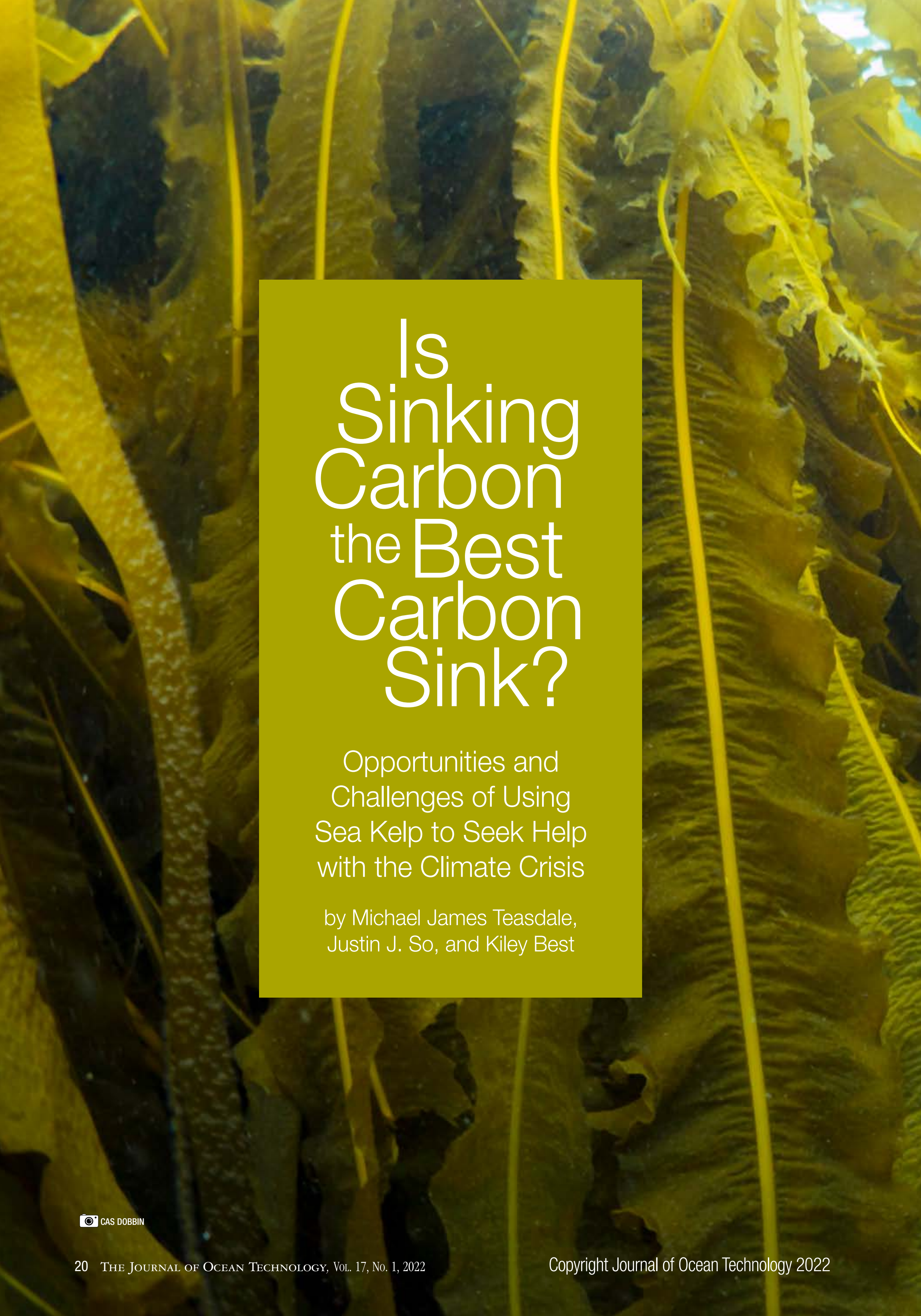

Is Sinking Carbon the Best Carbon Sink?

Opportunities and Challenges of Using Sea Kelp to Seek Help with the Climate Crisis

by Michael James Teasdale, Justin J. So, and Kiley Best

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Introduction

Seaweed farming is a sustainable and environmentally conscious industry that is being investigated globally as one of the potential avenues to reducing greenhouse gases and mitigating climate change. There are several research areas of these nascent technologies deemed "blue carbon." One of the concepts is sinking seaweeds to the seafloor to sequester carbon for approximately 1,000 years thereby acting as a long-term carbon sink and helping Canada obtains its net-zero carbon emissions. Other research involves adding a seaweed to livestock feed that causes the cattle to reduce the amount of methane they release. These research areas (and others) are being explored as the Canadian (and North American in general) farmed seaweed production continues its rapid expansion transitioning to larger scales of commercial production. Currently, the major market for North American farmed seaweed is human consumption but investors and seaweed startups are also considering and speculating on future opportunities that the blue carbon market may offer. This essay presents an overview of the feasibility of growing seaweed in Canada and Newfoundland and Labrador (N.L.) within the context of blue carbon and highlights some of the potential opportunities and challenges in terms of environmental conditions, logistics, regulations, and existing infrastructure.

Blue Carbon

Carbon Sinking (Sequestration)

Seaweeds are high in polysaccharide content and naturally have a role in capturing carbon in marine vegetated habitats. It is estimated that global wild seaweed could potentially sequester approximately 173 Tg C year^{-1} as they are transported to deepsea environments or buried in coastal sediments by ocean currents (see "Further Reading" at end of essay). The idea being that carbon in the seaweed's biomass will be locked up in the deepsea water cycle and will not re-enter the atmosphere for hundreds of years. In recent years, seaweed farming has garnered attention as a possible carbon sequestration strategy where farmed seaweed is transported and then sunk into the deep sea. Whether this potential strategy would be effective is still being scientifically debated. However, various companies are moving forward with feasibility and technical studies to evaluate this pathway for eventually providing "carbon offsetting credits." Ocean 2050 is currently leading a study to quantify seaweed carbon sequestration at seaweed farms across the globe (including Cascadia Seaweed in B.C.) to provide further scientific support to commercialize this strategy (see "Further Reading"). Other companies are exploring advanced solutions such as unmanned mobile seaweed farms that can grow and release seaweeds. There are several challenges to overcome a transition from an academic pursuit to a sustainable, viable industry method to capture carbon. Sinking seaweed is unlikely to be a practical measure of mitigating climate change at global scales; however, it could be used in the more near-future to minimize carbon footprints at the regional level. The current price of carbon would not cover the current costs of growing seaweed in North America. Another important consideration is the logistics for exporting the seaweed to appropriate depths (>1,000 m). For many of the areas in eastern Canada, this would mean transporting farmed seaweed hundreds of kilometres offshore and off the continental shelf that would have a considerable carbon footprint. The environmental effects of depositing large quantities of organic matter to deepsea environments is also largely unknown.

Farming (Livestock and Crop)

Another potential carbon mitigation involving seaweed is reducing the carbon footprint of farming (livestock and crops). Methane is a main contributor to greenhouse gas emissions in livestock farming via livestock digestion. Changes in livestock diets have been shown to alter methane production and recent studies have focused on seaweed as livestock food supplement for reducing methane emissions while supporting livestock health and production. Feeding small quantities of the tropical red seaweed *Asparagopsis* species to sheep, dairy cows, and steers have resulted in reductions in methane production of up to 67-98% (see "Further Reading"). Laboratory studies have also shown potential for reduced methane emissions in cattle with some North Atlantic brown (winged kelp, sugar kelp, knotted wrack) and red (Irish moss) seaweeds, though at lower reduction rates (see "Further Reading").

Small commercial operations and field trials are ongoing for producing and using seaweed as supplemental feed for livestock. North Atlantic Organics (Seacow Pond, P.E.I.) currently produces a dried seaweed meal for livestock made from wild harvested brown and red seaweeds. However, widespread implementation as a food supplement remains in the early stages with logistical and regulatory challenges. Seaweeds contain various compounds and metals that can be detrimental at high levels in livestock and humans (i.e., iodine, bromoform). Reduction of methane at national and global scales would also require large quantities of seaweed that are not currently harvested or produced. Methane reduction studies in livestock have mainly tested wild harvested seaweeds for efficacy and found their levels of active methane-reducing compounds somewhat inconsistent; farmed seaweed and their concentrations are more unknown (see "Further Reading"). Ultimately, costs for supplementing livestock feed with seaweed has to be financially sustainable especially if there is a financial burden with no parallel improvements to their products or efficiency. Yet, livestock products with "reduced carbon" or "carbon-neutral" labelling may have added marketplace value.

Seaweed farming could also contribute to reducing the carbon footprint of traditional crop farming via seaweed biochar. Biochars (made from organic materials like seaweeds under high heat and low oxygen conditions) are charcoal-like materials that can trap carbon for decades or more and also act as a soil amendment. As climate change mitigation, research suggests that seaweed may need to be combined with plant material (e.g., forestry and agriculture wastes) to effectively create high carbon biochars (see "Further Reading"). Due to the energy required to generate high temperatures for production, this method of sequestering carbon may be better suited to regions such as N.L. that have access to renewable energies.

General Ecosystem Services

Seaweeds are not only a potential carbon sink, but also a nutrient sink reducing the effects of eutrophication, including non-point and point source discharges to the marine environment such as those from municipal sewage, farm/ranch nutrient runoff, fish plants, aquaculture sites, and pulp and paper mills. Unlike terrestrial plants and seagrasses, seaweeds have no functional roots and instead take up nutrients (like nitrogen and phosphorus) directly from the water column. Those waste streams can have serious detrimental effects on the marine environment leading to anoxic dead zones, toxic algal blooms, and fish kills. Seaweeds could be used as a bio-mitigation standard to buffer wastewater eutrophication in coastal environments by creating a "seaweed biofilter" around point-source discharges. Those seaweeds could then be harvested and used as fertilizers or in the biochar process to cycle those excess nutrients back into the soil. For rural communities, this seaweed biofilter would be relatively cheap compared to traditional treatment systems and is a potentially effective solution for coastal water quality.

Again, there are logistical and regulatory challenges to consider with this approach. Nutrient uptake rates would vary with the seaweed growth cycle. Many regulations have not kept pace with current knowledge and technologies. For example, sewer and water regulations (at both Canadian federal and provincial levels) regulate the water concentrations at the "end of pipe," considered the last point of control before being released into the marine environment. But for these types of biofilters to work in an economically viable

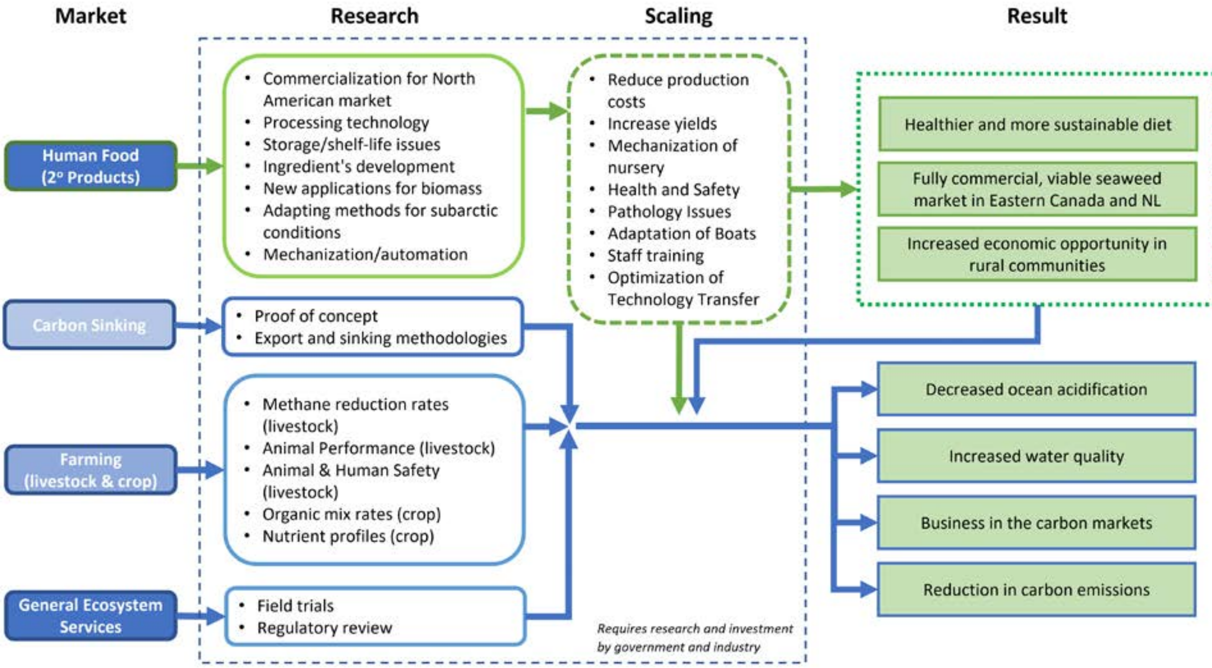

Figure 1: Pathway for development of current and future seaweed markets.

and efficient way, the water quality should be assessed on the ocean side of the seaweed biofilter. Other challenges include provincial regulations that limit aquaculture sites to a single farmed species. The use of integrated multi-trophic aquaculture (IMTA) where two or more organisms are farmed together has been suggested to mitigate and absorb the waste (in fish food and fish waste) generated from salmon farms. In N.L., with a growing salmon farming industry, this approach would not be possible under the current regulations.

Opportunities and Challenges

There are serious hurdles for N.L. and Eastern Canada that must be overcome both globally and regionally to partake in the blue carbon revolution. For any of these ideas to work, the province needs an existing, government- and private-supported seaweed farming industry. Many of these solutions relate to the economy of scale so would need to have a viable, thriving smaller scale seaweed farming industry with proven, robust technologies to be able to scale these operations as they would need large systems in place to tackle such enormous global issues like climate change or more local yet ubiquitous issues like seawater quality in Canada's coastal communities. For the blue carbon revolution to happen, we first need to ensure we have the necessary infrastructure and technologies in place to be able to grow and process seaweeds on a commercial scale (Figure 1).

Seaweed farming for human consumption, however, is an off-the-shelf existing market that is ready now and projected to grow; a key to moving the blue environmental revolution forward. Food is currently the main market driving seaweed farming in North America on a commercial scale. Seaweeds are low in fat and high in carbohydrates, protein, minerals, and vitamins. As seaweed farming reduces the effects of agricultural runoff and eutrophication, it is less carbon intensive than traditional land-based crops (mostly carbon neutral). Because of the environmental services associated with this kind of culture, seaweed farming is also more socially accepted by local coastal communities and environmental defence groups than other kind of marine aquaculture (a key piece for government and stakeholder support). Further development of the seaweed food market (as well as secondary products such as cosmetics, phyco-colloid

Figure 2: Typical phases of seaweed farming: Nursery Phase in 1-3: (1) Sourcing the reproductive tissue in the kelp. (2) Extracting the reproductive tissue (sorus). (3) Growing seaweed on spooled string in tank. Planting and Grow-out Phase in 4-6: (4) Transporting spool string to field. (5) Kelp growing on longline. (6) Young kelp on longline. Harvesting/Processing Phase in 7-9: (7) Pulling longline on board to harvest kelp. (8) Kelp harvest (9) Processing kelp in shredder. Photo credits: (2) (7) (8) Merinov | (1) (3) (5) (6) École des Peches et de L'Aquaculture du Quebec | (4) Kim, J.; Stekoll, M.; and Yarish, C. [2019]. Opportunities, challenges and future directions of open water seaweed aquaculture in the United States. Phycologia, 58(5), pp.446-461 | (9) Yarish, C.; Kim, J.K.; Lindell, S.; and Kite-Powell, H. [2017]. Developing an environmentally and economically sustainable sugar kelp aquaculture industry in southern New England: from seed to market.

extraction or other high value molecules extraction, biofuels, bioplastics) would enhance the financial feasibility of seaweed farming, thereby indirectly supporting some of these more nascent blue carbon technologies.

Growing Seaweed in North America and Canada

Seaweed farming produces 27 million metric tonnes annually and is the largest marine aquaculture market by weight (see "Further Reading"). Most of the global farmed seaweed production (>99%) is from Asia. Commercially scaled seaweed farming exists for the extractives (common gelling agents such as agar and carrageenan) as well as whole food products and other commercial applications (including livestock feed, supplements, polymers, chemicals, agrichemicals, cosmetics, nutraceuticals, functional foods, bio-oils, botanicals, and pigments). The typical process of seaweed farming consists of three steps: nursery phase (growing out in the lab in tanks), planting and grow-out phase (typically grown on lines similar to mussel aquaculture), and finally, harvesting/processing (Figure 2).

Seaweed farming in North America is an emerging industry although at a much smaller scale than in Asia. The largest and most mature seaweed farming operations in the U.S. are in Maine and Alaska with a focus on kelps (sugar, ribbon) and an emphasis on developing human food domestically for the North American market. Canada also has some long-term operators on the West Coast (Canadian Kelp Resources Ltd., B.C., established in 1982) and East Coast (Acadia

Seaplants Ltd. (N.B., N.S.), established in 1981). Acadia is one of the largest seaweed exporters in North America, although mostly focused on harvesting wild resources with some limited land-based seaweed aquaculture. Canada also has some new and emerging players such as Cascadia (B.C.; founded in 2019), planning one of the largest seaweed farming yields in North America. Its planned products include human food as well as experimental carbon sequestration.

Eastern Canada has a history of wild seaweed harvesting and was previously the world's largest producer of Irish Moss, primarily used for carrageenan extraction (see "Further Reading"). In Québec, Fermes marines du Québec is a private marine hatchery selling culture lines seeded with seaweed plantlets. These are cultivated on marine farms operated by Fermes Maricole Purmer, Ferme Maricole du Grand Large, or Maliseet Aboriginal Fisheries Management Association; the latter having one of the largest commercial seaweed farms (sugar kelp, winged kelp, and dulse) in Eastern Canada. Cultivated seaweed is ultimately processed into premium food products by Salaweg and Seabiosis. The development of this small industry is supported both by Merinov, a college technology transfer centre, and by Québec School of Fisheries and Aquaculture that have seaweed nurseries, an experimental grow-out field site, and a seaweed processing plant. Their focus is on domesticating new species, adapting and scaling the seaweed farming technologies for working in Atlantic and subarctic climates with ice, develop new products and processing methods, as well as training the seaweed farmers of the future.

In New Brunswick, Thierry Chopin, longtime researcher and advocate for seaweed farming, is leading the development of IMTA by incorporating blue mussel and kelp into existing Atlantic salmon aquaculture at Magellan Aquafarms Inc. (Bay of Fundy, N.B.). The Aquaculture Association of Nova Scotia is working with mussel farmers to further develop seaweed farming, which includes a three-year pilot program (ending in 2022) growing seaweed on existing mussel farms in Cape Breton, and with discussions to develop a seaweed nursery in Nova Scotia in cooperation with local research institutions. There is a long history of commercial wild harvesting Irish Moss for carrageenan extracts in P.E.I. North Atlantic Organics (Seacow Pond, P.E.I.) has a commercial operation for harvesting and processing seaweeds to supplement livestock feed.

Although not as extensive as the other east coast Canadian provinces, N.L. does have some limited seaweed harvesting and seaweed research but no existing seaweed farming operations. The provincial government had an initiative after the 1992 cod moratorium for the commercialization of N.L.'s kelp and seaweed with some projects developed including a nutritional supplement. Currently, there is a small-scale industry of companies using harvested kelp for skin care products, servicing restaurants, and selling raw/dried seaweed for human consumption.

Seaweed farming is on the rise in Canada but there are some challenges working in the difficult and harsh conditions of the North Atlantic in terms of space and time.

Space in terms of:

- Latitude – Sea-ice interacting with seaweed farms is a potential issue in the winter and early spring. Seaweed farmers from Québec have adapted their culturing gear to change the depth of the lines in autumn and spring, similar to mussel farms avoiding damage from sea-ice.
- Distance from Market – The most developed farms in North America (Alaska and Maine) have developed their products to be sold in the high-end restaurant industry and close to large urban areas and progressive markets (Maine sells to New York and Boston; Alaska targets the California market). A target for East Coast Canada could be Montreal and Toronto but

there are some logistical challenges similar to those faced by the more established shellfish and finfish aquaculture industries (although kelp has a longer shelf life).

Time in terms of:

- Hold Time – Short-term processing is another challenge. The harvest of cultivated seaweed from late May to June (three to four weeks), means that the processing facilities should be able to process large seaweed volumes in a short time, given that shelf life of fresh kelp is no more than two to three days.
- Development Time – Longer term, the lack of facilities capable of processing seaweed needs to be addressed in any development strategy for the kelp aquaculture sector. Traditional fish processing plants in coastal regions do not have equipment to process seaweed. Based on the recent developments in New England, it currently takes them approximately three years from initiating a pilot project to have an established commercial scale farm (see "Further Reading"). This means we need to be investing and developing now to compete with other growers in North America and tap into the blue carbon future.

Newfoundland and Labrador

The potential for seaweed farming and blue carbon in N.L. is considerable for the technologies discussed above (carbon sinking, farming, and general ecosystem services). For example, there are 6,000 dairy cows in N.L. emitting approximately 420 metric tonnes of methane annually. Supplementing their diet with a red seaweed (as discussed above) could equate to removing 10,000 metric tonnes of CO_2-equivalence from the atmosphere (annual equivalent of removing 2,000 gasoline-powered cars from the road). With a carbon tax of $50 per tonne of CO_2 in 2022 (projected to go to $170 per tonne by 2030) and industry and agencies working together to decrease production costs via increasing efficiencies and technologies, the financial and environmental rewards will continue to potential profitability.

N.L. also has many of the qualities that make it well suited for seaweed farming including over 17,542 km of coastline with most of it relatively untouched and sparsely developed as well as native populations of commercial seaweed species (including sugar, winged, and horsetail kelp). Like other areas in North America developing seaweed operations (i.e., Alaska and Maine), there are numerous small rural fishing communities with limited economic opportunity where supplemental farming in the offseason could prop up the local economies. In addition, community members already have skillsets and equipment (i.e., working on the water using moorings and fishing gear) that could easily be adapted to seaweed farming. N.L. also has existing infrastructure and resources including marine research centres focused on marine technology and aquaculture developments (Marine Institute, Ocean Science Centre) as well as fish plants that are only seasonally active that could potentially be used for processing and nursery activities.

Although the pieces are in place and the environment is conducive to develop seaweed farming in N.L., this will not happen on its own. A common theme of all the commercially viable operations in North America is investment by governments and industry in the local marine research to help with the methods of growing as well as commercialization of the products. N.L. invested in seaweed harvesting in the early 1990s (as well as currently heavily invested in fish farming) but a similar initiative needs to be launched now for seaweed farming so this province can take advantage of the current and expanding markets of seaweed for human consumption and the developing blue technologies. Now is the moment to invest in our coastal communities for the sake of their short-term economic viability as well as their long-term survival. Seaweed farming (as well as other carbon reduction initiatives) is required to mitigate the devastating effects that carbon emissions (i.e., the climate crisis) will continue to have on our coastal community's future with an increased frequency and severity of storms and coastal flooding. We could all benefit from supporting the regional development of a sustainable, carbon-friendly natural resource like seaweed that complements other carbon reducing initiatives and enhances the ecosystem services the ocean naturally provides.

Acknowledgement

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