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COMMITTEE ON FISHERIES

SUB-COMMITTEE ON AQUACULTURE

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RECOGNIZING AND ENHANCING THE CONTRIBUTION OF ALGAE TO GLOBAL AQUACULTURE DEVELOPMENT

EXECUTIVE SUMMARY

Algae, including seaweeds (or marine macro-algae) and microalgae, contribute nearly 30 percent of world aquaculture production (in wet weight), primarily from seaweeds. Seaweeds and microalgae generate socioeconomic benefits to tens of thousands of households, primarily in coastal communities, including numerous women empowered by seaweed cultivation and processing. Various human health contributions, environmental benefits and ecosystem services of seaweeds and microalgae have drawn increasing attention to the untapped potential of seaweed and microalgae cultivation. Highly imbalanced production and consumption across geographic regions imply great potential in the development of seaweed and microalgae cultivation. Joint efforts of governments, the industry, the scientific community, international organizations, civil societies, and other stakeholders are needed to realize the potential.

This working document examines the status and trends of global algae production with a focus on algae cultivation, recognizes the algae sector’s existing and potential contributions and benefits, highlights a variety of constraints and challenges upon the realization of the potential, and discusses lessons learned and way forward to unlock the full potential in algae cultivation and FAO’s role in the process.

Suggested action by the Sub-Committee
The Sub-Committee is invited to: ➢ Recognize the current importance and future potential of seaweed and microalgae cultivation; ➢ Share experiences and lessons learned in the development of this aquaculture sub-sector; and ➢ Recommend actions and activities, including specific guidance to FAO, to unlock the potential in the cultivation of seaweeds and microalgae.

INTRODUCTION

1. The scope of this document is algae, which in this document include seaweeds (macro-algae) and microalgae. Other aquatic plants, including freshwater aquatic macrophytes are not discussed.

2. Algae, particularly seaweeds, are an important component of global aquaculture currently produced by a relatively small number of maritime countries. In 2020, farmed algae, measured in wet weight, contributed nearly 30 percent of the 123 million tonnes of world aquaculture production, and red and brown seaweeds were, respectively, the second- and third-largest species groups in global aquaculture. Being mostly low-value commodities, however, seaweeds accounted for 5.9 percent of the USD 281 billion of world aquaculture production value in 2020.

3. Seaweeds are not well known in all parts of the world, as their production is mostly concentrated in Eastern and Southeastern Asia. While in Eastern Asia and Pacific Islands countries and territories, seaweeds have long been widely and frequently consumed human foods, in other parts of the world seaweeds are largely niche or novel foods. Seaweeds have multiple other uses in food and non-food industries, such as food additives, animal feeds, pharmaceuticals, nutraceuticals, cosmetics, textiles, biofertilizer/biostimulants, biopackaging, and biofuel, among others. However, knowledge of their contribution to these products is generally confined to seaweed-related industries and the scientific community.

4. There is a growing interest in seaweeds with a particular focus on their potential as a source of nutritious food to feed the growing human population and for the ecosystem services they provide. The existence of vast marine areas suitable for seaweed farming may further encourage the expansion of this important aquaculture subsector as wild resources will not be able to supply seaweeds to satisfy the growing international demand.

5. Commercial cultivation of microalgae as end products from aquaculture, including *Spirulina* spp. which are Cyanobacteria, is poorly monitored by national statistics in general. Worldwide production recorded in FAO statistics contributed less than 0.2 percent of global algae cultivation tonnage in 2020. Microalgae cultivated as food for larval rearing in hatchery operations and for conditioning of culture environment in grow-out facilities are usually not recorded in official statistics. Similar to seaweeds, microalgae also have great potential in various food and non-food uses; many of which nevertheless entail significant joint efforts to become fully commercialized.

STATUS AND TRENDS OF GLOBAL ALGAE PRODUCTION[1]

6. Current world seaweed production is primarily supported by aquaculture. In 1970, the 2.2 million tonnes of world seaweed production came almost equally from wild collection and cultivation. A half century later, while wild collection remained at around 1.1 million tonnes in 2020, the wild collection was dwarfed by the farmed production of 35.1 million tonnes, accounting for 97 percent of world total seaweed production in 2020.

7. The development of seaweed farming is greatly imbalanced between regions and among countries in the same region. In 2020, seaweed production in Asia (98.9 percent from cultivation) contributed 97.4 percent of world production, and six of the top ten seaweed producing countries were from Eastern and Southeastern Asia. The Americas and Europe contributed, respectively, 1.4 percent and 0.8 percent of world seaweed production in 2020. Seaweed production in these two regions was primarily fulfilled by wild collection, and cultivation only accounted for 5 percent and 7.7 percent of total seaweed production, respectively. In contrast, cultivation was the main source of seaweed production in Africa (77.4 percent) and Oceania (79.2 percent), although their contribution to world seaweed production was only 0.3 percent and 0.03 percent, respectively.

8. World cultivation of brown seaweeds, with relatively more diverse species mostly from temperate and cold zones in the northern hemisphere, reached 16.8 million tonnes in 2020 accounting for 48 percent of world seaweed cultivation in terms of tonnage and 47.7 percent in terms of value. Brown seaweed cultivation has concentrated on two cold-water genera: *Laminaria*/*Saccharina* (kelp) and *Undaria* (wakame). Red seaweeds production in the same year was 18.1 million tonnes accounting for 51.7 percent of world seaweed cultivation in terms of tonnage and 51.3 percent in terms of value. Red seaweed cultivation is concentrated on two warm-water genera, including *Kappaphycus/Eucheuma* and *Gracilaria* and one cold-water genus, *Porphyra* (nori). Cultivation of green seaweeds is small and around 23 000 tonnes were farmed in 2020 (0.07 percent of all seaweeds).

9. Substantial microalgae cultivation recorded in FAO statistics started in 2003 with 16 483 tonnes of spirulina (Cyanobacteria, also known as blue-green algae) cultivated in China. Global microalgae cultivation in 2020 was approximately 64 000 tonnes, mainly spirulina, cultivated in 12 countries, and green freshwater microalgae (primarily less than 300 tonnes of *Haematococcus pluvialis*), cultivated in two countries.[2]

SOCIAL, ECONOMIC AND ENVIRONMENTAL CONTRIBUTION OF ALGAE

Contribution to food, nutrition and human health

10. Most seaweed species are edible and human consumption of seaweeds dates back centuries. Coastal communities in many countries have cultural traditions of eating seaweeds. *Laminaria*/*Saccharina*, *Porphyra* and *Undaria* have become common foods in Eastern Asia and are widely and frequently consumed as soup ingredients, salads, sushi wraps and snacks, among others.

[1] Data from FAO. 2022. Fishery and Aquaculture Statistics. Global production by production source 1950–2020 (FishStatJ). FAO Circular No. 1229 provides more details on global seaweed and microalgae aquaculture status and developmental potential (www.fao.org/3/cb5670en/cb5670en.pdf). For further reference see also FAO. 2022. The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. Rome, FAO. https://doi.org/10.4060/cc0461en

[2] It should be noted that as microalgae cultivation tends to be regulated and monitored at the national or local level, separately from aquaculture, FAO statistics may miss substantial microalgae production in some countries, including Australia, Czechia, Iceland, India, Israel, Italy, Japan, Malaysia, Myanmar and the United States of America. See FAO. 2020. The State of World Fisheries and Aquaculture 2020. Sustainability in action. Rome. https://doi.org/10.4060/ca9229en

They have been introduced in other countries as part of Asian cuisine and have gained increasing global popularity.

11. Generally rich in dietary fibres, micronutrients and bioactive compounds, seaweeds are often treated as healthy, low-calorie food, particularly favoured by people who prefer low-carbohydrate or plant-based diets. Some seaweed species are known for their high protein content. Furthermore, multiple health benefits of seaweed consumption (e.g. improving gut health and reducing the risks of non-communicable diseases such as obesity and Type II diabetes) have been demonstrated.

12. Seaweeds have in general a relatively low level of fat but can still be a good source of essential fatty acids like the long-chain polyunsaturated omega-3 fatty acids. The level of omega-3s varies depending on species, season and which part of the seaweed is eaten. Less than 100 grams of fresh *Calliblepharis jubata*, or *Undaria pinnatifida* is needed to meet the recommended daily intake of omega-3, whereas 500 grams of *Grateloupia turuturu* would be needed. Seaweeds are at the same time low in omega-6, which results in a favourable omega-6/omega-3 ratio.

13. In addition to direct human consumption, seaweeds are also processed into food additives or food supplements. Japanese kelp (*Saccharina japonica*) was one of the earliest raw materials for producing monosodium glutamate. Agar extracted from agarophytes (e.g. *Gracilaria*), carrageenan extracted from carrageenophytes (*Kappaphycus*/*Eucheuma*), and alginate extracted from brown seaweeds (*Saccharina*) are seaweed-based hydrocolloids widely used as food additives to enhance the quality of a variety of foods, usually as thickening, stabilizing, gelling, and emulsifying agents. Additionally, seaweed extracts, such as iodine, fucoidan, fucoxanthin and phlorotannins are used as food supplements.

14. The nutritional value and health benefits of microalgae have been recognized (e.g. spirulina) and various microalgae extracts are used as dietary supplements or food additives.

Contribution to income, livelihood and social cohesion

15. In 2020, the 35.1 million tonnes of world seaweed cultivation production for various food and non-food uses generated USD 16.5 billion first-sale value. According to UN Comtrade statistics, 98 countries earned USD 2.48 billion of foreign exchange in 2020 through exporting seaweeds (USD 837 million) and seaweed-based hydrocolloids (USD 1.65 billion).

16. Seaweed cultivation operations are usually labour intensive and employ many part-time or occasional workers. Thus, a large portion of the USD 16.5 billion of first-sale value became wages or incomes that supported the livelihoods of numerous households in coastal communities. Activities further downstream tend to generate more income and employment. A relatively low level of mechanization and automation with the currently available technologies for mass scale production is one of the recognized limiting factors for the development of seaweed farming in high-income developed countries where labour cost is high.

17. Seaweed cultivation makes a significant contribution to community cohesion and women's empowerment. The characteristics of seaweed cultivation such as labour intensiveness, low capital investments and simple farming technology, allow for the participation of many resource-poor households or vulnerable individuals. It is particularly so for tropical red seaweed species in warm climate countries.

Environmental benefits and ecosystem services

18. Seaweeds and microalgae provide important environmental benefits and ecosystem services. Seaweed cultivation does not need to use directly terrestrial land, freshwater or feed. Microalgae can be grown in freshwater or marine environments and cultivated in marginal land in desert and arid areas. By extracting nutrients (nitrogen and phosphorus) from surrounding waters and absorbing carbon dioxide,

the photosynthetic process of seaweeds and microalgae can mitigate eutrophication, treat wastewater, reduce ocean acidification and capture carbon.

19. Seaweed and microalgae cultivation can contribute to global developmental needs addressing both climate change (e.g. capturing or sequestering carbon; reducing methane emissions from farmed cattle feeding on algae supplements) and human food security issues (e.g. production of edible algae-based products).

20. Other direct or indirect environmental benefits and ecosystem services of seaweeds and/or microalgae include: (i) providing habitats for fish and other marine organisms; (ii) serving as a buffer against strong wave action to protect the shoreline; (iii) providing alternative livelihoods to fishing communities; (iv) acting as natural plant growth stimulator and enabling the plants to withstand drought, disease or frost; and offering a non-chemical means of disease control as seaweeds have shown similar suppressive effects like some pesticides (e.g. fungicides, nematicides);[3] and (v) producing readily biodegradable goods and packaging; among others.

Contribution to aquaculture

21. Besides the direct contribution to aquaculture production, seaweeds and microalgae also help facilitate other aquaculture activities. The ability of seaweeds to assimilate carbon dioxide and extract inorganic nutrients (nitrogen and phosphorus) from surrounding waters makes integration of seaweed cultivation with the farming of animal species an appealing production system, capable of increasing environmental and economic benefits through better nutrient recycling and more efficient use of farming areas.

22. Integrated multi-trophic aquaculture (IMTA) systems have the potential to generate not only environmental benefits but also economic profits. Different IMTA systems have been adopted, such as (i) growing *Gracilaria* in shrimp or finfish ponds; (ii) farming kelp and bivalves (e.g. mussels, oysters or scallops) together in open oceans, sometimes adding deposit feeders such as sea cucumbers.

23. Seaweeds are used as the main feed materials for aquaculture production of abalone, sea urchins and sea cucumbers. Seaweeds are also used as supplemental fish feed ingredients that provide necessary amino acids, and beneficial polysaccharides, fatty acids, antioxidants, vitamins and minerals.

24. Microalgae with high content of lipids can be used to produce algae oils as a substitute of fish oils. Microalgae are the main source of the beneficial long-chain omega-3 oils for all aquatic animals. Astaxanthin extracted from *Haematococcus pluvialis*, a green microalgae species, is used as a pigmentation enhancer in the salmon farming industry. Many hatcheries rely on microalgae cultivation to provide live feed organisms, directly or indirectly (e.g. through cultivating zooplankton), as a first feed and for nursing the larvae of fish, molluscs, crustaceans or other aquatic animals. Microalgae produced as such are intermediate aquaculture products that are usually not recorded in official statistics.

25. Indeed, an important part of pond culture management is to monitor and promote desirable density and pattern of microorganisms, including microalgae, to maintain good water quality and provide natural food for target species through fertilization, water exchange and aeration. As pond culture is the main aquaculture grow-out system in freshwater or brackish-water environments for many major aquaculture species (e.g. carp, tilapia, catfish and shrimp), the hidden microalgae production, while not recorded in official statistics, tends to be enormous.

[3] Sultana, V., Baloch, G.N., Ara, J., Ehteshamul-Haque, S., Tariq, R.M. Athar, M. 2010. Seaweeds as alternative to chemical pesticides for the management of root diseases of sunflower and tomato. Journal of Applied Botany and Food Quality 84, 162–168.

ISSUES, CONSTRAINTS AND CHALLENGES

26. Reported experiences in Eastern and Southeastern Asia indicate that seaweed and microalgae cultivation can become robust industries that generate benefits and contribute to economic development. However, further development of seaweeds and microalgae in global aquaculture faces multiple issues, constraints and challenges.

Limited or uncertain demand for seaweeds

27. Expansion of seaweed production would need to be accompanied by increases in seaweed demand. One way is to increase seaweed consumption as human foods, which tends to utilize seaweeds efficiently and generate more income for seaweed farmers. Although most seaweed production in Eastern Asia is consumed directly as human foods, people outside this region generally have low or little exposure to or preference for seaweed consumption. The versatility and variety of many seaweeds suggest that they can be utilized in a broad range of food products, adding healthy, low calorie, nutrient dense opportunities for food manufacturers and distributors. However, demand for these applications remains low in spite of seaweed's nutritional value and health benefits and various ongoing efforts in promoting its consumption, particularly in Europe and Northern America.

28. Many non-food applications of seaweeds (e.g. pharmaceutical, nutraceutical, cosmetic, animal feed, biofertilizer/biostimulant, biopackaging, textile fibre, carbon capture or sequestration, biofuel, among others) are promising, yet they face technical, economic and/or market constraints and challenges. It is unclear which of the application(s) will become the main driving force(s) behind the next major breakthrough in seaweed development, comparable to the success of *Laminaria*/*Saccharina* or *Kappaphycus/Eucheuma*.

Limited or reduced availability of suitable farm sites nearshore

29. Most seaweeds are grown close to the surface of the water in order to have sufficient sunlight for photosynthesis; therefore, they are usually cultivated in nearshore areas for operational and logistic conveniences. Nearshore operations tend to be less expensive in terms of both investment and operating costs. However, multiple factors pose constraints or challenges to seaweed cultivation in nearshore areas, including, among others: (i) competition for nearshore areas from urban development, recreation, fishing, fish farming and/or other activities; (ii) pollution in nearshore waters; and (iii) rising seawater temperatures.

30. Cultivating seaweeds further from the coast in deeper waters can help overcome the nearshore constraints. In addition, seaweed cultivation could be integrated with other offshore activities, for example wind energy generation. However, seaweed cultivation in the open ocean faces the challenges of technical feasibility, economic viability, and the general lack of regulations on offshore aquaculture.

Shortage of labour

31. Seaweed cultivation usually entails a large amount of labour in planting, daily maintenance, harvesting and post-harvest handling, with a seasonal or occasional demand. The lack of suitable labour (low cost, flexible and stable supply) has been a major constraint over seaweed cultivation in developed regions. Labour shortages also pose challenges to seaweed cultivating countries in developing regions on their paths towards a more developed and urbanized economy, as economic developments create more attractive employment opportunities in other sectors (e.g. tourism) than laborious and strenuous jobs in seaweed farming, particularly for the younger generation. More automated farming systems and technologies would help address labour shortages and improve occupational health but would tend to increase production costs.

Constraints over integrated farming systems

32. Notwithstanding its conceptual appeal and successful applications, technical, economic and institutional constraints complicate the integration of seaweed cultivation with other aquaculture activities. Technically, IMTA is a complex aquaculture system whose performance is dependent upon the balance of a wide range of interactions among cultivated species and the overall expertise of farmers handling more than one species and having the capacity to adopt appropriate farming protocols for all integrated species and maintaining a well-functioning ecosystem.

33. In an IMTA system, infrastructure and operations needed for cultivating one species may impede that of another integrated species. For example, seaweed longlines may interfere with the access of large vessels to finfish cages; finfish cages may attract herbivorous fishes grazing on seaweeds.

34. Economically, IMTA systems, particularly large-scale operations, encounter the challenge of marketing multiple products along different value chains. While a diversified species composition in an IMTA system may help reduce the impacts of price fluctuations of individual species, the aforementioned complexities of the system would tend to increase the operational costs, and low-valued seaweeds may not offer enough financial incentive for finfish farmers to alter their business models.

35. Institutionally, finfish farmers tend to lack incentives to integrate seaweeds into their farming systems if regulations do not force them to internalize the cumulative impacts of their farming operations on the ecosystem at larger scale (fjords, channels or whole bays) and do not allow them to benefit from the positive impacts of seaweeds on water quality (e.g. increasing the number of fish allowed to be reared). Integration may also be hindered by a lack of regulations that facilitate collaboration between site owners who produce different species.

Low or declined seedling quality

36. Seedling production is key to successful and sustainable seaweed farming. The quality of seedlings has become increasingly crucial under deteriorating farming environments, such as rising seawater temperatures and more frequent and severe disease outbreaks.

37. Improper management of or constraints on seedling production, including the use of inbred stocks or repeated vegetative propagation, can lead to trait degeneration and the consequent loss of agronomic value of a farmed type due to possible reduced growth, lowered quality and higher susceptibility to diseases, among others. Low or declined quality of seedlings could also motivate the introduction of non-native seaweed species or genotypes, which pose risks to biodiversity and biosecurity.

38. Genetic improvement technologies, such as strain selection, selective breeding, hybridization, and micropropagation, can help improve seedling quality and production efficiency. However, these tend to be technically and financially demanding and often require public support. While seaweed breeding programmes and progress have played a vital role in the development of seaweed cultivation in Eastern Asia, a lack of genetic improvement persists in tropical red seaweeds (e.g. *Kappaphycus*/*Eucheuma*) that are primarily multiplied by vegetative propagation. While distinct morphotypes of *Kappaphycus*/*Eucheuma* are recognized, the genetic basis of these morphotypes is inadequately researched and poorly understood.

Miscellaneous issues or constraints over seaweed cultivation and value chains

39. Other significant issues hindering seaweed cultivation and value chains include: (i) deteriorating farming environments because of climate change, such as rising seawater temperatures, increasing extreme weather conditions, non-observation of biosecurity measures (e.g. measurements of nutrients (nitrogen content) and water motion/flow rates), and more voracious grazing of predators; (ii) more

frequent and severe disease outbreaks; (iii) high transportation costs; (iv) high intermediary costs; (v) low and fluctuating market prices, including uncertain export prices due to exchange rate fluctuations; (vi) low income for seaweed farmers; (vii) suboptimal practices (e.g. premature harvesting, year round cultivation and non-observance of pausing periods similar to fallow seasons for terrestrial crops) owing to financial constraints or unstable market conditions; (viii) low quality due to inappropriate post-harvest handling; and (ix) lack of value addition.

Issues and constraints over microalgae cultivation

40. Despite efforts in promoting microalgae as a new source of human food to fight hunger and malnutrition, including the efforts of FAO, global human consumption of microalgae mostly occurs through high-end food supplement products (e.g. *Chlorella* or spirulina powder) supplied by the nutraceutical industry.

41. Factors that constrain the use of microalgae in human foods include: (i) unappealing taste or colour; (ii) potential heavy metals and/or microcystin contamination under poorly managed cultivation; (iii) potential side effects caused by microalgae intake (e.g. allergies and gastrointestinal problems); and (iv) relatively high prices of quality microalgae products.

42. The high cost of harvesting and refining cultivated microalgae biomass is another factor contributing to the high production cost of microalgae, which is a main constraint over viable commercialization of microalgae biofuel production.

LESSONS LEARNED AND WAY FORWARD

Governance as foundation

43. Science- and evidence-based laws, regulations and guidelines (environmental regulations, spatial planning, food safety standards, occupational health requirements, technical guidelines and good aquaculture practices, among others) on seaweeds and microalgae are essential to laying a solid foundation for the sector's sustainable development. Seaweed farming should observe the best technical and normative guidance from global instruments, for example, the upcoming Guidelines for Sustainable Aquaculture, with tailored best practices to national and local conditions.

44. While it is usually the jurisdiction of individual countries to establish or adopt these criteria according to their socioeconomic and environmental conditions and developmental priorities, the international and scientific communities can help generate and share global knowledge and experiences to facilitate informed decision-making in the process.

Market demand as a driving force

45. Market demand has been a key driving force behind algae sector development. The kelp boom in Scotland in the eighteenth century for example was driven by demand for alkali to produce soap and glass; the Irish moss (*Chondrus crispus*) boom in Canada was driven by the demand for raw materials to produce carrageenan that subsequently fuelled the *Kappaphycus*/*Eucheuma* booms in the Philippines and in Indonesia.

46. Demand for healthy and tasty aquatic food has been the primary driving force behind the kelp boom in Eastern Asia, primarily China and the Republic of Korea. The boom has been sustained or reinforced along the way by other market forces, such as the demand for brown seaweed extracts (iodine, alginate, mannitol, fucoidan, etc.) and the demand for fresh seaweeds to feed abalone.

47. Nutritious, eco-friendly, and versatile algae have great potential in a variety of food and non-food applications, yet the potential may not turn into immediate market demand because of a variety

of constraints, such as low consumer exposure or preference, high production costs, market competition and stringent regulations.

48. Though attracting attention, many potential contributions of algae (e.g. health contributions, environmental benefits, and ecosystem services) may not automatically lead to immediate market demand or subsequent business opportunities to attract profit-seeking private investments in the sector. Market-based mechanisms, including carbon credits, nitrogen credits, blue bonds and green finance, among others, could be established to facilitate internalization of the positive externalities of algae. Coordinated support from governments, donors, civil societies and international organizations is crucial to facilitating algae sector development and integration into global food systems.

49. Another crucial lesson learned from the history of global algae development is that over-reliance on a narrow range of applications (particularly industrial commodities) can be risky or unsustainable. For instance, the aforementioned kelp boom in Scotland went into a steep decline in the early 1800s, as cheaper ways to produce soda and potash were discovered. The rapid expansion of *Kappaphycus*/*Eucheuma* cultivation in tropical areas, which supplies much cheaper raw materials for carrageenan production, has rendered the Irish moss industry in Canada a similar boom-bust experience, and the decline of the industry has caused significant socioeconomic repercussions.

50. Utilization of algae (especially seaweeds) as human foods, particularly for local consumption, tends to be the most stable market force that can serve as a stabilizer for algae sector development. However, the inertia of dietary habits and consumer behaviours poses a major challenge to the development of markets for algae food products, especially in places with little algae production, consumption and culinary traditions. Forming or changing dietary habits tends to be a long-term process that entails joint efforts of stakeholders and experts in policy, business and scientific communities.

51. Despite anecdotal evidence of increasing global or local popularity of sushi and other seaweed-based food products there is a general lack of detailed information and knowledge of algae-based food market potential (particularly market price and volume), which is essential to informed decision-making in policy and planning for the development of seaweed cultivation. In-depth, comprehensive assessments of algae markets and value chains at the global, regional, national and subnational levels are needed to fill the gap.

Innovation as a game changer

52. Science and innovations have been the main driving forces behind breakthroughs in seaweed or microalgae development. Fostering close collaborations between the algae industry and the cross-disciplinary research community are needed to transform the extensive potential of seaweeds and microalgae into acceptable, available and affordable food or non-food products. The public sector can facilitate the process by providing support for basic research on important topics, such as nutrition, genetic resources and diseases.

53. Public support (including financial incentives) is also needed to support the development and commercialization of innovations that tend to have significant technical, economic, environmental and/or social benefits.

Public support as enabling environment

54. The private sector, particularly in countries with little seaweed production and consumption, may lack incentives to devote substantial, long-term efforts to the development of seaweed markets with uncertain prospects. Thus, public support is needed to increase the public recognition and appreciation of seaweeds as nutritious human foods and help establish dietary habits in seaweed consumption. For example, with the safety and nutritional value of seaweeds ensured, public programmes, such as nutrition education and seaweeds on the menu of hospitals, schools and other public institutions, can be

implemented to promote seaweed consumption, which will not only increase seaweed demand immediately but also help foster future seaweed consumers.

55. The public sector should create an enabling environment to facilitate the development of algae cultivation. For example, governments can recognize seaweed and/or microalgae cultivation as a development priority and use licensing, financial support and other mechanisms to help reward the sector for its environmental benefits and ecosystem services.

56. Considering the significant regional imbalance in seaweed production and consumption, it may be worthwhile to strengthen seaweed cultivation and their value chain in some regions, and promote seaweed consumption.

FAO's role

57. FAO has conducted various projects that were either focused on seaweeds or that included seaweed development as a component; FAO has also generated and disseminated a number of knowledge products on algae.

58. FAO's work on the Progressive Management Pathway for Improving Aquaculture Biosecurity (PMP/AB) can help establish a progressive, risk-based and collaborative management framework for seaweed farming biosecurity at the enterprise, national and international levels. A forthcoming FAO publication on diseases of aquatic organisms will include a section on seaweed.

59. FAO is developing a background document that identifies potential food safety hazards (chemicals, pathogens and toxins) that could be linked to the consumption of seaweeds. The document would lay a foundation for further work in this area. FAO considers that there might be value in developing relevant Codex guidance on this subject and presented this issue for consideration in May 2021 during the Fourteenth Session of the Codex Committee on Contaminants in Foods (JECFA Secretariats, 2021). The issue will be followed up by the Codex Alimentarius Commission.

60. As part of its work on aquatic genetic resources, FAO is developing an information system on the farmed types of aquatic genetic resources, including algae, which can help address the paucity of information of the genetic basis of seaweed cultivation.

61. FAO databases on global fisheries and aquaculture production have been a unique source of data and statistics on global wild and cultivated production of algae. There is much room for improvement in statistics on the production of algae, in terms of accuracy and completeness (e.g. broader country coverage and more disaggregate species composition). Information and knowledge on other parts of the algae supply chains (e.g. processing and consumption) is also inadequate. Continuing support from FAO Members is needed for FAO to improve the quantity and quality of data and information on algae.

62. The Guidelines for Sustainable Aquaculture (GSA) propose a roadmap for Members towards more efficient, inclusive, resilient and sustainable aquatic food systems through good production management practices, innovation and investment. In this regard, the GSA can be used at the national and regional level to strengthen and improve enabling policies, legal and institutional frameworks, partnerships and investment actions for continued development of seaweed and microalgae aquaculture. The FAO Guidance on Social Responsibility in Fisheries and Aquaculture Value Chains, in addition to the GSA, provides tools for Members to increase social responsibility in seaweed farming value chains, including decent work and social protection in the sector.

63. Other areas of FAO work on the development of algae (primarily seaweed) cultivation and value chain may include, among others: (i) developing practical manuals on seaweed cultivation; (ii) establishing technical platforms to facilitate capacity-building, technology transfer and knowledge-sharing in key areas (farming systems and technology, genetic improvement, disease

control, among others); (iii) supporting market development for utilizing seaweeds as human foods; and (iv) facilitating collaboration and cooperation among Members in strengthening governance for sustainable algae sector development.