Project to Sequence the Atlantic Salmon Genome (ICSASG), which involved researchers, funding agencies and industry from Canada (British Columbia), Chile, and Norway produced a high quality Atlantic salmon reference genome[9] for use by researchers and industry worldwide. The

salmon genome continues to be utilized in projects studying issues such as the impact of cultured fish escapees on wild populations, populations that are at risk, host pathogen interactions, and biomarkers for certain traits including growth rate, disease resistance, hypoxia tolerance, and age at maturation. The Atlantic salmon reference genome was also beneficial to sequence other salmonid genomes such as Chinook salmon[10], coho salmon[11] and rainbow trout[12].

In Canada, the DFO has long incorporated genetics into its management of wild stocks and to monitor and facilitate hatchery management activities. As recently shown for one of the Pacific salmon species, coho salmon, parentage based tagging (PBT) may replace the older physical coded wire tags (CWT) technique as PBT accurately estimates the proportion of hatchery fish in wild populations and it assigns individuals not only to their stock but also to their parentage[14]. Improvements to determining the efficacy of hatchery release and how well hatcheries contribute to conservation and enhancement of fish stocks is crucial for sustainable fisheries.

Canada was also the first country to develop a genetically engineered Atlantic salmon which grows almost twice as fast as traditional salmon in aquaculture facilities, thus shortening the production cycle and quickening presence in the ocean. The fish has been commercialized by Aqua Bounty in the US and is approved for sale in Canada.



Current initiatives

Coho salmon, a highly valued Pacific salmon species, began to suffer serious declines in 1989. This was due to a productivity drop and high harvest rates to the point where the capture fishery for coho salmon was essentially closed in 1997. The current project **Enhancing Production in Coho: Culture, Community, Catch (EPIC4)** aims to revive and sustain wild coho salmon fisheries by developing better genomics tools for stock identification as well as policy recommendations for improved fisheries management and effective hatchery system.

The project, **Sustaining Freshwater Recreational Fisheries in a Changing Environment**, will provide solutions to sustain freshwater recreational fisheries in a changing environment. Over the next 50 years it

is estimated that 30% of rainbow trout habitat will be severely impacted by climate change. To sustain BC's rainbow trout freshwater recreational fisheries for generations this project aims to develop genomics tools and policy recommendations to preserve rainbow trout genetic diversity and to improve stocking programs.

Over 90% of juvenile salmon migrating from freshwater into the ocean will die before returning to freshwater to spawn. Disease may be a significant factor contributing to this mortality, however, knowledge about potential disease agents is limited. **The Strategic Salmon Health Initiative: An Inventory and Assessment of Health Risk of Microbes in BC** developed, evaluated, and demonstrated the application of a sensitive high throughput genomic platform for the identification of important viral, bacterial and fungal pathogens in wild and farmed salmon. In addition, this project also developed a viral disease development (VDD) biomarker panel to detect fish with an early viral infection or in a viral carrier state. The outcomes of this project will help to develop a strategy to protect wild Pacific salmon.

Environmental DNA (eDNA) technology is a promising approach to monitor and assess aquatic species presence by examination of DNA in water samples. The project **Environmental DNA (eDNA) methods: Case Study White Sturgeon** will inform how and when the eDNA approach can be applied in environmental assessments. The white sturgeon, *Acipenser transmontanus*, will be used as the test species as it is an iconic species in BC, its presence/absence in peripheral areas of its range is poorly understood and most populations are in decline.

As for all salmonids, chinook is sensitive to changes in environmental parameters such as temperature and dissolved oxygen. In a changing environment it is expected that future productive genotypes of chinook salmon will not be those most prevalent in BC today. To sustain this socially, environmentally, as well as economically highly valued species, the project **Atlas of Genetic Variation for Climate Change in Chinook Salmon** aims to make an inventory of genetic diversity of this Pacific salmon species across its full latitudinal range. This information will feed into conservation programs as well as selective breeding programs for the chinook salmon aquaculture industry.

Due to high temperatures and changes in ocean currents each year, especially in late summer, marine finfish farms struggle with hypoxia events which cause stress in fish, resulting in low performance and mortality events creating economic loss for the aquaculture industry. The project **Genomic Basis of Variation in Hypoxia Tolerance in Atlantic Salmon** investigates the ability of farmed Atlantic salmon families to tolerate low dissolved oxygen conditions. This information could be directly applied into selective breeding programs to produce Atlantic salmon which can cope with rising hypoxia events in the future.

The fisheries and aquaculture sector is facing tremendous challenges such as climate change, the need for sustainable and efficient seafood production, maintaining biodiversity, aquatic animal health as well as product safety, and the application of genomics technologies could be a viable part of the solutions. Key areas that could be explored are the diversification of aquaculture species and production systems; alternative and sustainable feed ingredients as well as the improvement of fishery management. While the seaweed industry is still relatively small in BC, there is an increasing worldwide demand for raw seaweed and value added products and thus an opportunity for BC to expand harvest and culture of

marine plants and to contribute to market demands[3]. Similarly, microalgae which can be cultivated under different conditions in fresh, salt and wastewater, attract increasing interest due to their huge potential for applications as biofuel, pharmaceuticals, and nutraceuticals. This is a chance for BC to develop a sector using renewable and sustainable microalgae resources with a significant economic potential – the global market for algae products is estimated to reach US$ 53 billion by 2026[4].

5. Approach

Genome BC's effort will focus on addressing sector challenges using genomics technologies and tools to restore and maintain healthy wild stocks, increase socially and environmentally responsible aquaculture production, and develop sustainable fish feed. Furthermore, we will focus our efforts in helping promote genomics among industry, government and First Nations as well as to create more and diverse productive partnerships. Use of genomics tools and approaches providing a sustainable, climate resilient, and diverse food source for all people in BC as well as aquatic flora and fauna.

6. Conclusions

While the value of genomics for fisheries, aquaculture, conservation and biosecurity is widely accepted, its application has not reached its full potential. Effective communication between researchers, managers and policy makers as well as the public is seen as a significant challenge, and one that must be overcome for effective translation of research outputs into practical solutions. In this regard, Genome BC plays a significant role by bringing academics, industry and government together to find solutions for future challenges such as climate change, increasing demand for sustainable seafood, and conservation of marine and freshwater ecosystems.

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