Blue Biotechnology: Its role in the future of food

Blå Bioteknik; Dess roll för framtida mat

Andrea Lundh

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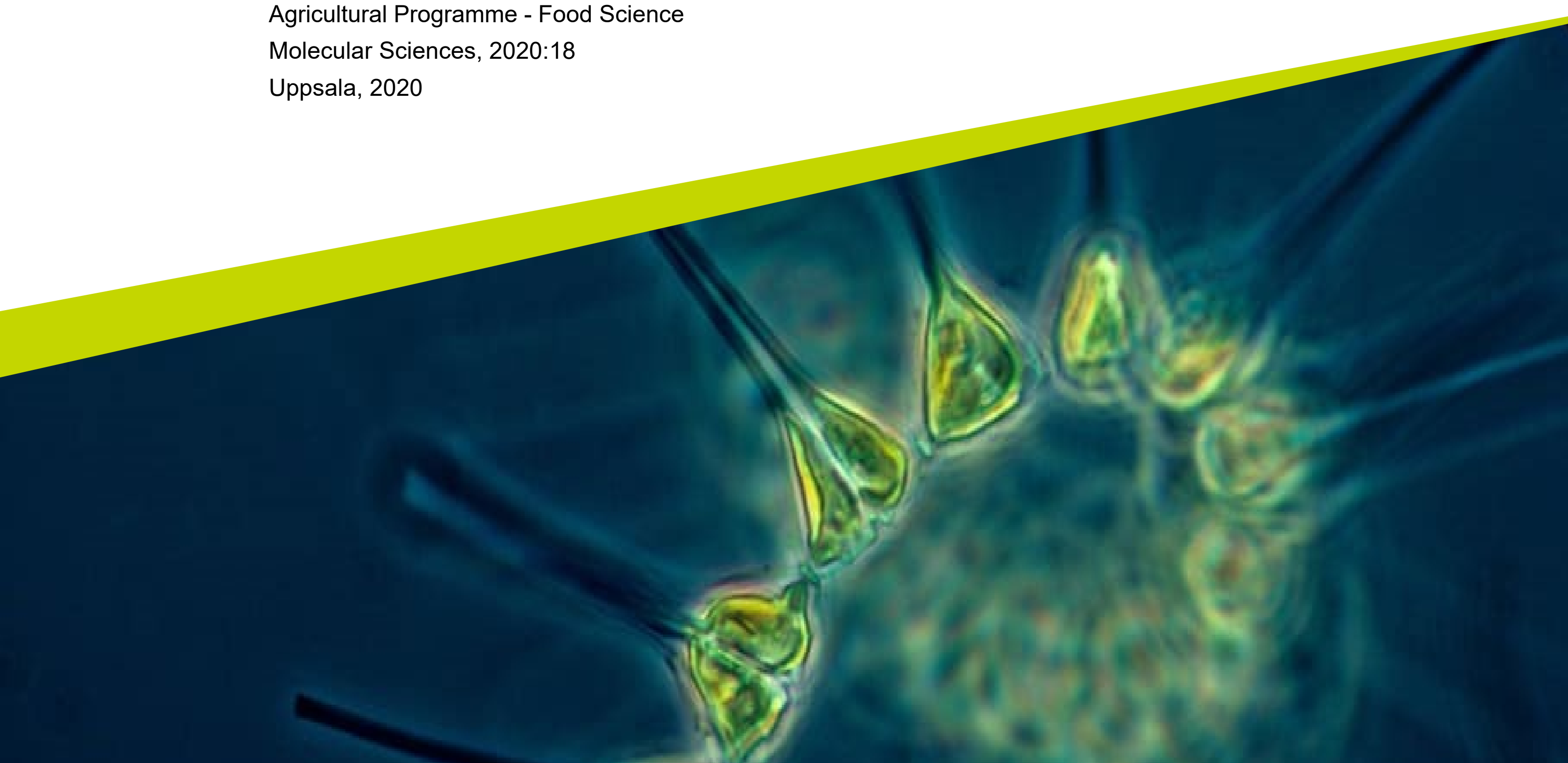

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Abstract

To provide healthy food and livelihoods to a growing population on Earth, while environmental issues becoming more adverse, as well as climate change becoming more critical, is one of today's greatest challenges. By 2015 the United Nations come up with 17 Sustainable Development Goals (SDG's) to tackle global challenges as poverty, global hunger, climate resilience, population growth control, achieving food security, and promotion of sustainable agriculture. All depending on the future food system. Agriculture alone will not be able to meet the goals. Fisheries and aquaculture will also be important and especially under-explored aquatic sources used in blue biotechnology. In this report trends in aquaculture, and the role of blue biotechnology as a contribution to safe and secure future food, as well as its possible to reduce world hunger and poverty are discussed. The major challenges aquaculture is facing for expansion are; biosecurity and disease challenges; environmental challenges, competition with (terrestrial animal) agriculture for water and land resources, and feed ingredients and nutraceuticals. Blue biotechnology applications as innovative systems reduce the use of land and freshwater and secure the ecosystem and biodiversity as well as the welfare of the fishes. The developed technological tools and increased knowledge minimize the use of antibiotics and the outbreaks of diseases by adapted vaccines. These findings and applications developed through blue biotechnology practices based on aquatic resources will increase resilience and the sustainable development of the extended aquaculture, but if existing technologies mention in this report will be enough is uncertain. If the aquaculture will succeed to minimize environmental impact and securing safe, secure, and nutritional food for the growing population needs further knowledge of how these technologies work in practice.

Keywords: Aquaculture, blue biotechnology, aquatic resources, SDG, sustainable development goals, blue growth, zero hunger, food security, agenda 2030

Sammanfattning

Att förse en växande befolkning med hälsosam mat och säkra en trygg försörjning, samtidigt som dagens miljöpåverkan blir allt mer negativ och klimatförändringarna blir allt mer kritiska, är en av världens största utmaningar. År 2015 antog FN en ny agenda innehållande 17 globala mål för att hantera globala utmaningar som fattigdom, klimatförändringar, skapandet av fredliga och trygga samhällen samt främjandet av hållbart jordbruk. Alla beroende av framtidens livsmedelssystem. Jordbruket kommer inte ensamt vara tillräckligt för att uppfylla målen, utan fiske och akvakultur krävs som komplement. Särskilt utökandet av akvakultur samt användning av underutforskade vattenresurser måste bidra. I denna rapport diskuteras trender inom vattenbruk, samt den blå bioteknologins roll för produktion av säkra livsmedel, liksom möjligheten att bidra till minskad hunger och fattigdomen i världen. De största utmaningarna som akvakultur står inför, i och med en expansion, är; utmaningar för biosäkerhet och sjukdomar; miljömässiga utmaningar, konkurrens med (betande djur) jordbruk för vatten- och landresurser, samt foderingredienser och näringsämnen i produktionen. Blå biotekniska applikationer, som innovativa system, minskar användningen av mark och vatten samt bidrar till balans i ekosystemet. Dessutom bidrar innovationer med hjälp av teknologin till att den biologiska mångfalden bevaras och fiskarnas välfärd förbättras. De utvecklade tekniska applikationerna och ökad kunskap minimerar användningen av antibiotika och sjukdomsutbrott genom vaccinering. Dessa framgångar tack vare den blå bioteknikens applikation i vattenbruk bidrar till hållbar utveckling av vattenbruk. Men, om teknik och innovationer som nämns i denna rapport är tillräckliga för en 100 % hållbar produktion är osäkert. Om akvakultur kommer att lyckas minimera miljöpåverkan av livsmedelsproduktion och säkra näringsmässig mat för en växande befolkning kräver ytterligare forskning och förståelse om hur dessa tekniker och system fungerar i praktiken.

Nyckelord: Akvakultur, vattenbruk, blå bioteknologi, marina organismer, globala målen, ingen hunger, tryggad livsmedelsförsörjning, hållbar utveckling, agenda 2030

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Abbreviations

AI	Artificial intelligence
EFARO	European fisheries and research organization
FAO	Food and Agricultural Organization
IMTA	Irrigated Multitrophic Aquaculture
LIFDC	Low-income food-deficient countries
RAS	Recirculating systems
SDG	Sustainable developments goals
SPF	Specific pathogen-free
SPT	Specific pathogen tolerant
SPR	Specific pathogen resistant
UN	United Nations

1. Introduction

1.1. Background

One of the greatest challenges faced by human mankind currently is to provide healthy food and livelihoods to the growing population projected to rise to over 9 billion by 2050, while addressing the adverse impacts of climate change and environmental degradation on the resource base. At the United Nations Sustainable Development Summit in the year 2015, all the member states of the United Nations, UN, adopted the 2030 agenda for Sustainable Development, setting out 17 Sustainable Development Goals (SDG's) to tackle these global challenges. These goals span the whole range of policy areas, from poverty alleviation to ending global hunger, climate resilience, population growth control, achieving food security, and promotion of sustainable agriculture (Rosa, 2017). Food and (animal) agriculture are vital to achieving many of these SDGs. However, there is strong evidence that (animal) agriculture alone will not be able to meet the goals. It has been suggested that much of this may come from under-explored aquatic sources. (Sorgeloos 2013) Owing to these, many of the United Nation´s SDGs are directly relevant to fisheries and aquaculture, in particular, SDG 14 (Conserve and sustainably use the oceans, seas and marine resources for sustainable development). The UN´s FAO highlights the critical importance of fisheries and aquaculture for the food, nutrition, and employment of millions of people, many of whom struggle to maintain reasonable livelihoods. At present, the global fish production reached an all-time high of 171 million tonnes, of which 88 % was utilized for direct human consumption. The contribution of aquaculture to the total production of aquatic animals from fisheries and aquaculture combined is nearly 50%. With capture fishery production relatively static since the late 1980s, aquaculture has been responsible for the continuing impressive growth, especially in the developing countries located in Asia and Africa, in the supply of fish for human consumption. (FAO, 2018). This production resulted in a record-high per capita consumption of 20.3 kg in 2016. Since 1961 the annual global growth in fish consumption has been twice as high as population growth and has also exceeded that of meat from all farmed terrestrial animals combined (FAO, 2018). This suggests that the aquaculture sector is crucial in meeting the UN's goal of a world without hunger and malnutrition. The sector's contribution to economic growth and the fight against poverty is growing and is expected to grow further in the future. It is, however, noteworthy to mention that the significant growth of the aquaculture sector is not without major issues. Aquaculture, in common with all other food production practices, is facing many major challenges for sustainable development/expansion: biosecurity and disease challenges; environmental challenges, competition with (terrestrial animal) agriculture for water, and land resources, and also for feed ingredients and nutraceuticals, amongst others. These and other challenges engendered the United Nations "Blue Growth Initiative" - an innovative, integrated and multisectoral approach to the management of aquatic resources aimed at maximizing the ecosystem goods and services obtained from the use of oceans, inland waters and wetlands, while also providing social and economic benefits. Therefore, it is highly imperative to develop and implement cutting-edge modern technologies, which are accessible, appropriate and adapted to the needs of aquaculture stakeholders mainly aquafarmers, for improving productivity while conserving natural resources.

Objectives: In this project, the current trends and future perspectives on how blue biotechnology can contribute to the sustainable production of safe and secure food for the growing population and can act as a valuable tool to reduce poverty will be reviewed and critically discussed.

1.2. Research questions

The research questions aimed to be answered were:

What role does blue biotechnology have in future food?

What role does aquaculture play in global food security?

2. Method

2.1. Literature research

Information and data for this report were obtained using scientific databases to find relevant literature; in particular Web of Science, ASFA (Aquatic Science and Fishery Abstract), FSTA (Food Science Technology Abstract), and Google Scholar were used.

Search words: “Blue biotechnology”, “Marine biotechnology”, “Food Security”, “Aquatic food security”, “Aquaculture”, “Aquatic foods”, “Food system”, “Blue growth”

Further, material and statistics have to a large extend been collected from the United Nations and their agency Food and Agricultural Organization as well as from the EAT-Lancet Report.arch words: “Blue biotechnology”, “Marine biotechnology”, “Food Security”, “Aquatic food security”, “Aquaculture”, “Aquatic foods”, “Food system”, “Blue growth”

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3. Literature review

3.1. Blue Biotechnology - The concept

The aquatic ecosystem with its oceans, inland waters, and wetlands harbour a variety of under- and unexplored resources, which could benefit human by contributing to the three pillars of sustainable development (social, economic and environmental) and the alleviation of poverty, hunger, and malnutrition (Burgess *et al.,* 2018). The oceans make up over 99 % of the biosphere (since organisms are found throughout the water column), and they are exposed to the greatest extremes of temperature, light, and pressure. Adaptation to these harsh environments has led to rich marine biodiversity and genetic diversity with potential biotechnological applications related to drug discovery, environmental remediation, increasing seafood supply and safety, and developing new resources and industrial processes.

The term biotechnology is widely used and has different meanings for different individuals; however, a useful and all-encompassing definition by the Organisation for Economic Co-operation and Development (OECD) is: 'The application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods, and services' (van Beuzekom & Arundel, 2006). Blue biotechnology or blue biotech is a dynamically developing branch of science. In more specific terms, blue biotechnology is the application of biotechnological tools on aquatic resources i.e., both plants and animals to develop commercially viable food and food products, human and farmed animal medicine, cosmetics, and nutraceuticals (food products with benefits for human and farmed animal health). Blue biotechnology has great potential to help address global challenges in population health, food security, and industrial and environmental sustainability as well as protecting and preserving the resources for future generations. The exploitation of marine micro – and macro-organisms is a promising tool to find solutions to these challenges through the provision of products for the pharmaceutical industry, the medical field, human diet, animal feed, the cosmetics and wellness sectors, and bioremediation (Schultz-Zehden & Matczak, 2012).

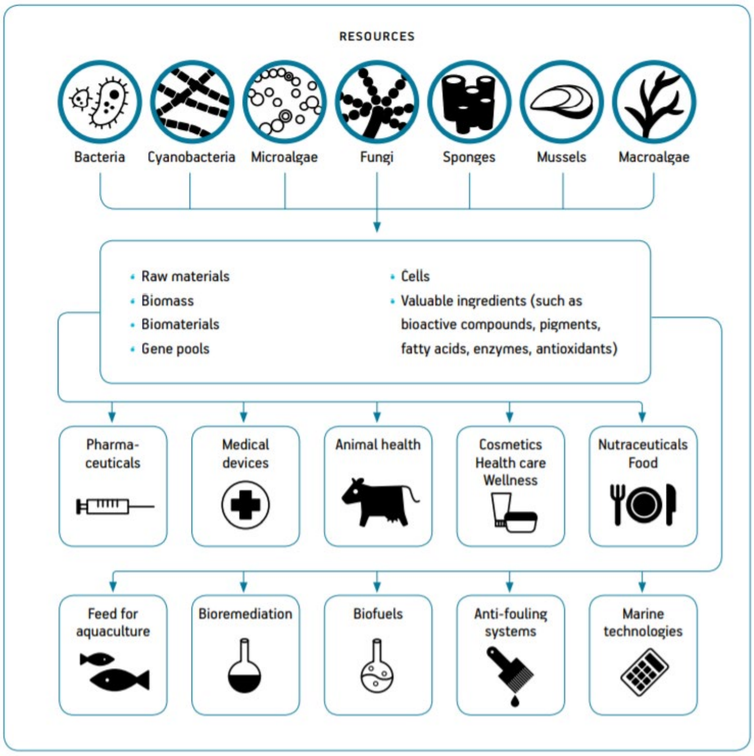


Figure 1: *Micro- and macroorganisms examples possible for applications in Blue biotechnology due to the beneficial properties applicable to science, human health, environment, and development of the economy. Source: (Schultz-Zehden & Matczak 2012)*

The marine aquatic environment presents a better opportunity for encountering successful candidates (in terms of plants, animals or microbes) than the terrestrial environment because of their biodiversity, our limited knowledge of them compared with our knowledge of terrestrial organisms and the range of extreme ecological environments in which they are found (Kijjoa & Sawangwong, 2004). It stands to reason that given the considerable species diversity of these waters, the potential for finding compounds of interest for application development is also significant. For example, it has been shown that some bacteria associated with macroorganisms from the Baltic Sea such as the alga *Saccharina latissima*, the sponge *Halichondria panicea,* and several bryozoan species exhibit a great potential for the production of antimicrobial compounds (Wiese *et al.,* 2009). Freshwater ecosystems can also provide extremely important ecosystem services. However, in this project, the (potential) benefits of these ecosystems to human mankind are not discussed as they fall beyond the scope of this project.

Marine ecosystem services, in particular, provide more than 60 percent of the economic value of the global biosphere(Martínez *et al.,* 2007) Recognizing this value, the global community has been putting more and more effort into the development of the economic capacity to exploit aquatic ecosystems, and the services they provide, in a sustainable manner. The use of an ecosystem for economic returns
and social benefits must, however, take place in a way that minimizes environmental degradation. If an ecosystem and its services are not maintained, or in some cases restored, the natural capital is eroded, and the system will not succeed; it will thus not contribute to improved food security and livelihoods or to achieving many SDG goals and targets. Restoring habitat and preserving biodiversity can help to improve aquatic ecosystem services and provide numerous benefits in terms of food, revenue, and jobs. For example, in Viet Nam, mangrove replanting by volunteers at the cost of USD 1.1 million saved USD 7.3 million annual expenditure on dike maintenance and benefited the livelihoods of an estimated 7 500 families in terms of labor and protection (IFRC, 2002).

3.2. Biosecurity, health, and diseases

Because of the intensification of cultural practices, the environmental conditions in the culture system can become sub-optimal for the farmed fishes, causing stress to the cultured animals. This eventually causes disease outbreaks. The hindrances of reducing disease outbreaks, and increase the animal welfare in aquaculture include limitations in diagnostic techniques and the availability of eco-friendly health management strategies; the existence of arcane bacteria or benevolent pathogens becoming pathogenic in new hosts and in new environments; the occurrence of subclinical infections and diseases caused by many different factors; the low degree of domestication; and the dearth information of animal welfare in aquaculture (FAO, 2018).

To prevent possible outbreaks of disease, antibiotic has been used in aquaculture production and the veterinary treatments e.g. vaccines and disinfections have been applied for reducing diseases affecting the quality of the fish, growth and poor survival. In aquaculture, the use of antibiotics has led to issues as antimicrobial resistance mainly caused by a too long time elapse from the start of the infection to applications of corrective management. Therefore a paradigm shift is needed (FAO, 2018).

Animal welfare management remains in the interaction of host, pathogen, and environment interactions but there are new ways forward with blue biotechnology. Besides improving management and innovative productions, e.g. biofloc, new diagnostic technologies, and vaccines are facilities for future reduction of diseases (Troell *et al.,* 2019). The new technologies may be established by applications of findings from metagenomics which is the study of genetic material recovered directly from environmental samples, and the approach of patho-biome which is the drive of disease causation by the interaction of pathogens with other microorganisms (Stentiford *et al.,* 2017). The use of vaccines is important for the reduction and elimination of antibiotics. Further innovation research programs include more officious vaccines, and vaccination of farmed aquatic animals has been practiced for decades, but only in the salmon industry so far. At the same time the use of vaccines- in Asia is not often successful, neither the use of vaccines on other species due to unavailability nor lack of good response. For example, it is impossible to vaccinate shrimps due to the non-adaptive immune system (FAO, 2018; Troell *et al.,* 2019). The vaccines must be supplemented with other technological solutions for decreased increased health in aquaculture production.

Development of diagnostic tools and the use of specific pathogen-free (SPF), specific pathogen tolerant (SPT) and specific pathogen resistant (SPR) stocks could also reduce risks of disease as well as secure biodiversity (FAO, 2018). Artificial intelligence (AI) is an example, though still on the experimental level; by using sensor chambers, fishes are treated individually for certain diseases instead of the treatment of a whole cage (Troell *et al.,* 2019). These technology applications are important actions for biosecurity in the long term as well as sustainable development in aquaculture.

Concrete actions for the antimicrobial resistance and selection in aquatic food are indicated in the One Health Platform (European Commission, 2017). The study of antimicrobial usage and antimicrobial genes are executed practises for improving the understanding of these problems. Also, FAO has developed an action plan, the FAO action plan on Antimicrobial Resistance, built on four pillars; awareness, evidence, governance, and best practices. As well as advanced science, the politics regarding socio-economic assessment and cost-benefits analysis of biosecurity, play a key role in securing resilience in the aquatic food system.

3.3. Climate-smart aquaculture

The challenge to produce sustainable, in all aspects, aquatic food to meet consumer's demand persists. The environmental footprint food production leaves behind depends on the system used. There are several different systems used in aquaculture production, which all use land, water, and energy differently. Depending on the system, the species of the fish, the feed for the fish, and the location of the production, the negative impacts will differ. To secure and develop a sustainable production of food, blue biotechnology applications in aquaculture will be needed.

By changing the traditional systems, nutrient and chemical pollution as well as land use and water consumption can decrease. The first, is the chemical and nutrient pollution caused by aquaculture and the reduction of this, by converting and treating waste. By closing the nutrient loop and recapture lost nutrients by farming macro algae or other microbes in the same system the production will transform organic waste into valuable products such as; new protein, fat, and vitamins at the same time as the energy is reused in the system (Kiessling *et al.* 2017). At the same time, food of the highest quality and securing food supply is produced, environmental services are developed. The technology solutions offered include complete aquatic system integrated multitrophic aquaculture (IMTA) but also aquaponics which consists of both aquatic and terrestrial components (Kiessling *et al.* 2017).

IMTA (see figure 2) is a system reducing nutrient concentrations by the co-culturing of organisms of different trophic levels. Plants and filtering organisms convert feed-waste from aquaculture and use the organic matter left for growth which results in a higher growth if comparing without. On the bottom of the system species using inorganic matters live and use the nitrate, phosphorus, and carbon dioxide as the species above leave behind, and release oxygen (Klinger & Naylor 2012). The system is in this way self-sustainable. If not consumed, phosphorus, nitrate, and carbon dioxide cause ecological damages such as algal blooms and eutrophication. If the production is placed in the sea, shellfish can remove up to 54 % of total particulate and the inorganic matter can be removed up to 60 % of the seaweed. If produced on land seaweed requires a greater amount of surface but can remove more ammonia than biofilters. The seaweed can later be used as human food. The diversification of the system results in multiplied incomes due to the cultivation of several species in the same system (Klinger & Naylor 2012). The technology pushes the economics forward of the industry and spreads the risks of the income and at the same time independent of external resources. The systems can further also be connected to oceanic energy platforms as wind and underwater turbines (Klinger & Naylor 2012). This secure livelihood and economic, social, and environmental sustainability.

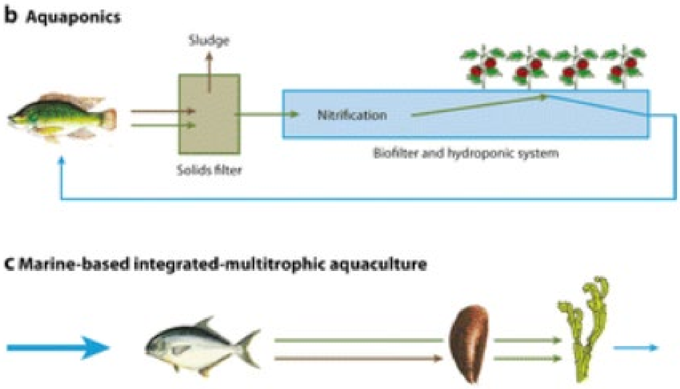


Figure 2: *Two different culture systems of aquaculture. Source: (Klinger & Naylor 2012)*

As seen in figure 2 aquaponic is another system re-using wastewater rich in inorganic nutrients for the growth of plants. An aquaponic system is an aquaculture system combined with a hydroponic system, and these are using both water and nutrients efficiently. In a traditional aquaculture system, the nutrients are disposed but in an aquaponic system, the waste is recycled by plants. The nutrients from the aquatic system are used for fertilization of plants and the water reduced-nutrient wastewater is transported back to the fish tank and used over again. The water-use is reported to be 320 litres/kilograms of fish and 98 % of the water in the system is recycled. At the same time, 7 kg of vegetables can be produced per 1 kg of fish in an aquaponic system (Klinger & Naylor 2012).

A third smart aquaculture system is the bio-floc system. In this system, the ammonia, oxygen, and biomass residues are re-used as in aquaponic systems but by the replacement to chemotrophic production instead of phototrophic production. The bacteria communities in the system building microbial biomass by the ammonia and phosphate excretions of the cultured organisms together with added carbon. The biomass can further be used as a fish-feed. Both bio-floc systems and aquaponics can be located within cities, on marginal or on peri-urban lands. All these locations result in end-products closer to consumers as well as the use of land previously underutilized. This results in reduced air miles together with the higher quality of the products (Klinger & Naylor 2012; Kiessling *et al.* 2017).

3.4. Competition with (terrestrial animal) agriculture for water and arable land resource

Besides the effect of pollution and imbalance in ecosystems caused by aquaculture, land- and water-use affects sustainability in the production. For the intensification of aquaculture production, the availability of space plays one role. The spatial planning of aquaculture is essential to manage the sustainable development regarding the use of land, water, and other resources and at the same time compete in the economic sector as well as minimize conflicts (FAO 2018).

When it comes to the use of land, aquaculture uses terrestrial areas for farming. There are no sources on the amount but 60 % of the aquaculture are land-based ponds, coastal ponds correspond to 10% and the rest are produced in open water systems (Troell *et al.* 2019). Conventional aquaculture systems are land-use demanding. The systems require land when the production is performed ashore, as well as do the production of feed for aquaculture practices use land. The increase of aquaculture has led to transformations of landscape and by 2010 an estimation of 18.8 MHA of land was occupied for aquatic food production. Interestingly the use of land for plant-based feed for the industry corresponded in the same year for 26.4 MHA. (Waite *et al.* 2014) Coastal agricultural land and wetland valuable for ecologically aspects mainly in South China, Bangladesh, Vietnam, Indonesia, and India are converted from natural areas into production zones (Troell *et al.* 2019). But the total use of land from aquaculture does only corresponds to 1 % of agricultural production land use. Compared with other food products aquaculture are ahead when it comes to efficient land-use and for future food analysis, the agricultural yield has to been taken into account, the output of food production per area. Grazing ruminants as cows, sheep, and goats use three-quarters of all agricultural land. Notable is that some of these areas are not utilisable for other production systems. To be able to compare these the energy efficiency has to been taken into account. For almost all countries the total land use from feed production would reduce if producing more seafood than meat comparable due to protein content. If switching future demand of meat to seafood 747-729 MHA of earth could be spared (Froehlich *et al.* 2018).

Aquaculture also consumes a large amount of freshwater. Both for the production of agricultural feed resources and production in pond-based systems. The excessive use of water occurs in the on-land systems and by 2010 aquaculture contributed to 2 % of agricultural consumption of water, which corresponds to 201 cubic kilometres (Waite *et al.* 2014). The use of water is due to evaporation and leakage to keep the water-level constant as well as aerate and filter the water. These systems consume water but others that only use it temporarily. The temporary use of water is not better for sustainable production due to risks that the production influences the content of the water. During production the salinity, toxicity, and the level of nutrients can be changed and when released affecting surrounding the ecosystem. By the addition of new chemical components e.g., antibiotics or a high level of nutrients the natural systems will be affected and contaminated, this can lead to consequences for other species and the balance of the ecosystem (Troell *et al.* 2019).

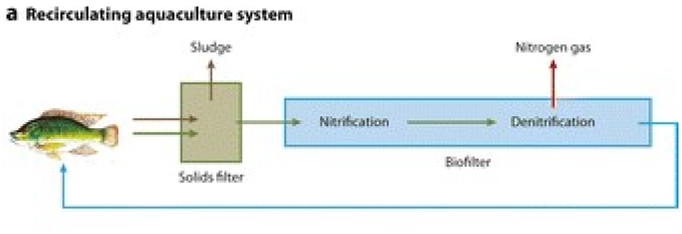


Figure 3: *The principle of recirculating aquaculture system. Source: (Klinger & Naylor 2012)*

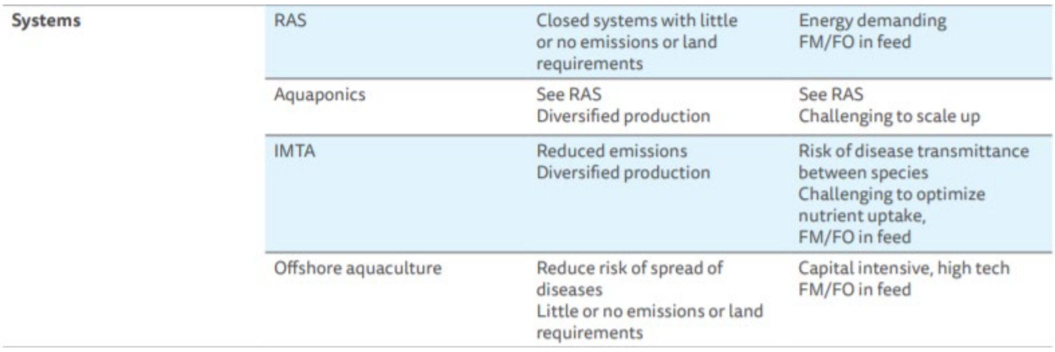
Efficient systems, as the two mentioned above but also recirculation aquaculture systems (RAS), figure 3,can help increase the seafood produced per area land. A low stock pond culture with few inputs produces 2,000 kg of fish per hectare per year compared with an intensified production where water is exchanged, aerated and mixed, which can produce 20.000-100.000 kg per hectare per year (Klinger & Naylor 2012). This indicates the value of the development and use of efficient systems.

At the same time, there are several developed systems using water differently and much more effectively. Recirculating systems, RAS, is a system where the water is re-used after the removal of waste products of the production, e.g. bacteria or fish-feed. In conventional aquaculture production, the use of water is 3000-45000 litres/kilograms of seafood, and in constrain, in a RAS system, freshwater use can be approximately 50 litres/kilograms seafood and for artificial saltwater approximately 16 litres/kilograms. There are also aquaponic systems that are combined with a hydroponic system and these are using both water and nutrients efficiently. In a traditional aquaculture system, the nutrients are disposed but in an aquaponic system, the waste is recycled by plants. The nutrients from the aquatic system are used for fertilization of plants and the water reduced-nutrient wastewater is transported back to the fish tank and used over again. The water-use is reported to be 320 litres/kilograms of fish and 98 % of the water in the system is recycled. At the same time, 7 kg of vegetables can be produced per 1 kg of fish in an aquaponic system (Klinger & Naylor 2012).

Further, there are also other species as bivalves, other filtering organisms, and seaweeds that are independent of freshwater. These marine species will be important for the use of blue biotechnology as future food when considering the environmental impact on water use (Troell *et al.* 2019).

Due to European fisheries and research organization (EFARO) the combination of RAS and exposed offshore productions will develop new business models allowing faster fattening in the juvenile stages of the fish. At the same time, the on-growing period is shorted in the sea. By this combination, the economy of RAS is maximized and the production in the sea will potentially be doubled (Kiessling *et al.* 2017). This shows, in table 1, the value of blue growth to the ecosystems approach by using energy more efficiently, adapting to climate change and it is an innovation that can improve social, economic and ecosystem outcomes.

Table 1: *Desciption of the potential (middle column) and the constrains (the right column) for different innovative systems in aquaculture. RAS stands for recirculationg system and IMTA for integrated multi-thropic aquaculture. FM is the abbreviation of fish meal and FO for fish oil.*



Systems	RAS	Closed systems with little or no emissions or land requirements	Energy demanding FM/FO in feed
	Aquaponics	See RAS Diversified production	See RAS Challenging to scale up
	IMTA	Reduced emissions Diversified production	Risk of disease transmittance between species Challenging to optimize nutrient uptake, FM/FO in feed
	Offshore aquaculture	Reduce risk of spread of diseases Little or no emissions or land requirements	Capital intensive, high tech FM/FO in feed

Source: (Troell *et al.* 2019)

The spatial planning of aquaculture has to meet the sustainable development goals by integrating social, economic, environmental, and governance objectives. To follow FAO’s Code of Conduct for responsible fisheries and realize the value of the blue growth, aquaculture has the potential to achieve this (FAO 2018).

3.5. Feed resources

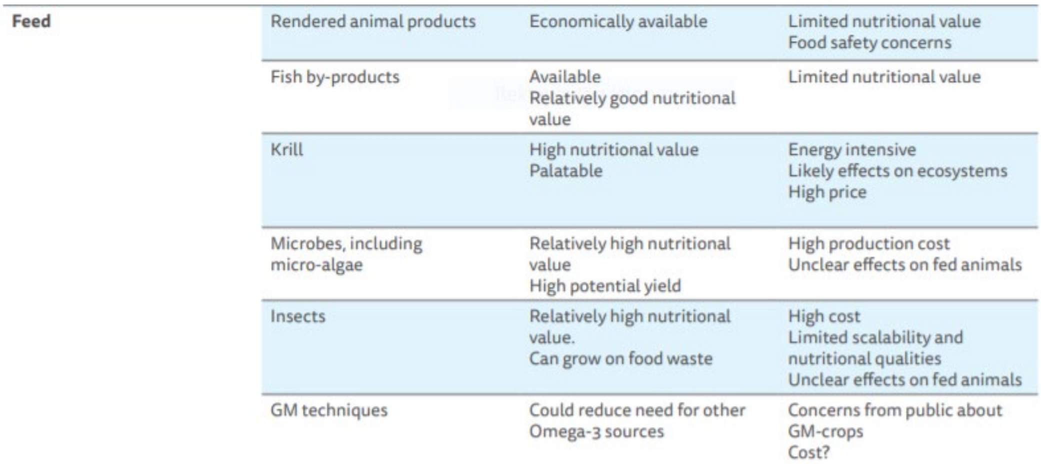
In the production steps, along the supply chain, the most improvements can be found, e.g. the feed manufacturing. The fish feed is a recurrent problem and contributes to secondary problems affecting planetary boundaries. Both use of freshwater, GHG-emissions, and the use of land. The fish feed also spurs unsustainable wild fisheries by the use of fish resources in aquafeeds for carnivorous fish. The increasing demand for aquafeeds and the use of natural resources resulting in unsustainability due to the not resilient wild fishery.

Traditionally, fishmeal has been widely used, but it is a limited resource (around 5 million tonnes per annum). The fish meal is produced of highly nutritious wild capture fishes and was the greatest source of fish feed, but over the years due to the limitation, the source has been spread between industries and decreased as fish feed. Though, by 2010 aquafeed did use up to 73 % of all fish meal produced, which has to be reduced (Simon 2016). Between 1995 and 2015 the need for fish feed has increased due to the extension of the production of fish species depending on a feed from 12 to 51 million tonnes. Mainly due to intensification in production systems when farmed shrimps, tilapias, carps, and salmonids (Hasan, 2017). Due to the limited amount of fish meal and fish oil because of concurrence from other sectors, as well as declining access of marine feed ingredients due to reduced capture fisheries, the production of the feed ingredients has to occur for further food security anchoring from the industry. Replacement of fish meal and fish oil are crucial for the future. Another important aspect is the nutritional characteristics of human consumption; the ingredients should not compete with direct consumption by humans. Food conversion ratios have fallen from 3:1 to 1.3:1 (feed:biomass) by the last 25 years mainly because of better feed formulations, feed manufacturing methods, and on-farm feed management, but even more has to come to meet the expansion of aquaculture to secure food supply (Hasan, 2017).

The innovations regarding feed include new feed ingredients as by-products in the form of seafood waste, cuttings, and trimmings, from aquaculture and capture fisheries. Also, blood meal and bone meal from terrestrial waste processes are used as fish feed, tough not allowed in the EU (Simon, 2016). The challenges are to meet the nutritional qualities compared with fish meal and fish oil regarding amino acid composition, fatty acids, and minerals. One valuable and protentional ingredient is krill with an appealing nutrient composition. Though for an increase in scalability negative effects on ecosystems will come as a result, and the support of unsustainable wild capture fisheries will be a fact. Instead of finding natural resources with related planetary boundaries, there are other potential key features as future feeds. The techniques affecting genetics and metabolics for production of microbes containing omega-3 fatty acids, and other single-cell organisms (SCO) are interesting but produced only on pilot level (Troell *et al.,* 2019). The SCOs have high potential because of rapid growth and high potential yields but the production is expensive. Another consideration is the unknown impact on the physiology of farmed animals (Troell *et al.,* 2019). The culture of marine micro-organisms for the production of fatty acids rich in omega-3 is one possible solution but is not currently economically beneficial. The genetic engineering of higher plants to produce the health-benefiting LC omega 3 oils are sensitive due to ethic and moral and could be criticized from a range of consumer and NGO groups if not tested rigorously (Simon, 2016).

Another potential feed is insects. Due to lower production yields and less diverse nutritional values insects are less promising compared with SCOs. There is still a need for further research and knowledge before the implementation of insects as feed.

Table 2: *Potentials and constraints of 6 different innovations for feed transformations of aquafeeds.*



Feed	Rendered animal products	Economically available	Limited nutritional value Food safety concerns
	Fish by-products	Available Relatively good nutritional value	Limited nutritional value
	Krill	High nutritional value Palatable	Energy intensive Likely effects on ecosystems High price
	Microbes, including micro-algae	Relatively high nutritional value High potential yield	High production cost Unclear effects on fed animals
	Insects	Relatively high nutritional value. Can grow on food waste	High cost Limited scalability and nutritional qualities Unclear effects on fed animals
	GM techniques	Could reduce need for other Omega-3 sources	Concerns from public about GM-crops Cost?

Source: (Troell *et al.* 2019)

An example of a successful replacement of fishmeal in aquafeeds is the bioactive developed NovacqTM developed by CSIRO. The result of feeding with NovacqTM has been showing similar or better results comparing with a classical fishmeal-based diet. This finding is opening up the beliefs for further potential feed without marine ingredients (Simon, 2016).

To sum up; all potential innovations listed in table 1 need further research and more knowledge of each is required for future use. It is unlikely that one of these alone will fill the demand, and be able to provide the growing sector. Most likely a combination of terrestrial, marine, and innovation feeds are needed.

4. Discussion

To meet the increased demand for food for the growing population, the whole agriculture session is not enough. At the same time oceans are overexploited and no longer a reliable source for food. A paradigm shift in the food system is needed. As the UN states; aquaculture is crucial to secure a world without hunger and malnutrition (Rosa, 2017). Aquaculture is already a broad industry but to meet the increasing demands it has to expand. As reported the expansion will occur through intensifying the production and the systems, alongside the development of new technology (Sorgeloos, 2013; FAO, 2018; Troell *et al.,* 2019). To decrease the overuse of resources and to minimize the negative effects on the environment caused by wild capture fisheries or by aquaculture production blue biotechnology has to be utilized in the future. An example is the adaption of fish feed to control the outcome and quality of the fishes and at the same time, the resources used are minimal. The technology helps to count the exact amount of macro- and micronutrients needed for the optimal outcome of the production. Furthermore, the bacteria and the immune system can be controlled without the use of antibiotics. Instead, marine seaweeds consisting of interesting molecules can be used, or techniques affecting genetics and metabolic processes, to prevent the problems with diseases and bad growth (FAO, 2018). The example of feed affecting several aspects important for sustainable development and topics included in the SDGs. (Rosa 2017). The availability of land, energy, and freshwater, all effecting climate resilience as well as ecosystems. The production of secure and safe food for future food security, and to the end of global hunger.

If existing technologies mentioned in this report will ensure the adaption to a sustainable reformation through the expansion aquaculture is facing, is uncertain. If the aquaculture will succeed to minimize environmental impact and securing safe, secure, and nutritional food for the growing population needs further knowledge of how these technologies work in practice. Important is the transformation of the industry in low-income areas where the fish brings a crucial nutritional value as well as social and economic benefits for the development of livelihoods. Asia is, as mention, accounting for the major part of aquaculture production and to make new techniques, feeds, and other innovations available and affordable in this geographical location, as well as for small-scale , are central. The trends mentioned in this report regarding; Competition with (terrestrial animal) agriculture for water and arable land resources, biosecurity, health and disease, climate-smart aquaculture, or smart aquaculture, and feed resources, are all bringing technological solutions potential to contribute to the sustainable increment of aquaculture. Worth to mention is though that most of them are in a very early stage and the actual results, remains to be seen.

Alongside the promising potentials, risks follow. As well as research and science have to be applied, regulations and governance have to be implemented. To control and locate new operations, minimize the use of chemical hazards and antibiotics, reduce nutrient runoff, and apply sustainable feed from diverse productions, management, and programs are needed. The blue growth initative, FAO's Antimicrobial Resistance, One Health Platform, only to mention some discussed in this paper.

Further transparency and certifications are potential factors spurring sustainability in the food supply chain. Deepen knowledge of risks, as well as potential, is a crucial tool to transform the aquatic food production to a completely sustainable system. Risks regarding environmental impacts and health issues, and potential regarding the development of potential systems and techniques (Troell *et al.,* 2019).

The aquaculture will expand and there is potential to do it sustainably. The nutritional value the fish brings emphasizes the need for fish as a resource for global population growth and in meeting the SDGs (Tacon & Metian, 2013). The need for fish brings awareness of the environmental problems the production is facing. These problems should be met and conquered by blue biotechnology through; developed techniques for aquatic systems, developed to feed and actions to preserve biodiversity, all explained and exemplified in this report. Together with multi-sector as well as multi-level action guided in a scientific target, possibilities for a more resilient aquatic food supply are possible.

5. Conclusion

To summarize no action or technique alone will change the food system and bring resilience to the future food supply. Probably a strategy including several, more or less effective interventions will constitute for the strategy of future aquaculture, but blue technology will play a key role for the future aquatic food production. The aquatic food production will play an important role in the future food system due to nutritional values, economic values, and social practices, thus contributing to the 2030 Agenda. However, aquaculture raises several question marks regarding the sustainable use of resources and still poses challenges to achieve complete resilience in the system.

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