Salmon aquaculture in the Bay of Fundy, New Brunswick, Canada. Photo credit: Thierry Chopin.

ESSAY

Marine Aquaculture in Canada:

Well-Established Monocultures of Finfish and Shellfish and an Emerging Integrated Multi-Trophic Aquaculture (IMTA) Approach Including Seaweeds, Other Invertebrates, and Microbial Communities

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INTRODUCTION

Worldwide aquaculture is among the fastest growing food sectors, accounting for nearly 50% of the total finfish and invertebrate production and 96% of the total seaweed production (Chopin 2014).

Few jurisdictions can match Canada's natural advantages—enormous coastal geography; abundance of cold and clean water; favorable climate; rich marine and fishery tradition; established trade relationships with the United States, Asia, and Europe; and a commitment to sustainable and responsible best practices. However, during the past decade, production has more or less stagnated (12% increase in volume and 4% in value since 2008; AquaStats 2012) and Canada has remained a middleweight contributor, ranking only 21st among aquaculture producing countries (Canadian Aquaculture Industry Alliance [CAIA] 2014).

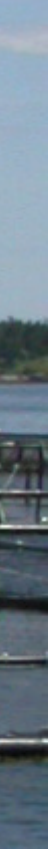
This overview of the marine aquaculture industry in Canada is based on statistics for the years 2012 and 2013, the most recent years for which complete statistics are available. There is also a developing freshwater aquaculture sector, but it will not be part of this article. In 2012, Canada produced 173,252 tonnes of farmed seafood valued at CAD$826 million. In 2013, 16% of Canada's total fish production was in aquaculture products and accounted for 35% of its total value. Canada exported more than 65% of its aquaculture production to over 22 countries around the world (more than 90,000 tonnes valued at more than CAD$601 million; CAIA 2014; Fisheries and Oceans Canada [DFO] 2014). Canada's primary farmed seafood export markets include the United States (more than 88,000 tonnes valued at more than CAD$576 million), Japan (CAD$11.3 million), Taiwan (CAD$3.6 million), Singapore (CAD$1.5 million), China (CAD$1.2 million), and Hong Kong (CAD$0.5 million; DFO 2014). Canada is the main seafood supplier to the United States. Other suppliers include China, Thailand, Indonesia, Chile, and Vietnam (Agriculture and Agri-Food Canada 2010). Approximately 50% of these imports come from aquaculture (National Oceanic and Atmospheric Administration 2013, 2014).

Marine aquaculture operations in Canada are established in British Columbia, New Brunswick, Prince Edward Island, Newfoundland, Nova Scotia, and Québec. The industry can be divided into three sectors: the dominant finfish sector, a strong shellfish sector, and the often ignored, but emerging, seaweed sector, mostly associated with the development of integrated multi-trophic aquaculture (IMTA; a combination of finfish, invertebrates, and seaweeds for environmental sustainability, economic diversification, and societal acceptability of aquaculture practices; Chopin et al. 2012).

THE FINFISH SECTOR

Farmed salmon, by far the most important finfish species grown by Canadian aquaculturists, with a production volume of 123,949 tonnes valued at CAD$599 million, accounted for over 80% of volume and value of finfish produced in 2012 (AquaStats 2012; Newfoundland and Labrador Department of Fisheries and Aquaculture [NLDFA] 2014). British Columbia accounted for 58% (71,998 tonnes), New Brunswick accounted for 24% (30,217 tonnes), Newfoundland for 13% (15,831 tonnes), and Nova Scotia for 5% (5,903 tonnes; AquaStats 2012; NLDFA 2014).

Of Canada's total farmed salmon production, 26% (31,779 tonnes) was consumed domestically (AquaStats 2012; NLDFA 2014). An additional 3,263 tonnes were imported. With a population estimated at approximately 35 million, Canada's per capita consumption



of farmed salmon is around 1.0 kg/person. This is very similar to the U.S. consumption. The United States is the destination for 97% of Canadian salmon exports.

Other finfish species currently undergoing aquaculture development, or being cultivated on a smaller scale, include Sablefish, sturgeon, Rainbow Trout, steelhead trout, halibut, and Arctic Char.

THE SHELLFISH SECTOR

Mussels accounted for 68% of the total Canadian shellfish production and 43% of its value in 2012: 28,124 tonnes valued at CAD$44.5 million (AquaStats 2012). Prince Edward Island remains the dominant Canadian mussel producer with 21,834 tonnes valued at CAD$28 million (78% of total Canadian production). Newfoundland produced 16% (4,400 tonnes valued at CAD$13.5 million), and Nova Scotia produced 5% (1,400 tonnes valued at CAD$1.9 million; AquaStats 2012).

The primary markets for mussels from Atlantic Canada are the U.S. and Canadian fresh, live markets. Canada exported 53% of its production in 2012, with almost 100% going to the United States (AquaStats 2012). The remainder of Canada's mussel exports was shipped, as both fresh and value-added products to markets in Europe, Asia, and the Middle East (Statistics Canada 2014). Canadian consumption of mussels is 0.5 kg/person, which is low when compared to European standards.

In 2012, Canada produced 11,191 tonnes of farmed oysters valued at CAD$23.5 million. Oysters accounted for 26% of the total value of shellfish production (AquaStats 2012). Oyster production is distinctly divided between two Canadian regions: 64% of the volume and 43% of the value was accounted for by Pacific oysters produced in British Columbia; the remainder was accounted for by Eastern/Atlantic and European oysters produced in Atlantic Canada (AquaStats 2012).

In 2013, 30% (3,304 tonnes) of the Canadian farmed oyster production was exported for a value of CAD$23.4 million; 89% were exported as live, fresh oysters. The United States is the primary export market for Canadian farmed oysters (87%; DFO 2014). The demand is currently expanding very rapidly and exceeds Canada's current supply. In an effort to meet this demand, growers are planning major production expansions.

Other shellfish species under aquaculture development, or cultivated on a smaller scale, include Manila clams, varnish/savory clams, cockles, Japanese scallops, sea scallops, and quahaugs. With the development of the deposit-feeder component of IMTA systems for recapturing the large organic particles from the fed component (fish or shrimp), advances in the aquaculture of other invertebrates such as sea urchins, sea cucumbers, polychaetes, and lobsters are anticipated (Chopin et al. 2013).

There is also increased recognition that marine microbial communities could play a significant, and presently underestimated, role in the recycling of organic matter. With a better understanding of the contributions of the "good microbes," it is possible to conceive that their activities could be enhanced by appropriately designed structures; that is, developing methods for their cultivation.

The need for diversification of the Canadian aquaculture industry is imperative to maintain its competitiveness.

THE SEAWEED SECTOR, EMERGING MOSTLY THROUGH THE DEVELOPMENT OF INTEGRATED MULTI-TROPHIC AQUACULTURE (IMTA)

The seaweed aquaculture sector is often neglected and ignored in world statistics, despite the fact that it represents 49% of the world mariculture production (23.8 million tonnes in 2012 valued at US$6.4 billion; Food and Agriculture Organization of the United Nations 2014). As 96% of the seaweed aquaculture is concentrated in six Asian countries (China, Indonesia, the Philippines, the Republic of Korea, Japan, and Malaysia), there is a lack of appreciation for this resource in the Western world (Chopin 2014).

Integrated Multi-Trophic Aquaculture (IMTA) offers an opportunity to reposition the value and roles that seaweeds can have in integrated food production systems and in ecosystem health. One often forgotten function of seaweeds is that they are excellent nutrient scrubbers (Chopin et al. 2001). Consequently, seaweeds can be used as the inorganic extractive component of IMTA, recapturing the dissolved nutrients released from the fed component. They can also be used for recapturing the dissolved nutrient effluents of water treatment facilities in coastal communities. Moreover, having organisms able to accumulate phosphorus is becoming increasingly attractive when considering that, in the not too distant future, the next "P peak" will not be that of petroleum but that of phosphorus.

Nutrient biomitigation is not the only ecosystem service provided by seaweeds. Seaweeds can be cultivated without the addition of fertilizers and agrochemicals, especially in an IMTA setting, where the fed component provides the nutrients. Seaweed cultivation does not require more arable soil and land transformation (deforestation). If appropriately designed, it can be seen as engineering new habitats, harboring thriving communities, and can be used for habitat restoration. Moreover, it does not need irrigation, on a planet where access to water of appropriate quality is becoming more and more of an issue.

As photosynthetic organisms, seaweeds are the only aquaculture component with a net production of oxygen, whereas all other components (fed and organic extractive) are oxygen consumers, hence contributing to avoidance of coastal hypoxia. While performing photosynthesis, seaweeds also absorb carbon dioxide and, hence, participate in carbon sequestration, even if in a transitory manner. Consequently, they could be a significant player in the evolution of climate change, slowing down global warming, especially if their cultivation is increased and spread more evenly throughout the world. By sequestering carbon dioxide and increasing pH in seawater, seaweeds could also play a significant role in reducing ocean acidification and shellfish mortalities recently reported.

Seaweeds are prime candidates for the integrated sequential biorefinery (ISBR) approach: on one hand, a wide range of biobased, high-value compounds (edible food, food and feed ingredients, biopolymers, fine and bulk chemicals, agrichemicals, cosmetics, bioactives, pharmaceuticals, nutraceuticals, botanicals, etc.); on the other hand, lower-value commodity bioenergy compounds

Mussel aquaculture in Prince Edward Island, Canada. Photo credit: Thierry Chopin.

(biofuels, biodiesels, biogases, bioalcohols, biomaterials, etc.). Over the last decade, the Canadian IMTA Network (CIMTAN) at the University of New Brunswick has adopted this ISBR diversification strategy with an industrial partner, Cooke Aquaculture Inc., in Atlantic Canada. IMTA kelps recapture some of the inorganic dissolved nutrients from fish farms, and the partners are developing markets for their uses in human consumption, cosmetics, partial substitution in fish feed and biochar production, along with eco-labeling and organic certification.

Before the development of IMTA, two companies were already cultivating seaweeds:

- Acadian Seaplants Limited, producing the red alga *Chondrus crispus* (Irish moss) in land-based seawater tanks in Nova Scotia for the edible Asian sea-vegetable market.
- Canadian Kelp Resources Ltd., cultivating the brown algae *Alaria marginata*, *Saccharina latissima*, and *Macrocystis integrifolia* as sea-vegetables for human consumption, pharmaceutical, homeopathic and cosmetic companies, health food stores, and feeds for abalone and sea urchin cultures.

ECONOMIC IMPACTS AND LABOR FORCE OF THE AQUACULTURE INDUSTRY

Gardner Pinfold Consultants Inc. (2012) measured the economic impacts of the aquaculture industry in Canada in 2010, considering the value of the output and the gross domestic product (GDP), labor income, and employment (in full-time equivalents) at three levels: direct (impacts of the aquaculture industry itself [hatcheries, grow-out operations and processing]), indirect (impacts in the industries supplying goods and services to aquaculture [feed, equipment, advice]), and induced (impacts arising from spending of income earned by those employed directly and indirectly).

The value of the total output was CAD$1.114 billion. The aquaculture industry generated a total GDP of CAD$1.064 billion (CAD$354 million in direct GDP; CAD$464 million in indirect GDP; CAD$246 million in induced GDP). The total labor income was estimated at CAD$618 million (CAD$193 million directly; CAD$286 million indirectly; CAD$139 million being induced). Consequently, the cumulative gross value of output generated was CAD$2.796 billion.

The aquaculture industry created an estimated 13,070 full-time equivalent jobs (4,812 directly; 5,643 indirectly; 2,615 being induced).

CONCLUSIONS

The principal challenge for the Canadian aquaculture industry is an overly complex, uncertain, and confusing regulatory system that restricts growth and limits investment. This industry is regulated by an obsolete, reactive, and inefficient Fisheries Act dating back to the establishment of Confederation (1867), at a time when commercial aquaculture did not exist—a wildlife management act that was never intended for an innovative, food production sector. A new Aquaculture Act would provide the Canadian aquaculture industry with a more modern and effective approach to governance—a piece of framework legislation that, while respecting provincial jurisdictions, would harmonize the application of federal regulations nationwide and enable the development of new practices within an ecosystem/multispecies/multi-activity management approach—to give this industry the definition, the clarity, the recognition, and the vision for growth it requires.

In light of this difficult situation, the need for diversification of the Canadian aquaculture industry is imperative to maintain its competitiveness. Moreover, it is clear that in some regions, the scope for expansion of monoculture activities is limited. Developing IMTA systems should not only bring increased profitability per cultivation unit through economic diversification of cocultivating several value-added marine crops but it should also bring environmental sustainability and societal acceptability. Moreover, the IMTA multicrop diversification approach (fish, seaweeds, invertebrates, and microbes) could be an economic risk mitigation option to address pending climate change impacts. The ecosystem services provided by extractive aquaculture should be recognized and valued

Kelps cultivated at an IMTA site in the Bay of Fundy, New Brunswick, Canada, in proximity to salmon cages provide key services to the ecosystem and represent an additional crop with many product applications. Photo credit: Thierry Chopin.

by fed aquaculture and society and lead to the implementation of nutrient trading credits (NTCs), which could be used as financial incentive tools to encourage mono-aquaculturists to contemplate IMTA as a viable aquanomic option to their current practices. Increasing responsible aquaculture production through diversification, regulatory reform, and new legislation would also have a positive impact on jobs and economic opportunities in rural/coastal communities.

Canadians consume around 5.2 kg of fish and shellfish per year (CAIA 2014). This level of consumption is 33% below the Health Canada Food Guide recommendations. The seafood consumption of 88% of Canadians does not meet these guidelines and thus greatly increases their risk of coronary heart disease. Given the degree of "health consciousness" among Canadian consumers, a campaign emphasizing the health benefits of eating more farmed seafood could be very effective in increasing its demand. Access to more farmed seafood, including seaweeds, would enable meeting increasing market demands for fresh, local, safe, and sustainably produced seafood. For buyers and consumers, these attributes should be used for differentiation through branding, eco-certification, and organic labeling.

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