Building a Global Roadmap for Sustainable Aquaculture Growth

The Evidence Base: Why the development of sustainable aquaculture is essential to a healthy planet, ocean and food systems

BLUE FOOD PARTNERSHIP

FRIENDS of OCEAN ACTION

WORLD ECONOMIC FORUM

Contents

Preface

Sustainable aquaculture has the significant potential to meet growing protein needs in a nutritious way that has a low impact on the environment, fights climate change, and works towards zero hunger. Recommendations have encouraged responsible development of aquaculture products to increase by 25 - 41 million metric tonnes to make a total of 93.6 - 109 million metric tonnes by 2030.

To engage in this promising opportunity, Friends of Ocean Action and the World Economic Forum has brought together the Blue Food Partnership, a multi-stakeholder platform, which aims to catalyse science-based actions towards healthy and sustainable blue food value chains, including aquaculture. The Partnership's objectives are 1) to integrate the critical role of blue food in sustainability narratives at a policy level in international fora; and 2) to identify and scale pre-competitive initiatives on priority blue food topics. The Partnership includes representatives of the private sector, the science community, non-profit and international organisations, and government.

As part of their work, the Blue Food Partnership is building out the Sustainable Aquaculture Working Group. The vision of the working group is to help enable and increase the production of responsible and sustainable aquaculture to meet the demands of a fast-growing world population as well as to work towards achieving relevant Sustainable Development Goals. These include SDG 2: Zero Hunger; SDG 3: Good Health and Well-being; SDG 8 Decent Work and Economic Growth; SDG 12: Responsible Consumption and Production; SDG 13: Climate Action, and; SDG 14: Life Below Water.

Towards this vision, the Working Group's goal is to collectively co-create a science-based road map for sustainable aquaculture growth that will provide guidance towards the design and delivery of sustainable aquaculture growth.

This report has been produced to support the goal of the Sustainable Aquaculture Working Group. It aims to demonstrate why it is critical to develop a global sustainable aquaculture roadmap by collating themes and messages through a literature review of peer reviewed science papers, narratives, and opinion pieces by global experts. It also aims to show how sustainable aquaculture can support the success of a number of UN SDGs as noted above. Finally, the themes, messages, and data points from this paper will inform the scope and development of the Working Group's sustainable aquaculture roadmap.

1. Introduction

1.1. Methodology and Scope setting

The approach taken for this review was to identify key data sources, such as international governmental bodies, academic papers, government, NGO reports, news articles and industry reports in order to understand the trends, current landscape, publicly available projections, opportunities and challenges within the seafood and, specifically, the aquaculture industry.

The data sources were identified through contact with industry experts and academics as well as online research. Each has been reviewed to collate key messages, areas, or regions of interest for aquaculture, and to note where data is lacking and requires further attention. Key messages have been organised around themes, such as disease and pathogens, environmental concerns, economic implications, and food and nutritional security.

A significant variance appears to exist across the figures for aquaculture volumes cited within different reports, papers, and datasets. There are several reasons contributing towards this variation, including differences in the definitions or scope of aquaculture being discussed (e.g., for example the inclusion or exclusion of seaweeds), estimates made where data is weak, the sources used for datasets, or the data periods used within models.

Many reports refer to FAO data for aquaculture and fishery production that was available and relevant to the period, species, and region of study in question. Historic FAO figures have been amended over time where new learning has allowed. For example, in 2007 China's fisheries and aquaculture statistics for 2006 were revised, with an overall reduction in production volume of ~13%, with adjusted figures produced by the FAO for the period 1997-2005 reducing both China's and global statistics (Garibaldi, 2012). Similarly, following a census in 2016, China's fisheries and aquaculture statistics were also adjusted, with a reduction across aquaculture production of 7.0% (3.4 million tonnes).

The *Fish to 2030: Prospects for Fisheries and Aquaculture* report (The World Bank, 2013) considered the contemporary situation for fishery and aquaculture supply and demand, as well as modelling seven scenarios using IMPACT modelling to investigate potential changes for global fish markets. The figures presented in Table 1 below present the projected volume estimates for the 'baseline' scenario which was considered the most plausible scenario.

Table 1. Summary results under baseline scenario ('000 tonnes) (The World Bank, 2013)

	Total Fish Supply ('000 tonnes)		Food Fish Consumption ('000 tonnes)	
	Data 2008	Projection 2030	Data 2006	Projection 2030
Capture	89,443	93,229	64,533	58,159
Aquaculture	52,843	93,612	47,164	93,612
Global Total	142,285	186,842	111,697	151,771

The figures are provided as a foundation and for reference against differing figures presented within the literature reviewed, with further information on forecasts presented in section 2.5. The aggregation of data also presents problems when looking at national and global aquaculture figures, as different species and production methods present different nutritional benefits, input requirements, value, and environmental impacts, etc.

This is an issue called upon in many academic papers and industry reports with emphasis on the need for relevant, disaggregated data to assess the industry more accurately and for modelling systems.

The key papers reviewed for this report include academic, government, NGO and industry sources taking a broad view of aquaculture to identify key areas of interest globally and across production systems and species (Table 2). Further sources were used in the scoping and aquaculture introductory sections of the report, with a full list of references available at the end of the paper.

Table 2. Key papers referenced in this project

Ref.	Organisation / Researcher	Title	Year
1	The World Bank	Fish to 2030: Prospects for Fisheries and Aquaculture	2013
2	EAT Forum	Scoping report: The role of seafood in sustainable and healthy diets	2019
3	UN Food and Agriculture Organization (FAO)	The State of World Fisheries and Aquaculture (SOFIA) – Sustainability in Action	2020
4	Naylor R. L, Hardy R. W, Buschmann A. H., Bush S. R., Cao L., Klinger D. H., Little D. C., Lubchenco J., Shumway S. E. & Troell M.	A 20-year retrospective review of global aquaculture	2021
5	United Nations (UN)	The role of aquatic foods in sustainable healthy diets	2021
6	Blue Food Assessment - Stockholm Resilience Centre, Stanford University and EAT	Aquatic foods to nourish nations Environmental performance of blue foods Harnessing the Diversity of Small-Scale Actors is Key to the Future of Aquatic Food Systems	2021
7	Béné C., Arthur R., Norbury H., Allison E. H., Beveridge M., Bush S., Campling L., Leschen W., Little D., Squires D., Thilsted S. H., Troell M., Williams M.	Contribution of Fisheries and Aquaculture to Food Security and Poverty Reduction: Assessing the Current Evidence	2016
8	Belton B., & Thilsted S. H.	Fisheries in transition: Food and nutrition security implications for the global South	2014
9	Bogard J. R., Farook S., Marks G. C., Waid J., Belton B., Ali M., Toufique K., Mamun A. & Thilsted S. H.	Higher fish but lower micronutrient intakes: Temporal changes in fish consumption from capture fisheries and aquaculture in Bangladesh	2017
10	Edwards, P., Zhang, W., Belton, B., & Little, D. C.	Misunderstandings, myths, and mantras in aquaculture: its contribution to world food supplies has been systematically over reported	2019
11	Gephart J. A., Golden C. D., Asche F., Belton B., Brugere C., Froehlich H. E., Fry J. P., Halpern B. S., Hicks C. C., Jones R. C., Klinger D. H., Little D. C., McCauley D. J., Thilsted S. H., Troell M. & Allison E. H.	Scenarios for global aquaculture and its role in human nutrition	2020
12	Belton B., Little D. C., Zhang W., Edwards P., Skladany M. & Thilsted S. H.	Farming fish in the sea will not nourish the world	2020
13	Belton, B.	Fishing and aquaculture: underestimated as a source of income and food	2021
14	Bush S. R., Belton B., Little D. C., & Islam M. S.	Emerging trends in aquaculture value chain research	2019
15	Tlusty M. F., Tyedmers P., Bailey M., Ziegler F., Henriksson P. J. G., Béné C., Bush S., Newton R., Asche F., Little D. C., Troell M. & Jonell M.	Reframing the sustainable seafood narrative	2019
16	Oglend, A. (2020). Challenges and opportunities with aquaculture growth.	Challenges and opportunities with aquaculture growth	2020
17	Tezzo, X., Bush, S. R., Oosterveer, P., & Belton, B.	Food system perspective on fisheries and aquaculture development in Asia	2021
18	Merino G., Barange M., Blanchard J. L., Harle J., Holmes R., Allen I., Allison E. H., Badjeck M. C., Dulvy N. K., Holt J., Jennings S., Mullon C., & Rodwell L. D.	Can marine fisheries and aquaculture meet fish demand from a growing human population in a changing climate?	2012

1. Introduction

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Ref.	**Organisation / Researcher**	**Title**	**Year**
19	Cohen P. J., Allison E. H., Andrew N. L., Cinner J., Evans L.S., Fabinyi M., Garces L. R., Hall S. J., Hicks C. C., Hughes T. P., Jentoft S., Mills D. J., Masu R., Mbaru E. K. & Ratner B. D.	Securing a just space for small-scale fisheries in the blue economy	2019
20	Cao, L., Naylor, R., Henriksson, P., Leadbitter, D., Metian, M., Troell, M., & Zhang, W.	China's aquaculture and the world's wild fisheries	2015
21	UN Global Compact	Practical Guidance for the UN Global Compact Sustainable Ocean Principles (Aquaculture)	2020
22	UN Intergovernmental Panel on Climate Change (IPCC)	AR6 climate change 2021: The physical science basis	2021
23	Australian Centre for International Agricultural Research	Local champion inspires budding aquaculture farmers	2021
24	Metian, M., Troell, M., Christensen, V., Steenbeek, J., & Pouil, S.	Mapping diversity of species in global aquaculture	2020
25	Stentiford G. D., Bateman I. J., Hinchliffe S. J., Bass D., Hartnell R., Santos E. M., Devlin M. J., Feist S. W., Taylor N. G. H., Verner-Jeffreys D. W., van Aerle R., Peeler E. J., Higman W. A., Smith L., Baines R., Behringer D. C., Katsiadaki I., Froehlich H. E. & Tyler C. R.	Sustainable aquaculture through the One Health lens	2020
26	Costello, C., Cao, L., Gelcich, S., Cisneros-Mata, M.Á., Free, C.M., Froehlich, H.E., Golden, C.D., Ishimura, G., Maier, J., Macadam-Somer, I. & Mangin, T.	The future of food from the sea	2020
27	AquaInsights	An Introduction to Tilapia in Sub-Saharan Africa	2021
28	Shinn, A.P., Pratoomyot, J., Griffiths, D., Trong, T.Q., Vu, N.T., Jiravanichpaisal, P., Briggs, M.	Asian Shrimp Production and the Economic Costs of Disease	2018
29	International Labor Organization (ILO)	The future of work in aquaculture in the context of the rural economy	2021
30	Organisation for Economic Co-operation and Development (OECD)	OECD-FAO Agricultural Outlook	2020

1.2. Context of global aquaculture production

Seafood, both wild capture and aquaculture, plays an essential role in food and nutrition security and livelihoods for people `around the world. The world's demand for fish and fish products does not show signs of slowing. While wild capture fisheries provide part of this essential role, catch volumes are relatively stable. The 2018 total catch of 96 million tonnes according to FAO actually reflected an all-time high of production, consumption and trade reached. With consumption of seafood at around 156 million tonnes, it falls on aquaculture to make up the balance. Further, with wild capture fisheries largely unsteady and battling to manage sustainable yields it will need aquaculture to increase production volume to supply the increasing demand which will be needed for the growing population and changing consumption trends. Aquaculture production has been increasing at a rate of 7.5% growth per annum since 1970, although particularly over the past decade global growth rates have slowed (FAO, 2020; OECD, 2020). However, for aquaculture to provide food and nutritional security in a sustainable way, it is recognised that ongoing growth needs to be achieved while also responding to both environmental and social challenges, and thus requires responsible aquaculture development strategies.

The United Nations Food and Agricultural Organisation (FAO) maintains data on volumes, species, locations, and trends in aquaculture production. This data shows that there has been an increase of 122% in food fish consumption from 1990 to 2018, which was met by a rise of 14% in global capture fisheries production, and a 527% rise in global aquaculture production in the same period (FAO, 2020). In per capita terms, annual food fish consumption increased from 9.0kg per capita (live weight equivalent) in 1961 to 20.3kg in 2017 (FAO, 2020). Since 2016, growth in aquaculture production has provided over half of fish for human consumption, and in 2018 the share was 52% (FAO, 2020).

The sustainability of production varies significantly across species, with aquatic plants and bivalves lower impact than carnivorous species, and production type, for example between open mariculture systems and closed recirculating systems, in addition to the management and technological integration of the production unit. Focusing on sustainable aquaculture, 3% of global aquaculture is certified by the two largest responsible aquaculture assurance bodies, Aquaculture Stewardship Council (ASC) and Global Aquaculture Alliance Best Aquaculture Practice (GAA-BAP), according to Naylor *et al.* (2021), although the Certification and Ratings Collaboration (CRC) indicates that 56.1% (64.11 million tonnes) of aquaculture production is classed as being either certified, rated or in an improvement project

Of the 114.4 million tonnes in live weight of aquaculture production (including aquatic animals, aquatic algae and ornamental shellfish and pearls), 51.3 million tonnes were produced from inland aquaculture of aquatic animals, which accounts for 62.5% of the world's farmed food fish production (FAO, 2020). Inland aquaculture operations of aquatic animals are mainly freshwater, however in some countries there are also saline-alkaline aquaculture operations for growing 'local species naturally adapted to such environments, or introduced species, including marine species, that tolerate the conditions' (FAO, 2020). Inland aquaculture production systems commonly use earthen ponds, with other systems including raceway tanks, aboveground tanks, pens, and cages. Integrated systems, such as rice-fish systems, also have strong traditional roles in areas of Asia where they have undergone expansion (Campanhola & Pandey, 2019; FAO, 2020).

Global or national figures and data relating to 'sustainable' or 'responsible' aquaculture are not widely available. According to the FAO (2021), the growth of aquaculture activities 'outpaced the development of legislation and legal frameworks to govern aquaculture'. The specifics for responsible aquaculture will vary based on the production system and species, however many countries still lack the legislative and institutional frameworks and organisation to manage responsible aquaculture development.

2. Global trends in the aquaculture sector to 2030

2.1. Regions; as producers and consumers

By region, Asia is the largest producer within the last 20 years to 2018, with 89% of world aquaculture, particularly in China, India, Indonesia, Viet Nam, and Bangladesh. However, Norway, Chile and Egypt have consolidated sizable shares over the same period (FAO, 2020).

The importance of aquaculture is further evident from the FAO (2020) report (Figure 1), that 'In 2018, 39 countries, located across all regions except Oceania, produced more aquatic animals from farming than fishing. These countries, home to about half of the world population, harvested 63.6 million tonnes of farmed fish, while their combined capture production was 26 million tonnes. Aquaculture accounted for less than half but over 30% of total fish production in another 22 countries in 2018, including several major fish producers such as Indonesia (42.9%), Norway (35.2%), Chile (37.4%), Myanmar (35.7%) and Thailand (34. 3%)'.

For decades, China has been the largest producer of aquaculture and has the most diverse species composition. However, Cao *et al.* (2015) states that domestic consumption trends indicate that China's role may shift from 'the world's leading exporter to a net importer in the coming decades' which could have significant consequences on the availability of aquaculture product exports from China and demand on marine ingredients for aquafeeds.

Regional growth in South America and Africa have increased at a higher pace than Asia, with South and Southeast Asia growing at a greater pace than East Asia (Naylor *et al.*, 2021).

According to the ILO (2021), Africa is also expected to see significant increases in employment in aquaculture due to its growing population. Africa's annual growth rate for aquaculture production has shown the highest annual growth and is expected to continue expanding, providing 61% of the continent's total fish production by 2030 (increasing from 18%). This represents a significant contribution to Africa's food security with several countries formulating aquaculture development strategies to support the sector.

As stated in Tezzo (2020), South and Southeast Asia are recognised as expected to continue their role as the 'largest suppliers of farmed fish globally for the foreseeable future', with Asia representing 89% of global aquaculture supply, although Africa and Latin America are rapidly expanding and expected to take an increasingly important role in total aquaculture production (Belton, 2021).

As introduced in Section 1.1, global food fish consumption has grown consistently since 1960, averaging 3.1% annual growth and outpacing population growth (1.6%) as well as consumption of other animal proteins excluding poultry. Drivers for the trend in increased food fish consumption extend beyond the increase in supply and include technological

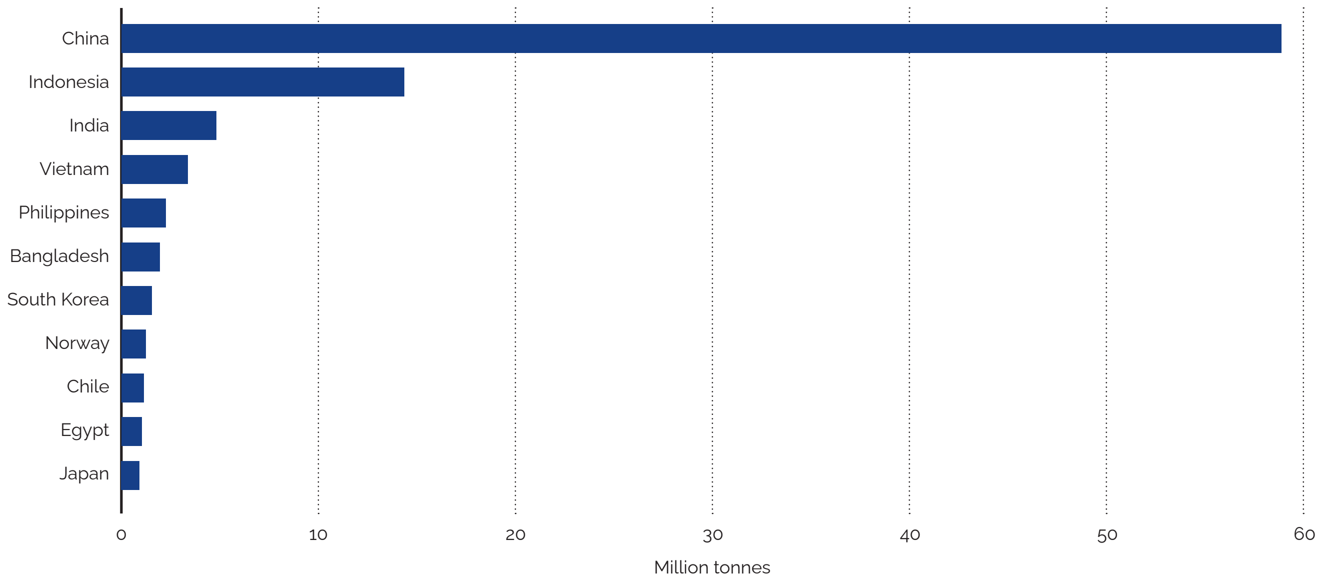

Figure 1. Top 10 aquaculture producers – 2017 (FAO, 2020)

advancements along the fish supply chain and socio-economic factors such as income, urbanisation, and increased awareness of the understanding of the health benefits of fish consumption (FAO, 2020). Behind the global consumption figures exists significant regional variation in per capita fish consumption, ranging from 1kg per annum to in excess of 100 kg per annum. This variation is attributed to 'cultural, economic and geographic factors, including the proximity and access to fish landings and aquaculture facilities' (FAO, 2020). Accordingly, per capita fish consumption in island states far exceeds that of inland nations.

Table 3 shows annual per capita fish consumption across country groupings by development status. Fish consumption in developed countries peaked in 2007 at 26.4kg per capita, followed by a gradual decline to 24.4kg in 2017. Increase in consumption amongst least developed countries has been attributed primarily to the expansion of production and imports in several African states. Importantly, despite lower overall consumption of fish in developing countries, fish consumption represents a higher proportion of total animal proteins in diets of those in developing countries compared to those in developed countries, representing 29% of animal protein intake in the diets for least economically developed countries, and 18% in low-income food deficient countries (FAO, 2020). This is in comparison to 11.7% of animal protein from fish in the diets of those in developed countries, which has declined due to increased consumption of other animal proteins.

Table 3. Per capita fish consumption by economic country grouping, 1961-2017 (FAO, 2020)

	Annual Per Capita Fish Consumption (kg)	
Economic Country Grouping	**1961**	**2017**
Developed countries	17.4	24.4
Developing countries	5.2	19.4
- Least developed countries	6.1	12.6
- Low-income food deficient countries	4.0	9.3

Globally, total fish consumption used to be dominated by Japan, the United States of America, and Europe, representing 47% of total consumption in 1961 which declined to 19% by 2017. Figure 2 below presents regional food fish consumption for 2017, showing the dominance of Asia, from which China accounts for 10% of global food fish consumption (FAO, 2020).

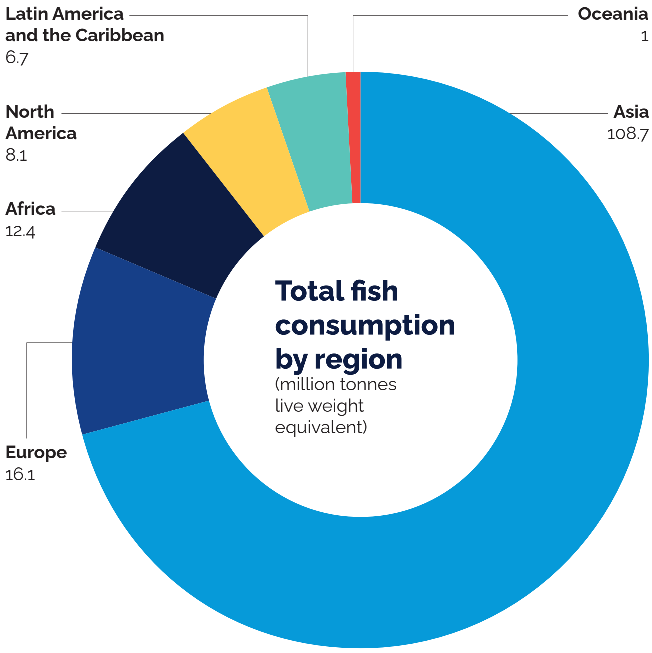

Figure 2. Total food fish consumption by region, 2017 (million tonnes live weight equivalent) (FAO, 2020).

2. Global trends in the aquaculture sector to 2030

2.2. Species

The FAO definition of aquaculture: The farming of aquatic organisms including fish, molluscs, crustaceans, and aquatic plants with some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding and protection from predators.

Demonstrating the variety within aquaculture production, Figure 3 below shows the composition of global live-weight aquaculture production and growth over the 20-year period 1997-2017, as identified by Naylor *et al.*, 2020.

For 2018, the FAO recorded aquaculture production for reporting countries and territories under a total of 622 units, defined as "species items". Aquaculture production of these 622 species items corresponds to 466 individual species, 7 interspecific hybrids of finfish, 92 species groups at genus level, 32 species groups at family level, and 25 species groups at the level of order or higher (FAO, 2020) (Figure 4).

According to the FAO (2020), farming of aquatic animals in 2018 was dominated by finfish (54.3 million tonnes, including numerous carp species and Nile tilapia (*Oreochromis niloticus*) harvested from inland aquaculture (total 47 million tonnes) and Atlantic salmon (*Salmo salar*) harvested from marine and coastal aquaculture (total 7.3 million tonnes).

Following finfish were molluscs (17.7 million tonnes) – mainly bivalves including numerous cupped oyster species (*Crossostrea* spp.), Japanese carpet shells (*Ruditapes philippinarum*), and scallops (Pectinida), crustaceans (9.4 million tonnes) such as whiteleg shrimp (*Litopenaeus vannamei*) and red swamp crawfish (*Procambarus clarkia*), marine invertebrates (435,400 tonnes), aquatic turtles (370,000 tonnes), and frogs (131,300 tonnes). Whilst aquaculture production represents a great number of species, production volume is 'dominated by a small number of "staple" species or species groups at the national, regional, and global levels' (FAO, 2020); for finfish production, 27 species and species groups accounted for over 90% of total finfish production, with 20 species accounting for 83.6% of total finfish volume.

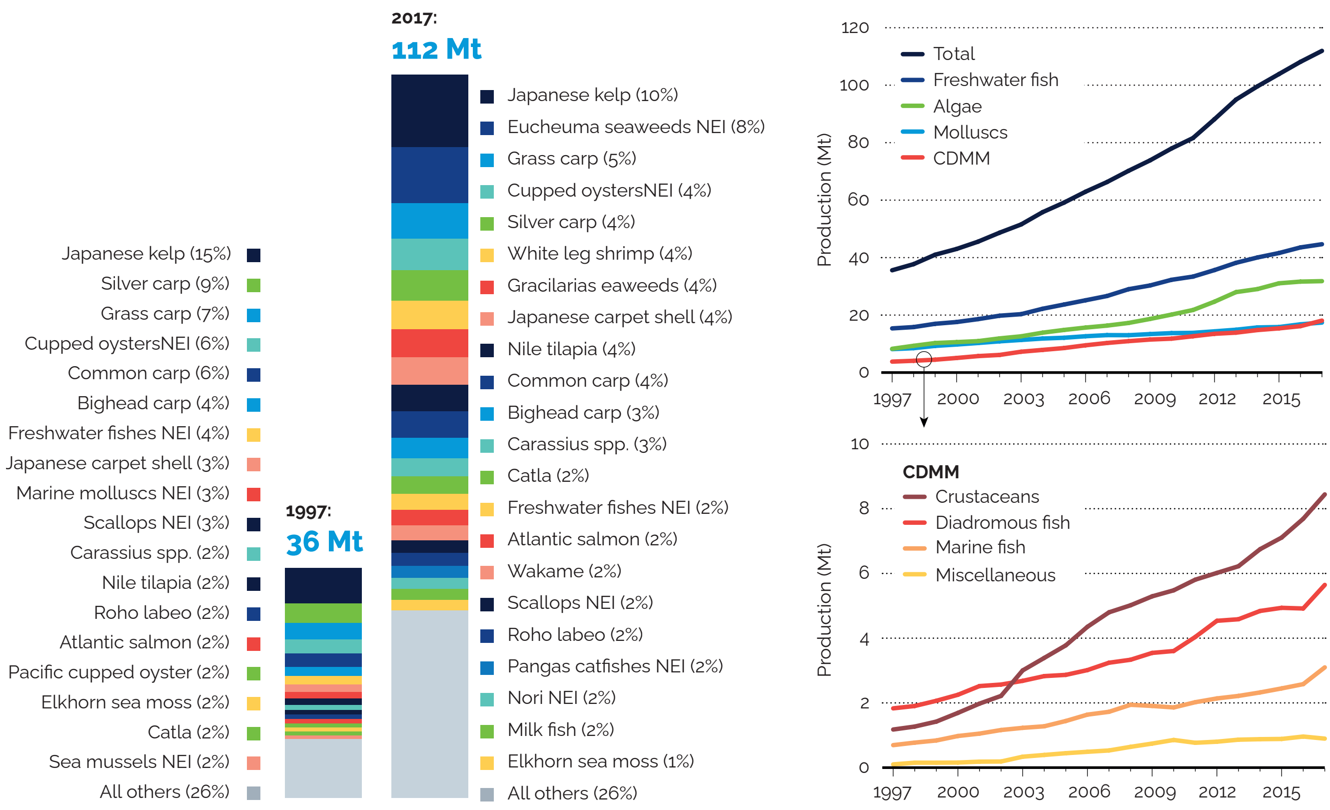

Figure 3. Composition and growth of global live-weight aquaculture production (Naylor et al., 2020)

Aquatic plant production, including seaweeds and microalgae species, has increased in volume over recent decades from 10.6 million tonnes in 2000 to 32.4 million tonnes in 2018, of which 97.1% by volume was comprised of farmed seaweed (FAO, 2020). Despite growth rates slowing, production of tropical seaweed species in Indonesia for carrageenan extraction has been identified as a major source of farmed seaweed production over the past 10 years, increasing production from 4 million tonnes in 2010 to over ~11 million per year across 2015-2018 (FAO, 2020).

Seaweed consumption can offer nutritional benefits from its macronutrients, such as 'sodium, calcium, magnesium, potassium, chlorine, sulphur and phosphorus', micronutrients, such as 'iodine, iron, zinc, copper, selenium, molybdenum, fluoride, manganese, boron, nickel and cobalt', and vitamins B12, A and K (FAO, 2018). However, according to Naylor *et al.* (2020), whilst some studies highlight the micronutritional value of seaweeds for human consumption, these benefits are presently difficult to quantify due to the variation in produce and the absence of 'clear scientific evidence regarding nutritional bioavailability and metabolic processes associated with algal consumption'. Recent research has been conducted into the use of microalgal biomass as a 'cost-competitive fish meal replacement' in aquaculture feed, and macroalgae in 'dairy and cattle feed for reducing methane emissions', although neither solution is currently developed at commercial scale (Naylor *et al.* 2020).

Whilst recognised within the definition for aquaculture, national and regional regulations and data collection for microalgae are often separate from national aquaculture systems. In 2018, global microalgae production recorded by FAO in 2018 totalled 87,000 tonnes from 11 countries, with 86,600 tonnes reported by China alone. Data is unreported from numerous microalgae producing countries, including 'Australia, Czechia, France, Iceland, India, Israel, Italy, Japan, Malaysia, Myanmar and the United States of America' (FAO, 2020).

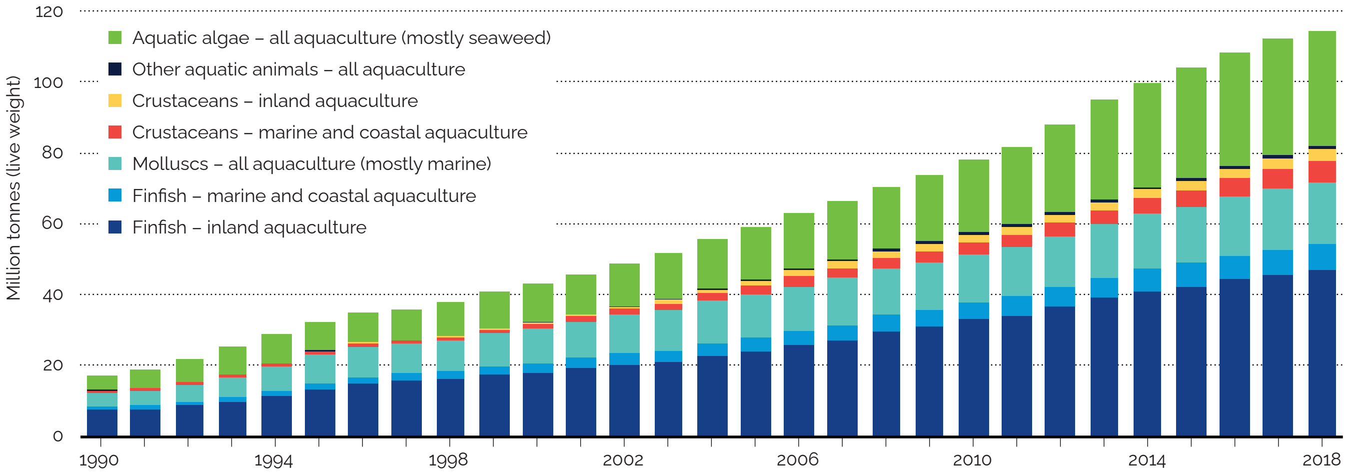

Figure 4. World aquaculture production of aquatic animals and algae, 1990-2018 (FAO, 2020).

2. Global trends in the aquaculture sector to 2030

2.3. Trade and consumption

Fish and fish products are amongst the most highly traded food products, with 38% of all caught and farmed fish traded internationally (exported) in 2018. Across the period 1986-1995 (average per year) to 2018, global fisheries and aquaculture exports increased from 34.9 million tonnes to 67.1 million tonnes, representing an increase from 34.3% to 37.6% of exports as a share of total production (FAO, 2020). Fish and fish product exports have grown at an average rate of 8% between 1976 and 2018 (4% adjusted for inflation) representing an increase from USD 7.8 billion to USD 164 billion. Whilst a sharp decline in the global growth rate was observed in 2015 (10%) following slowing due to ongoing impacts of the global economic crisis of 2008-2009, this was followed by three years of recovery. Recent impacts on international trade have included trade wars between China and the United States of America, and the COVID-19 pandemic which each negatively impacted trade in 2020. Whilst fish are highly traded in terms of volume, aquaculture production primarily feeds domestic markets. This is illustrated by the fact that 89% of aquatic animals produced in the world's 10 highest aquaculture-producing developing countries are consumed within those countries' domestic markets (Belton, 2021).

The biggest trading country is China, which has continued to hold its position as the main exporter of fish and fish products since 2002 (FAO, 2020). China contributes '>60% of global aquaculture volume and roughly half of global aquaculture value', with most of its domestic fisheries considered as overexploited (Cao *et al.*, 2015). Other top exporters are Norway, Viet Nam, India, Chile, and Thailand, in declining order. Fish and fish product exports account for a significant amount of merchandise trade from many island and coastal states, representing over 40% of merchandise trade in states such as Cabo Verde, Faroe Islands, Greenland and the Maldives (FAO, 2020). With many developing countries amongst the top producers, seafood exports hold the potential for significant economic benefits within these countries.

The largest fish importing market is the European Union (34% in value terms), followed by the United States of America and Japan (FAO, 2020). This is a continuing trend of developed countries dominating fish imports; however, the role of developing countries has been growing at a rate that exceeds imports by developed countries, increasing from a share of 19% by quantity in 1976 to 49% by quantity in 2018. This increase in demand is largely driven by increased urbanisation and an expanding middle-class in addition to increased available supply. China has been increasing imports and in 2011 became the third major importing country (by value). According to Cao *et al.* (2015) domestic consumption trends indicate that China's role may shift from 'the world's leading exporter to a net importer in the coming decades'. Whilst fish consumption is expected to grow across most continents (Figure 5), the OECD (2020) has projected a decline in consumption in Sub-Saharan Africa due to population growth exceeding fish supply.

The aquaculture industry is described as increasingly 'multi-polar' to reflect its 'diffusion of sources of demand and sites of production' with Asian economies driving a 'South-South mode of economic globalisation' in place of the historically South-North unidirectional trade flow (Bush *et al.*, 2019).

In addition to fish traded for human consumption, fishmeal and fish oil products or ingredients remain important for fed-aquaculture production and are often sourced from what capture fisheries produce. China's growth in aquaculture production and the composition of species produced will be important in determining the future of fishmeal and fish oil trade flows and will apply continuing pressure to increase feed efficiencies and development of alternatives.

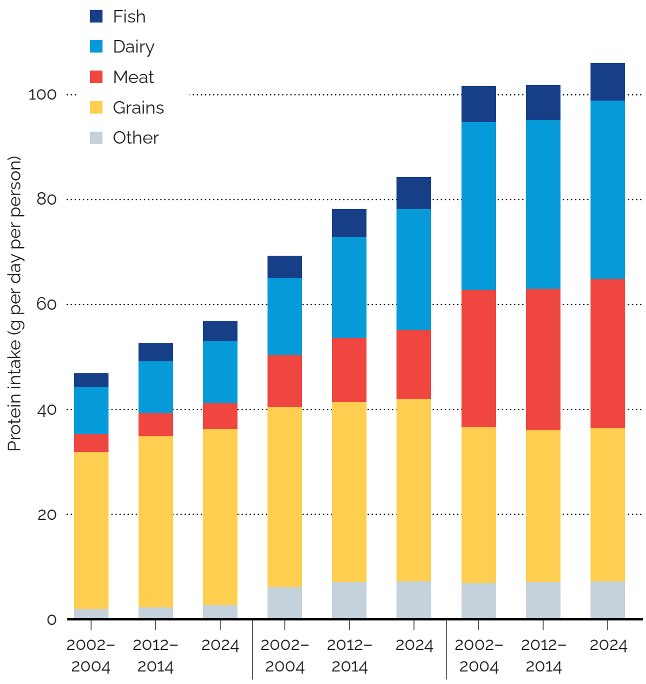

Figure 5. Protein intake over time, by country status (OECD, 2020).

2.4. Data issues and definitions

Most papers reviewed remark on data issues within the available global and national data for fisheries and aquaculture production, particularly beyond environmental and ecosystem impacts and integrating social, cultural, and economic metrics.

Data gaps or uncertainty include: the types of aquaculture production; the composition of species, which is often nationally aggregated with fisheries or at a species-group level; the lack of accurate reporting, estimated from 35-40% of producing countries and insufficient data quality and completeness (FAO, 2020). Global data on aquaculture production employment is often nationally aggregated with fisheries employment or from small-scale aquaculture production with informal employment, which is not accurately reported or easily defined (ILO, 2021). Additionally, due to the aggregation of data provided by countries when reporting to the FAO, it is difficult to separate mariculture, coastal aquaculture and inland (freshwater) aquaculture. Specifically, finfish production can be both in coastal ponds or sea cages, particularly in Asia, which impacts the ability to fully evaluate the impacts of these species. (FAO, 2020). There is also limited research available on freshwater fish production due to its 'relatively dispersed nature, the poor consistency of associated data, and the bias of northern-dominated research towards exported seafoods' which does not reflect Asia's global dominant role in freshwater fish production (Tezzo *et al.*, 2020).

These gaps and weaknesses in data hinder the ability to gain an accurate picture of aquaculture development status and trends, also affecting modelling systems and scenario analysis when used as inputs. This presents complications when forecasting and noting trends, for example, due to the need for comprehensive data to guide evidence-based sustainable aquaculture policies, decisions, and development investments. Understanding specific definitions used and data sources is critical when interpreting data and comparing figures.

2.5. Forecasts

Forecasts and projections for aquaculture production and human aquatic food consumption to 2030 vary depending on the data inputs, modelling and scenario decisions, and assumptions made by the research team. This section describes available forecasts from the OECD, FAO, and World Bank.

2.5.1. The OECD (2020)

2029: 200 million tonnes – total fish production
105 million tonnes – total aquaculture production

The OECD states that global fish production (capture and farmed) will reach 200 million tonnes by 2029, reflecting an increase of 25 million tonnes (14%) from the base period of average production from 2017-2019. For aquaculture, 2029 production is projected at 105 million tonnes, exceeding the capture sector by 10 million tonnes. Drivers for the growth in aquaculture production identified in the report include relatively low feed prices and profitability remaining high in the sector. This projection includes a slower pace of annual growth than the previous decade (decreasing to 1.3% from 2.3%). The decrease in the rate of growth is associated with a decline in China's fisheries and aquaculture production. Although often sourced from capture fisheries, by-products are increasingly being used as an alternative source of fishmeal and fish oil, with IFFO reporting that over recent years 33% of fishmeal production was from by-products (Jackson and Newton, 2016).

The paper projects that by 2029, growth in per capita fish food consumption will slow from 1.3% which was the average for the period 2010-19, to 0.5% per annum and reaching 21.4kg by 2029. Increases in per capita fish consumption is anticipated to continue across all continents with the exception of Africa, where population growth is expected to increase at a faster rate than fish supply growth and Sub-Saharan Africa's per capita fish consumption will contract by -0.7% per annum over the next decade.

The source acknowledges the uncertainty behind projections, with external factors, such as the climate and environmental conditions, and policy factors, such as fisheries management and trade policies, capable of influencing outcomes.

2. Global trends in the aquaculture sector to 2030

2.5.2. The FAO (2020)

2030: 204 million tonnes – total fish production
109 million tonnes – total aquaculture production

The FAO SOFIA 2020 report projects that total fish production (excluding aquatic plants) will expand from 179 million tonnes in 2018 to 204 million tonnes in 2030. This represents an increase of 15%, 26 million tonnes. This is a slowdown in growth of production based on the previous decade up to 2018, which grew a total of 27%. Aquaculture is expected to continue to drive growth into the future and reach 109 million tonnes in 2030, increasing 32% from 2018, although at a slower rate (2.3% from 4.6%) than the previous decade to 2018. Contributing factors for this slowdown include 'broader adoption and enforcement of environmental regulations; reduced availability of water and suitable production locations; increasing outbreaks of aquatic animal diseases related to intensive production practices; and decreasing aquaculture productivity gains' (FAO, 2020). The deceleration in China's aquaculture production is expected to be compensated by an increase in production from other countries.

The share of fish production for human consumption is expected to continue growth to 89% by 2030, this is due to a combination of 'high demand resulting from rising incomes and urbanisation, linked with the expansion of fish production, improvements in post-harvest methods and distribution channels expanding the commercialisation of fish. Demand will also be stimulated by changes in dietary trends, pointing towards more variety in the typology of food consumed, and a greater focus on better health, nutrition and diet, with fish playing a key role in this regard.' (FAO, 2020). Global fish consumption is projected to increase by 18% between 2018 and 2030, with a live weight equivalent of 28 million tonnes. The rate of growth in global consumption is expected to be slower than the decade leading to 2018, primarily due to 'reduced production growth, higher fish prices and a deceleration in population growth' (FAO, 2020). Per capita consumption will increase across all regions except Africa, and by 2030 Asia will account for 71% of consumption of the world's fish available for human consumption.

2.5.3. The World Bank (2013)

2030: 186.842 million tonnes – total fish production
93.612 million tonnes – total aquaculture production

The Fish to 2030: Prospects for Fisheries and Aquaculture report (World Bank, 2013), also presented in section 1, considered the contemporary situation for fishery and aquaculture supply and demand, as well as modelling seven scenarios using IMPACT modelling to investigate potential changes for global fish markets. The resulting most plausible projections for total global fish supply in 2030 was 186.842 million tonnes, with food fish consumption representing 151.771 million tonnes. Of this, aquaculture was projected to account for 93.612 million tonnes of total fish supply, with the whole volume projected to be used for food fish consumption.

2.6. Responsible aquaculture development; toward sustainable food systems

Over the last 20 years there has been a movement towards understanding, applying, and recognising best practices in aquaculture. This has resulted in certification and ratings schemes defining those practices and evaluating the performance of aquaculture production systems. Certification is carried out on a specific unit of certification (i.e., a farm) on a voluntary basis by a third-party certification body, while ratings are carried out by a ratings organisation on a non-voluntary basis and by broader units, for example countries or areas. Ratings focus on assessing as many seafood sources as possible in key markets to provide information on the full spectrum of low-to-high performance for fisheries and aquaculture. This information can be used to identify opportunities for producers to pursue improvement projects and certifications, as well as help businesses evaluate sourcing options. Certifications directly engage with fisheries or farms and require them to address social and environmental challenges to improve and meet the certification standard. For example, the Aquaculture Stewardship Council (ASC) species standards include requirements covering 'water quality, responsible sourcing of feed, disease prevention, animal welfare, the fair treatment and pay of workers and maintaining positive relationships with neighbouring communities' (ASC, 2021). Certifications also engage with the supply chain to verify the sustainability or responsibility and origin of certified products (Certifications and Ratings Collaboration, 2021), with GLOBALG.A.P. certification covering all stages from feed, hatchery, grow-out, harvest and postharvest (GLOBALG.A.P., 2021).

Based on data from the Certifications and Ratings Collaboration tool, which draws on publicly available global production data for farmed and wild fisheries as of 2018, proportions of seafood have been attributed to certification and ratings as of 2020. The data shows that of the total 114.29 million metric tonnes (M MT) of aquaculture production, 56.1% (64.11M MT) is classed as being either certified, rated or in an improvement project, leaving 43.9% (50.18M MT) not certified or rated (Figure 6). The tool does not currently include data for two other main responsible aquaculture assurance certification developers, BAP and GlobalG.A.P, which would further increase volumes for current certified and rated aquaculture production.

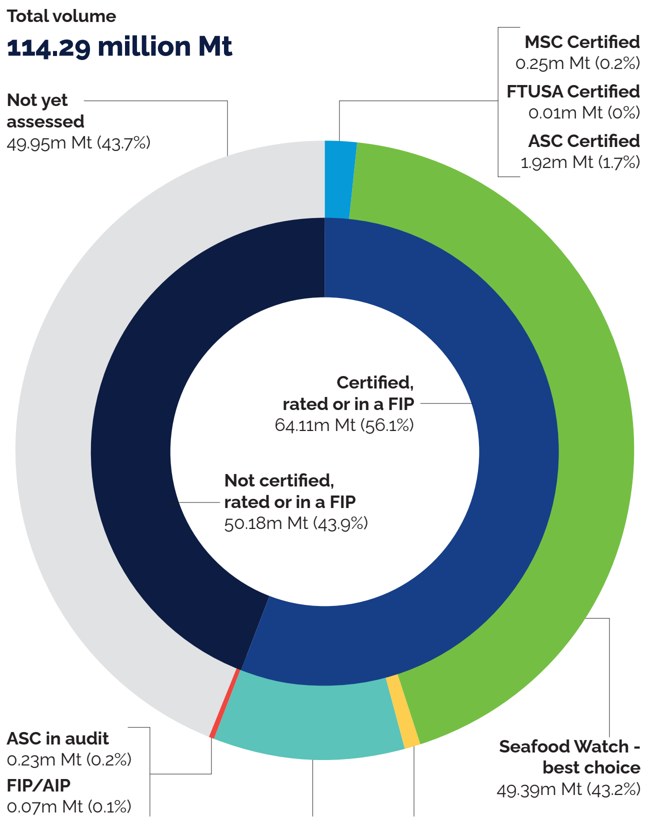

Figure 6. Global Seafood Production (Certifications and Ratings Collaboration, 2021).

2. Global trends in the aquaculture sector to 2030

Within the 56.1% classed as certified or rated, as shown in Figure 6, the majority is certified or green rated[1], indicating a high level of best practice production, with low impact species such as seaweed and bivalves making up the majority of this rating. The remaining proportion is either rated 'good alternative' or 'avoid and needs improvement' (Sustainable Seafood Data Tool, 2020).

This analysis also suggests that of global aquaculture production evaluated, 10% (11.38M MT) is rated as seafood to 'avoid' from the perspective of responsible production, a large part of which relates to farmed shrimp.

The FAO (2017) recognises that 'standards frameworks and certification systems are likely to be important tools in the delivery of SDGs in the aquaculture sector'. Schemes that align with the SDGs can provide an industry incentive and framework for the sustainable development of aquaculture production. Standards which previously focused on environmental impacts and fish health have expanded to include worker, community, and economic criteria, increasing relevance to multiple SDGs. Additionally, the number of species for which responsible farming standards are available continues to grow, furthering the opportunity for farms to certify their responsibly produced aquaculture and contribute to the achievement of SDGs.

[1] Members of the Certification and Ratings Collaboration (CRC) for aquaculture include: Aquaculture Stewardship Council, Fair Trade USA, Monterey Bay Aquarium Seafood Watch Program, and Sustainable Fisheries Partnership.

2.7. Aquaculture supporting success of the SDGs

Sustainable aquaculture currently supports numerous UN SDGs, with the potential to increase its role through responsible development. This section highlights main direct links between sustainable aquaculture and SDGs; further indirect links can be made to several other Goals.

2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING

As is evident from the statistics presented within this paper on the volume of fish from aquaculture, which has expanded dramatically over recent decades, aquaculture will continue to have an important role in **SDGs 2 'Zero Hunger'** and **3 'Good Health and Well-being'**. Aquaculture production is important for global food systems, but also has a localised role to play in the rural communities of many small-scale operations where the fish produced is a vital source of protein, macronutrients and micronutrients in local diets.

5 GENDER EQUALITY

'Gender Equality', SDG 5, is supported through the high rates of employment for women along seafood supply chains (ILO, 2020). Whilst data can be difficult to analyse due to the dispersion of rural operations and aggregation of fisheries and aquaculture employment data, opportunities for women include in the processing, preparation and sale of aquaculture products. However, the quality of these jobs can draw criticism, such as the treatment of shrimp processing workers in industrial operations and issues around health and safety.

8 DECENT WORK AND ECONOMIC GROWTH

'Decent Work and Economic Growth', SDG 8, is supported through the employment and economic benefit brought by aquaculture operations and supply chain activities, particularly in rural communities and developing countries. Aquaculture can play an important role in contributing towards local economies, particularly small-scale operations, and on a broader scale towards GDP, with large-scale industrial operations of importance. 'Decent work' can be supported throughout aquaculture supply chains with aquaculture development increasing job and business opportunities, however ensuring 'decent jobs' with good wages and safe working conditions within formal and informal employment will be important in the development of responsible aquaculture.

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

SDG 12 'Responsible Consumption and Production' is supported through the supply of a food source and animal protein for human consumption that can then have a lower environmental impact than terrestrial sources (FAO, 2020). Advances in aquaculture practices, technology, innovation, and environmental impact management are also contributing to improvements in responsibly produced aquaculture, resulting in lower impact food systems.

13 CLIMATE ACTION

SDG 13 'Climate Action' can be supported through aquaculture planning, especially for small island developing States and developing countries, helping nations to respond to hazards and disruptions caused by climate change through providing additional food sources from more resilient and adaptive food systems (FAO, 2017). Furthermore, where aquaculture products replace foods with a higher environmental impact and greenhouse gas (GHG) emissions, the responsible development of aquaculture can play a role in reducing demand for terrestrial food production and its associated GHG emissions.

14 LIFE BELOW WATER

SDG 14 'Life Below Water' refers to the sustainable management, protection, and restoration of marine and coastal ecosystems. Through reducing the demand on wild capture fisheries, aquaculture can lessen the depletion of wild stocks from human consumption. Additionally, responsible management and governance of aquaculture production can build more resilient food systems, with research and innovation reducing waste, resource needs and environmental impacts. In addition to lowering negative impacts, production of aquatic plants and animals can have direct ecosystem benefits, such as the water filtering capabilities of bivalves and seaweeds.

17 PARTNERSHIPS FOR THE GOALS

SDG 17 'Partnerships for The Goals' represents an important aspect in realising the social, environmental and economic potential benefits of aquaculture production. This is due to the scientific, governance, industry, and community factors that influence production and consumption, as well as supply chains and trade flows that stretch across the globe. Widely identified challenges in aquaculture development include gaps in data and falling outside of regulations and government departments, which can be targeted through national and international partnerships.

3. Cross cutting themes

3.1. Food security and nutritional benefits

Seafood is recognised as filling a vital role in food and nutrition security across the globe, providing protein, micronutrients, and fatty acids all crucial for human development. These nutritional benefits are particularly important for cognitive development, pregnant women, and children. In addition to providing critical food and nutrition security for many developing countries, seafood has a significant role in the health of Western diets too (EAT Forum, 2020).

A future potential 'production-consumption' cap has been identified by the EAT Forum (2020), which will require increased production of seafood products to continue to meet the healthy reference diet. However, that report took a generalist approach to the role of seafood and EAT has supported recent academic research that takes a more detailed look into the role of aquatic foods in diets at a regional level, such as Golden *et al. Aquatic Foods to Nourish Nations* (2021). This paper seeks to understand the impacts of aquatic foods for human nutrition based on different production scenarios, considering the specific nutritional diversity of different food sources and micronutrients deficiency needs across regions, countries, and demographics. Due to the limitations on capture fisheries growth, aquaculture is projected to continue its expansion and leading role in producing fish for human consumption. Some papers investigate differences in the nutritional profiles of farmed fish compared to capture fish products, with aquaculture having a decreased nutritional profile for micronutrients (Bogard *et al.*, 2017; Belton and Thilsted, 2014). However, in a study in Bangladesh during a period of significant aquaculture consumption increase, whilst micronutrients intake was shown to decrease, there was a significant increase in protein and fatty acid intake due to the overall increased availability and accessibility of fish products (Belton and Thilsted, 2014).

The UN (2021) remarks on the major contribution of aquatic foods towards transition to socially, economically, and environmentally sustainable diets. The paper emphasises the importance of focusing beyond finfish, which are often economically valuable, to other species which present broader or improved nutritional content. Challenges stated within the paper include the unaffordability of a healthy diet for many people, the lack of diversity within current aquatic food systems, and cites further research needed to fully understand the range of food safety issues it may pose. The Global South is home to nearly all countries heavily dependent on aquatic foods for nutrition, including 'many of the lowest-income countries in Africa, Asia and the Pacific' (Belton, 2021). Asia and Africa were identified in numerous papers as critical areas for aquaculture development for food security.

3.2. Poverty alleviation, livelihoods and economic benefit

Poverty alleviation and livelihood support from aquaculture are explored through the employment opportunities and national and community economic gains that can be observed in producing countries, particularly small island states, and coastal and rural communities. The ILO (2020) confirms that it is difficult to ascertain specific data on aquaculture employment and supply chain due to the aggregation of fisheries and aquaculture data and the informality of the sector in many developing countries. However, the paper reports on an average annual increase of 4.29% of direct employment within aquaculture across the period 1995 to 2018. In 2020, aquaculture accounted for the direct employment of an estimated 20.5 million people. The employment support extends further when considering aquaculture-related activities, which underpin the livelihoods of an estimated 27.7 to 56.7 million people in the formal and informal economy according to an FAO study. Future employment in the sector is expected to expand across Asia, including 'Bangladesh, China, India, Indonesia, Pakistan, the Philippines and Viet Nam' (ILO, 2020). Africa is also expected to see significant increases in aquaculture employment due to its population growth and expansion in people engaging in agriculture activities.

The role of aquaculture in poverty alleviation in developing countries has been investigated in one of the reviewed papers, with the message that currently any potential direct link between the two factors has not been 'sufficiently studied to understand this relationship' (Béné *et al.*, 2016). Another paper (Belton and Thilsted, 2014) considers the risk to livelihoods within small-scale fisheries due to growth in aquaculture, stating that aquaculture does not have the 'comparable ability' to provide 'additional labour and income opportunities when alternatives are limited, reducing the vulnerability and food security aspects of poverty' that small-scale fisheries provide and that it does not meet the wider cultural and social roles of the fishing industry and wild capture products.

More recently, the UN (2021), FAO (2021) and Béné *et al.* (2016) recognise the rural community economic benefits that can be achieved through small-scale aquaculture production in emergent and developing countries, in addition to the localised food and nutrition security benefits. Short *et al.* (2021) reviewed 70 case studies from around the world and remarked on the diversity of small-scale actors within fisheries and aquaculture, and the 'outsize impact [of these actors] on human health and the economy', despite smaller sectors often being overlooked and facing 'persistent misconceptions that all actors can be managed the same'.

To meet future demands for fish products and continue to achieve economic value whilst reducing environmental impact, the reduction of marine ingredients in feed and further efficiencies in operations are recognised as important factors. However, taking a view that only considers the realisation of economic value can have negative impacts on local communities and the resilience of aquaculture food systems. For example, focusing on high-value, large fish cultivation instead of local indigenous species and polyculture ventures could provide immediate economic gains but affect long-term performance whilst not meeting local consumption preferences (Metian *et al.*, 2019). Furthermore, improvements in feed production, such as the growing use of marine by-products, has the potential to be an increasing source of further social and economic benefits. Additionally, supporting businesses have grown upstream and downstream of production units, such as transport and logistics providers (Belton, 2021).

The future growth in fish consumption is expected to come from demand from changing tastes due to urbanisation and increasing household incomes on the one hand, and a growing population particularly in developing countries on the other. The needs and preferences for these consumers are not aligned, with middle-class consumers preferring a narrow set of larger, expensive fish products, whilst meeting growing food demands in developing countries must focus on availability, accessibility, and local food uses and preferences (Naylor, 2021; Belton *et al.*, 2020; Belton, 2021). Economic development and foreign exchange earnings from exports are widely recognised in the literature as benefits of aquaculture production. Seafood is one of the largest traded commodities from the global south to the north and aquaculture plays a growing role in this.

3. Cross cutting themes

3.3. Communities, equity and gender

The FAO (2020) recognises the importance of coastal aquaculture in supporting livelihoods, employment, and local economic development within coastal communities in producing developing countries and the UN (2021) refers to the cultural and economic importance of small-scale aquaculture activities for rural poor communities, providing healthy, accessible, and affordable food sources.

Concerns have been raised about the increasing industrialisation of the industry, which may draw production away from small-scale producers and the reliant local communities. However, Belton (2021) recognised the emergence of a 'hidden middle' category, particularly in Asia, that does not fit into the previously polar narratives of small-scale farms and large industrial operations through the development of 'strongly commercially oriented, specialized, small- and medium-scale farms.'

The ILO (2021) remarks upon the role of aquaculture in the employment and livelihoods of rural communities in developing countries, with women representing a significant portion of the workforce, although accurate data on global aquaculture employment is difficult to define due to the dispersion of informal, small-scale operations and the aggregation of fisheries and aquaculture data. The report states that women represent 19% of the workforce in primary aquaculture production, however when considering further along the value chain to include both primary and secondary activities in the fisheries and aquaculture sector, women constitute 50% of the workforce. The role of women in seafood processing can become even more significant when looking at employment regionally, such Viet Nam where women represent 85% of the workforce. Whilst this represents an important source of employment opportunities, the ILO notes disparities between the employment of men and women within aquaculture and levels of participation within the sector. Additionally, the provision of decent work within seafood processing and aquaculture production more widely is an essential consideration, with poor working conditions, social protection, and health and safety concerns identified as areas in need of improvement by the ILO. The importance of improving human well-being and equity was identified by the FAO (2010) as a core principle recommended for the planning process for aquaculture.

3.4. Impact of climate change

The extent of the impact of climate change on aquaculture production has been considered in several papers, with no generally agreed consensus identified. In the IPCC report (2021), fisheries and aquaculture were considered collectively and identified as being 'an asset with high impact and risk relevance for climatic impact-drivers' of: coastal floods, mean ocean temperature, marine heatwave, and ocean acidity. For aquaculture, an increase in air temperature can affect aquaculture siting suitability and flooding with salt water can affect production for freshwater and inland production. Naylor *et al.* (2021) recognise that the uncertainty on the impacts of climate change on aquaculture presents a challenge and potentially significant risks on the sector, with Gephart *et al.*, (2020) stating that climate system changes may affect the 'scale, type and quality of aquaculture production'. The UN (2020) states that potential impacts from climate change could include 'ocean acidification, sea temperature rise, oxygen levels, algae blooms and extreme weather events' which may affect organism health and the reliance of operations.

Another important aspect is the impact of aquaculture production on the climate. Some studies are available on the impacts of aquaculture on the environment and climate change, particularly in comparison to alternative animal protein sources such as beef and poultry. The FAO (2020) states that 'the output of fisheries and aquaculture produces lower greenhouse emissions for the equivalent nutrition than do most agricultural food systems', whilst it does contribute to other environmental impacts. However, whilst recognising the opportunity for aquatic foods to provide more sustainable diets, Gephart *et al.* (2021a) comments on the 'sparse inclusion of blue foods in environmental impact studies relative to the vast diversity of production'. The UN (2020) remarks on the role of aquaculture in helping to 'contribute to diverse and healthy diets by providing low carbon, nutritious food to a growing world population' as well as 'curb climate change and contribute to the development of a sustainable ocean economy'. MacLeod *et al.* (2020) investigated greenhouse gas emissions from global aquaculture (excluding aquatic plants) and identified that global aquaculture accounts for 'approximately 0.49% of anthropogenic emissions in 2017', a value it compares to being similar in magnitude to the emissions from sheep production. Factors contributing to the lower impact of aquaculture cited within the paper include the lower emissions intensity of aquaculture production compared to terrestrial livestock 'due largely to the absence of enteric CH_4 in aquaculture, combined with the high fertility and low feed conversion ratios of finfish and shellfish' (MacLeod *et al.*, 2020).

3. Cross cutting themes

3.5. Economics of disease, animal welfare and aquaculture management

Rapid and intensive growth of aquaculture has encountered serious episodes of disease resulting in huge national income losses (despite compensatory price rises in response to supply shortage), amounting to billions of dollars annually (Shinn et al, 2018). Examples of this include the Chilean salmon ISA disease crisis (described by Asche, 2009) and the Asian shrimp virus outbreaks across producers such as Thailand and Viet Nam (throughout 2010-2017). Collective losses due to these viruses and other shrimp diseases globally have been estimated at up to US$ 23.6 billion and 4.8 million tonnes of shrimp, with a further loss of US$ 7 billion in feed sales (this study) accounting for export losses of US$ 13.4 billion (Shinn et al, 2018). Asche (2009) notes the drop from 400 thousand tonnes of production to around 100 thousand tonnes in the matter of just one year; the cumulative financial loss was estimated at US$ two billion. The paper concludes that disease will create an even larger challenge to aquaculture development in less developed countries.

There is recognition that disease can be controlled with better farm-level practices but that since aquaculture is connected, there must be coordination between farms and regional management to properly tackle it. This includes where farms are sited, biosecurity measures, regulations/planning and cumulative impact. Poorly managed farms and aquaculture development can have a range of negative impacts, including habitat conversion and ecosystem disturbance, water pollution and disease outbreaks, community disruption and poor working conditions. The need for a more robust and comprehensive approach to aquaculture management is laid out in the "Ecosystem Approach to Aquaculture" by the Food and Agriculture Organization and the World Bank (FAO, 2010). Three principles are recommended to guide the planning process:

- Aquaculture should be developed in the context of ecosystem functions and services (including biodiversity) with no degradation of these beyond their resilience.
- Aquaculture should improve human well-being, with equity (e.g., access rights, fair share of incomes) for all relevant stakeholders.

- Aquaculture should be developed in the context of other sectors, policies, and goals, as appropriate.

Specifically, regarding disease risk management, the Sustainable Fisheries Partnership (SFP, 2021) recommends health management plans and emergency disease response plans are developed for all production zones and updated regularly. Biosecurity protocols and disease responses should be coordinated across all producers in a given zone. Lastly, across a region, incidents of disease and management actions taken should be monitored and publicly reported.

The Global Seafood Alliance (GSA, 2021) identifies animal welfare as increasingly in the spotlight and that animal health and welfare is a crucial pillar of Best Aquaculture Practice, with GSA President George Chamberlain remarking on the 'environmental control, nutrition, biosecurity and health management, husbandry and handling, and humane slaughter' improvements that have been made within the sector, with reference to ongoing research and technology contributing to these gains in responsible aquaculture production. The BAP Standards view and address animal welfare through: stocking density, regular inspections, humane slaughter, transportation conditions, and responsible antibiotic use (BAP, 2020).

It is important to continually raise the bar with ongoing advances in research and technology - responsible aquaculture is a journey, not a destination.

Studies have identified a need for production to be distributed more evenly between species from different groups (e.g., fish, crustaceans, molluscs and aquatic plants), with the expectation that it reduces the risks related to production failure from, for example, diseases or weakening markets, at least at a national level (Elmqvist*et al.*, 2003; Gephart *et al.* 2020). Thus, a diversified production should be more resilient to future perturbations, although it depends on the type, severity, and duration of disturbance (Walker *et al.*, 2004). It has been proposed that culturing more species provides a form of insurance and offers better adaptation possibilities under different climate change scenarios, especially unexpected events such as diseases or market issues (Cochrane *et al.* 2009; FAO 2016).

5. Conclusion

Based on the literature reviewed for this evidence base paper, it is apparent that sustainable aquaculture can play a significant role in globally achieving future food and nutrition security and contributing to a number of SDGs. According to the UN, aquaculture is capable of reducing the climate change impacts of food systems by reducing demand on current land-based livestock protein sources which can have greater environmental impacts than aquatic food sources. Management of aquaculture to sustainably reach production goals for 2030 and beyond needs to consider the diversity of the sector and its differing role across scales and within communities, due to the range of 'geographies, cultures, technologies, markets, and access rights' the sector covers (Short *et al.*, 2021).

Research and data gaps have been identified that will be important to address with plans for future aquaculture development, such as the aggregation of data between fisheries and aquaculture, across areas such as production volumes, impacts and employment, as well as within aquaculture where species or production type data is often aggregated. Furthermore, the often informal and widely dispersed nature of small-scale aquaculture can mean that data is difficult to capture. To support responsible growth, further understanding and data is needed around these areas.

All the findings from this evidence base paper will be taken into consideration as the Sustainable Aquaculture Working Group shapes the global roadmap towards the design and delivery of sustainable aquaculture growth to 2030.

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