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Leveraging marine biotechnology for an All-Atlantic sustainable blue economy

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Despite the lack of research, development, and innovation funds, especially in South Atlantic countries, the Atlantic is suited to supporting a sustainable marine bioeconomy. Novel low-carbon mariculture systems can provide food security, new drugs, and climate mitigation. We suggest how to develop this sustainable marine bioeconomy across the entire Atlantic.

Challenges for the All-Atlantic Ocean Research and Innovation Alliance (AAORIA)

The Atlantic is suited to a sustainable marine bioeconomy. The AAORIA Declaration was ratified by the signatories of the Galway and Belém Statements, along with Morocco and Argentina in 2022. Colombia, the Dominican Republic, Ghana, Norway, Portugal, and the UK also indicated their support for the declaration. The AAORIA was established to promote research, development, and innovation (RDI) [1]. The AAORIA is confronted with immense challenges in the face of climate change, food insecurity, and wars; however, much is desired in terms of RDI funding, particularly in countries from the South Atlantic. Securing RDI funding for developing countries is essential. However, it is unclear how AAORIA will obtain matching resources from developing countries[i].

The role of biotechnology in food security

The world population is currently ~7.88 billion people, of which, almost 900 000 suffer from hunger[ii]. The population is estimated to reach ~10 billion by 2050, which will require the production of larger amounts of food, putting significant pressure on traditional agriculture and aquaculture practices. While aquaculture is responsible for the annual production of 88 million metric tonnes (MT) of fish, most of the production is in inland (fresh) waters, with <40% of the production from marine systems (mariculture) [2]. Less than 20% of the world's protein supply originates from the ocean [2]. Harvesting wild populations of marine organisms cannot sustainably provide sufficient additional food, with over one-third of stocks estimated to be overfished, including those that are the base of fish feed for aquaculture (fish oil and fish meal for artificial foods). Fishing by international commercial fleets is unsustainable in the Atlantic [3].

Mariculture could provide a sustainable alternative while reducing the need for freshwater [4]. Only a small portion of the ocean is used for mariculture production, and less than 5% of Economic Exclusive Zones (EEZs) are required to supply the protein for a given country. Many Atlantic countries have not fully used their EEZ potential for mariculture. Finfish mariculture could produce nearly 50 million MT of meat per year in 2050 [4], but further expansion may be limited by food availability for reared finfish. Expanding sustainable mariculture will require innovation in the field of biotechnology (e.g., innovative feeds, breeding for fast growth, pathogen resistance, temperature tolerance, and novel rearing systems), building on past successes (Box 1). Marine spatial planning for farm locations and selection of appropriate species are essential to sustainably produce sufficient biomass in a cost-effective manner to serve a new or established market.

Low-carbon and integrated multitrophic mariculture

Traditional mariculture for human consumption tends to focus on raising finfish that consume fish-based food [2]. An estimated 3 MT of anchovies are required to produce 1 MT of Atlantic salmon. In addition to the low energy efficiency, overfeeding of fish in open-net pens contributes to hypoxic water and sediment underlying farms, decreasing biodiversity. Approaches to addressing these issues include moving to novel low-carbon mariculture systems [integrated multitrophic systems (IMTA), biofloc technology (BFT), and recirculating systems].

Low-carbon mariculture can include shifting from finfish to low trophic animals (e.g., mussels, scallops, oysters, and clams). Low-carbon mariculture may also be achieved by using plant-based food sources for finfish. While soybeans have been used as a source for fish foods, the production of soybeans globally is thought to be responsible for large areas of deforestation, including in the Amazon [5]. Alternative plant products for fish feed include seaweeds and algae. Seaweed mariculture production (~36 million MT) is a growing industry (~6% per year), while research into the large-scale production of algal species has been increasing [6]. Algae-based feed may improve overall health and disease resistance.

Although most research and current production focuses on a small number of algae species (e.g., *Kaphaphyccus alvarezii* and *Gracilaria* spp.), diversifying the algal species of interest provides opportunities to improve and expand production [7]. Understanding genetics and physiology of diverse algae may provide solutions to digestibility, heavy metal accumulation, and production of antinutrients. At the same time, development of non-feed products (e.g., biofertilizers, biostimulants, and pigments) and innovations in processing biomass may increase revenues and profits. IMTA focuses on the simultaneous

Box 1. Lessons from around the world

The Blue bioeconomy is blooming around the world with thousands of ongoing projects[iii]. The European Marine Biological Resource Centre provides an array of services[iv], while IMTA projects offer great promise for the Mediterranean Sea[v]. Macroalgae (*Saccharina latissima*, *Ulva intestinalis*, and *Fucus vesiculosus*) farming is proposed for eutrophication mitigation in the Baltic Sea. In Canada, a company and a government laboratory have teamed up to develop a resilient seed stock, encourage modernization of regulations, and build local demand for products[vi]. Japan and China are the major marine food producers and have developed an advanced value chain for marine-derived (seaweeds) products[vii]. Some of these mariculture advances in Japan stem from the organization of local farmer unions from the 1950s onward. South Korea is also advanced in the field of blue bioeconomy [12]. The South Korea–Indonesia Marine Technology Cooperation Centre and the China–Malaysia Marine Cooperation, which focus on training and technology sharing, are cases of success[viii,ix]. Seaweed rearing is providing income to local communities in Indonesia. African countries (e.g., Kenya and South Africa) are leveraging the blue economy through algae and mollusc (scallop) mariculture, focusing on low-carbon aquaculture[x,xi]. The unique diversity of polar regions is also being explored as a source for new food items and to support a new blue economy sector[xii].

production of primary producers (algae), filter feeders (e.g., bivalves), secondary consumers (e.g., shrimps and fish), detritivores (e.g., tunicates, sea urchins, sea cucumbers, and polychaetes), and finfish [8]. IMTA reduces impacts associated with finfish mariculture, including hypoxia or anoxia caused by excess artificial food. Alternative species may be resources for novel biotechnological products.

Preparing for the effects of climate change

Increasing temperatures, decreasing oxygen, eutrophication, sediment loading, and other types of pollution are all affecting coastal areas where mariculture activity occur [6]. While expansion of mariculture into open ocean regions with less pollution and human impacts may be an option, logistical challenges (e.g., distance, depths, and wave/wind exposure) may limit the sustainability of open-ocean mariculture. Instead, preparing for the challenges of climate change in coastal regions is necessary to build a sustainable, secure mariculture economy. Mariculture systems for alternative species and genetic modification of brood stocks adapted to higher temperatures are needed [7]. Coastal pollution, especially eutrophication, may be addressed by developing low-carbon or multitrophic approaches, where excess nutrients can be removed through algae or seaweed production and particulate matter can be reduced through filter feeders [8]. Processed algae could become sustainable biofertilizers in agriculture or a food additive in poultry, which contributes to animal health (e.g., omega-3).

Prevention and treatment of diseases in mariculture

Traditional mariculture of single species at high stocking densities provides for rapid spread of pathogens, parasites, and disease. Typical management of infectious disease includes biosecurity, the use of vaccines (mainly for fish), antibiotics, and other chemicals. Bacterial pathogens, including vibrios, are often members of the coastal bacterial community [9]. An alternative to broad application of antibiotics and chemicals is the use of BFT [8]. Bioflocs consists of microbes (prokaryotes and eukaryotes) associated with particles (particulate organic matter), similar to naturally occurring marine snow [8]. BFT helps to reduce excess inorganic nitrogen around farms, improving water quality while having beneficial impacts on the health and production of the animals. BFT has been shown to promote broodstock quality, enable higher stocking densities without increasing diseases, and reduce the cost of production by decreasing food costs. Environmental changes may be expected to alter the identity and prevalence of pathogens. Microbiome databases of ocean conditions will enable researchers to identify species with the potential to emerge as new pathogens [10].

Priorities toward an All-Atlantic sustainable bioeconomy

Embracing RDI initiatives should focus on codesigning, codeveloping, and cosharing a range of different biotechnology and aquaculture approaches that address different environments and economic needs across the Atlantic [11]. The new AAORIA will have a central role in this endeavour, but there remain several challenges in developing a blue bioeconomy (Box 2). A major priority should be raising RDI funding across the South Atlantic. Innovations and investments in the codevelopment of high-value food products can increase revenues to offset higher costs that may be associated with new approaches and techniques. Some of these high-value products may not be food but could provide materials to industry or the medical field. To achieve an All-Atlantic sustainable bioeconomy, we propose the following three major actions:

Action 1. All-Atlantic RDI initiatives focused on biotechnology can support the codevelopment of a sustainable blue bioeconomy but will require sustained financial support. Support needs to be coordinated across countries to reduce duplication of effort and to enhance knowledge sharing to move the field forward quickly. Governments, with advice and guidance from science and industry, need to establish strong, supportive regulatory environments that will encourage investment by industry but protect and support local communities and environmental health.

Action 2. Codesign joint initiatives to support capacity-building, research, and innovation projects in relation to marine-based food production. Current collaborations between different stakeholders need to be leveraged to cotest novel approaches for food production. Funding schemes that support local innovations and leverage local and indigenous knowledge can apply historical practices to current challenges.

Box 2. Challenges in developing a blue bioeconomy

Developing countries, including those in Latin American, Southeast Asia, and the Gulf of Guinea, lack RDI funding, credits for business, guidelines for farming and processing, monitoring systems, and value chains for marine-derived products [13,14]. Poor environmental health, poor institutional frameworks, and climate change are major problems in developing countries. Even within developed countries, historical regulations, a changing climate, and limited product markets can hinder the development of new blue bioeconomic opportunities, as has been observed by kelp farmers in Nova Scotia (Canada[xiii]). New regulations that address the use of genetically modified organisms in mariculture and the benefit sharing of increased revenues from high-value food products are necessary [15].

Blue economy governance requires balancing the needs of different activities that compete for access to marine systems and the communities that they support. Traditional fisheries, mining, oil, and gas activities may limit local communities from accessing marine areas and pose serious problems for the health of these areas. While pollution and climate change impose challenges for ocean health and food production, the role of the oceans in regulating the climate makes the blue economy a delicate path to pursue. A regulation body to evaluate and decide how much and in what way oceans can be exploited for human well-being is necessary. Governance needs to consider risks of ocean exploitation for food and biotechnology, not only the ecological risks but also the societal risks for other activities that may lose their income.

Action 3. Codevelop innovations in mariculture (e.g., low carbon and IMTA) to study the applicability across the Atlantic. Fund research to develop novel approaches to waste and disease management that increases mariculture sustainability. Support the development of novel sectors through investments in high-value food products or other bioproducts (e.g., biofertilizers, industry, and medicine). Strong collaboration between industry, academia, government, and local communities can highlight the links between food production and social and environmental health and the need to support a sustainable bioeconomy.

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Declaration of interests

None are declared by the authors.

Resources

[i]https://allatlanticocean.org/news/conclusions-from-the-2023-all-atlantic-ocean-research-and-innovation-alliance-forum/

[ii]http://wfp.org

[iii]https://bluebioeconomy.eu/

[iv]https://www.embrc.eu/

[v]www.ocean4biotech.eu/

[vi]https://ecologyaction.ca/our-work/marine/seaweed-farming-training-centre

[vii]http://xsjt.chinaaquatic.cn/product

[viii]www.mtcrc.center

[ix]https://en.xmicc.org.cn/detail/205.html

[x]www.sei.org/events/high-level-side-event-on-blue-economy

[xi]www.fao.org/3/cc3102en/cc3102en.pdf

[xii]www.qdkangjing.cn/en/

[xiii]www.cbc.ca/news/canada/nova-scotia/kelp-industry-nova-scotia-atlantic-voice-1.7023666

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