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The importance of fisheries and aquaculture production for nutrition and food security.

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Summary and Keywords

Aquatic food has a significant role to play in global nutrition and food security but is often ignored in that debate. Understanding its potential role is made difficult by the fact that aquatic food covers a large number of species which come from both capture fisheries and aquaculture, the marine and freshwater environments and include finfish, crustacea, molluscs, echinoderms, aquatic plants and other aquatic animals. Further complications arise from the fact that both supply and consumption vary significantly between countries.

There are several criteria which need to be considered when discussing nutrition and food security, these include how much food is produced, whether that production is sustainable, whether the production supports livelihoods, what the nutritional content of the food is and whether that food is safe. We conclude that there are many benefits to aquatic food under each of these criteria but there are also some hurdles which need to be overcome. Increased production, to feed a growing global population, relies on the growth of aquaculture. Limitations to that include the supply of raw ingredients for aquafeeds, reducing losses due to disease outbreaks, ensuring high standards of food safety and overcoming environmental limitations to expansion. There are also problems with welfare conditions for people working in the supply chain which need to be addressed.

Given the challenges to nutrition and food security which we are currently facing, it is essential that aquatic food is brought into the debate and the significant benefits that aquatic foods provide are acknowledged and exploited.

Key words: Aquatic food, finfish, crustacea, food security, nutrition security, fisheries, aquaculture

Introduction

In order to achieve nutrition and food security, all people need to have access at all times to the adequate utilization and absorption of nutrients in food, in order to be able to live a healthy and active life (1). Access implies that there needs to be enough food available, that is safe to eat and that people can afford to buy it. Therefore five key elements to consider when looking at the role of fisheries and aquaculture in food and nutrition security are levels of production, livelihoods associated with the sectors, environmental benefits, nutritional content and aquatic food safety.

When we consider the role of aquatic food within food security we have to take into account that it comes from a range of sources and covers a large number of species globally, and that there is significant variability inherent in such a wide range of aquatic food systems. The importance and potential for increased contribution to food security varies spatially and geographically often influenced by consumer demand, product availability including what species are consumed and what the limitations are for increased supply. For the purposes of this article we will assume aquatic food includes finfish, crustacea, molluscs, echinoderms (e.g. sea cucumber), aquatic plants and other aquatic animals such as reptiles and amphibians. These sources of food can come from wild capture fisheries or be farmed in aquaculture systems and in either case can come from freshwater or marine environments. Aquatic food plays a varied role in diets globally (2). In 2016 the global per capita fish consumption rose to above 20kg per year for the first time (3): this is 6.7% of all protein consumed by humans. However, this varies between countries with, according to FAO, China having the highest overall consumption, followed by the rest of Asia (3). This consumption is predicted to increase globally over the next few years although this increase is not uniformly distributed. For example, demand in Europe is expected to remain relatively constant whilst the total demand from China, Asia and Africa is expected to increase, this is largely due to the increase in population predicted in these places (2). In this paper we will consider the global picture of aquatic food systems but will limit the discussion largely to finfish, crustacea and molluscs.

In recent years aquatic food has undergone a significant change in terms of its supply: input from capture fisheries has been relatively static since the late 1980s whereas aquaculture production is increasing rapidly. In 1974 aquaculture provided only 7% of fish for human consumption, that figure had increased to 26% by 1994 and to 50% by 2013. A recent Worldbank reported predicted that Aquaculture would provide 60% of fish (by which they mean finfish, molluscs, and crustaceans) for direct human consumption by 2030 (4). Aquaculture is the fastest growing primary production sector with global aquaculture production expanding at an average annual rate of more than 8% over the last 30 years (4) which is faster than human population growth.

One of the major advantages of aquatic food over other meat sources is the fact that it is, on average, produced more efficiently and with fewer emissions.

Aquatic food also has significant nutritional benefits. It provides a diverse range of micro and macronutrients which can contribute towards providing a balanced and healthy human diet.

Consumption of seafood is widely promoted as a vital source of easily digestible protein and essential fatty acids (FA) required for a range of metabolic functions, thus supporting human health and wellbeing. These essential FA must be acquired from the diet and seafood. The current dietary recommendations for a healthy diet in the UK are to eat two 140g portions of fish per week, of which one should be an oily fish.. Fish in particular are widely recognised as a healthy form of animal protein, being low in fat, high in the aforementioned omega-3 fatty acids, and rich in a range of essential vitamins and minerals, including vitamin D, calcium, and iodine, and has a protective effect on risk for cardiovascular disease (5,6,7). In developing countries, seafood from wild-caught sources is often the only source of protein available and provides essential micronutrients for women and children.

Despite these positive contributions that aquatic food makes to diets globally it is not well incorporated in the food security debate. Food and nutrition security is a well-established research area which has received increasing attention over the last few years. However, data on the dietary contribution from aquatic food products within the broader food security arena is more limited compared with terrestrial food sources (8,9). Preliminary results of a scoping review which is currently being carried out by the authors, assessed the representation of aquatic foods within the broader food security literature and has found that only a small proportion (<15%) of papers published since 2007 which use the key term 'food security' include aquatic food as an integral component of the work. By not including aquatic food products within the wider food security arena communities and regions which rely on aquatic foods are underrepresented, and potential food security synergies unexplored.

The contribution of aquatic food to nutrition and food security:

1) Production

Fisheries production has been static since the 1980s. Some areas are managing stocks more successfully than others. There are a large number of areas which have been historically overfished and there are some well-known examples of fisheries collapses with further collapses predicted (10,11). However, in some cases carefully managed fishing practices have allowed fisheries to recover to the point where they are being fished sustainably. In a 2013 paper, Fernandes et al. (12) examined the status of 57 fish stocks in the Northeast Atlantic which had been monitored for over 60 years (12). Their analysis showed that whilst in 2002 a large number of those stocks were being significantly overexploited, over the last 10 years there had been a reduction in exploitation and many stocks were recovering (12). Unfortunately not all stocks are as well monitored and managed as they are in Europe and in many places fishers have to adapt to catching the species available, rather than the species in demand, if stocks fluctuate or even disappear. It is generally accepted that although some fisheries are being managed sustainably, it is unlikely that we will see an increase in fish supply from fisheries alone.

Therefore, in order to increase supply we have to turn to aquaculture to meet the predicted increased demand for fish protein. There is huge potential for growth within aquaculture by utilising the same types of technique which have been exploited in the livestock industry such as genetic selection of desirable traits. In addition there are some benefits to aquaculture, such as the diversity of potential species to domesticate and new technologies such as open ocean aquaculture which also provide opportunities for growth.

However, in order to achieve this increase there are also a number of limiting factors have to be overcome. These include, but are not limited to, supply of raw ingredients for aquafeeds, reducing animal loses from disease outbreaks and ensuring highest standards of food safety. The increased intensification of the aquaculture sector, to meet the continued global demand, has exacerbated these constraints. Feed inputs are not required for the mollusc and plant aquaculture sectors, with more limited resource requirements needed to produce the aquafeeds for the freshwater fish farmed, compared with marine production. Whereas, the crustacea and marine farming, often these are intensive monoculture systems, require high quality protein (fish meal) and oil in the commercial aquafeed diet to raise the animals (13). Terrestrial sectors such as the poultry and pig farmers use fish meal, so the demand for these raw ingredients is larger than aquaculture alone (13), but the intensive marine farming sector remains one of the highest users of these finite resources. Several studies have addressed alternatives to using wild-caught supplies of fish meal and oil for aquaculture which include alternative diets (14), substitution of raw ingredients (15) and dietary management practises (16). Use of marine microalgae have perhaps shown the most promise as alternative provides of essential fatty acids for aquaculture. These are the primary producers rich in essential fatty acids, EPA and DHA (17) and they are already used in aquaculture for live feed for a wide range of mollusc, crustacean and fish species (18). Several constraints have been identified in the uptake of marine microalgae as alternative source of dietary oils for aquaculture with the biggest conflict coming from the biofuels sector (19). The interaction between wild capture fisheries and aquaculture has been discussed in detail in, e.g. a paper by Jennings et al. (ref) Implementing alternative feed ingredients within the aquafeeds sector is time consuming and will not emerge overnight. Consideration must be given to the characterisation, digestibility, palatability and function of the dietary ingredients within the farmed aquatic animal (20). Research within this field is gaining momentum but must be integrated within a holistic approach that ensures the health of the farmed stocks. Addressing shortages in aquafeed production and changes in dietary components alone, will not resolve the sustainability issues in aquaculture. Development and intensification of the aquaculture sector will only be achieved in we deliver high quality feed alternatives/management practises in combination with improved animal health and welfare. Infectious disease outbreaks continue to threaten the development of this rapidly expanding food sector (21). The lack of efficacious vaccines against infectious agents resulting in large scale disease outbreaks is contributing towards the continued reliance on antibiotics in aquaculture. This has significant repercussions for food security as well as public health. Further research is required to provide suitable alternatives to antimicrobials, particularly in low and middle income countries (LMIC) where intensification of terrestrial and aquatic food is predicted to expand (22). Ensuring that all food is safe to eat, is one of the core pillars in global food security (23) and must be applied to aquatic food irrespective of supplier.

2) Livelihoods:

Aquatic food production supports a range of livelihoods along the supply chain, from primary producer/fisher to retail sector. In the 2016 FAO report (2), nearly 60 million people globally were engaged in the primary production of edible seafood products which included both farmed and capture fisheries. Small scale operations (both in fisheries and aquaculture) play a critical role in supporting livelihoods, particularly in rural areas by supporting food security and reducing poverty (2). In 2014, 84% of the global population engaged in the aquatic food production sector were in Asia, and 94% of jobs in aquaculture are also in Asia. Gender studies have highlighted that 19% of those engaged in fisheries and aquaculture sectors are women, and in the secondary sector engagement (e.g. processing) 50% of the workforce is women (24). The role of women in seafood supply chain varies tremendously not only between countries but also between providers of the seafood. In Nigeria, 73% of the fisheries workforce is women, involved in both harvest and post-harvest roles whereas in EU only 21% are women (24). Women are more traditionally involved in the rural, small scale aquaculture operations, as these can be better integrated into their other livelihood activities, but a higher number of women are employed in processing of farmed aquatic food, often in low paid, unreliable employment with no welfare considerations (25). Encouraging women’s participation in aquaculture can be beneficial to their own status in the family and community, as well as providing production benefits - in a Bangladesh-based study, fish production increased 10-20% when women were engaged in small-scale aquaculture (24). Such increases in women's participation can lead to improved production, income levels, and nutrition security for the whole family, as women in aquaculture have been found to prioritise family consumption of their home-grown fish more highly than men (26, 27, 28).

Another area of interest with respect to livelihoods is what the impact of climate change will be for capture fisheries (29). Climate change is predicted to have a significant impact on fish species distribution, and model predictions show that it might lead to numerous local extinctions within 40 years (26, 29). In their 2010 paper Badjeck et al. (29) argued that climate change impacts on livelihoods will vary across scales, by sector of activity and by actors (individuals, communities, private sector and governments). They proposed that responses should include management approaches which reduce vulnerability to multiple stressors, as well as recognition of the opportunities that climate change could bring and of the potential contribution of fisheries to mitigation efforts either through emission reductions or carbon sequestration (29). It is likely that climate change will also impact on the species which can be produced through aquaculture and the diseases which might infect farms; fish farmers will have to be able to adapt to these changes (30).

3) Environmental impacts

There are several possible measures of sustainability (4, 31, 32) but on most of those aquatic foods perform well, particularly in comparison to red meats. For example, in animal husbandry practise feed conversion ratio (FCR) is used as a measure of the efficiency with which animal feed is converted into the food output. If we consider feed conversion efficiency in terms of units of output per units of feed input in production units then the least efficient dietary protein source is beef (e.g. 31, 32, 33). Farmed fish are one of the most efficient forms of meat production, with an FCR efficiency that is similar to poultry (31, 32). In their recent paper, Fry et al (33) suggested that FCR, which is the commonly used measure, does not account for differences in feed content, feeding rates during production, edible portion of an animal, or nutritional quality of the final product. There are also other factors to consider including the production length which is much shorter for farmed fish compared with cattle. Fry et al. (33) considered both protein and calorie retention for a range of different aquatic and terrestrial species, their results showed that calorie and protein retention rates were similar for aquaculture and terrestrial animals but that chicken and Atlantic salmon performed best for these two measures (32).

In terms of carbon equivalent footprint, beef and sheep have the highest emissions regardless of whether they are intensively or extensively farmed with means ranging from ~25 (beef intensive) to ~58 (beef extensive) kg CO_2 per kg product (Figure 2. in ref 4). Seafood supplied from fisheries produce ~12 kg CO_2 per kg product, while pork has very similar emissions to seafood from aquaculture, at approx. 6 kg CO_2 per kg product, meaning on emissions they are both slightly worse than poultry (4). There is increasing pressure for land and water resources meaning that expansion of both terrestrial animal and aquaculture farming is limited under the current farming practices. To address food insecurity technical, environmental and cost-effective solutions must be implemented that support sustainable intensification of all food production. Scope for expansion in aquatic food production may, therefore, lie more in the marine environment than the inland aquaculture sector which remains a user of land and water resources, particularly freshwater (34). If aquatic food is to play a more significant role in addressing food insecurity then we must consider the diversity in production systems, species and food products supplied as strengths but only if production can be achieved through sustainable resource use, and without negative impacts on ecosystem services and biodiversity.

In addition to their relatively low carbon footprint, as compared with other forms of animal protein, finfish and molluscs, can provide important ecosystem services. Wild fish, for example, play a role in regulating both marine and freshwater ecosystems through their diet, which in turn influences nutrient availability and thus dynamics of other organisms such as plankton and algal populations (35). A number of other ecosystem services are also provided by wild fish, such as bioturbation of sediments (36), and the contribution of marine-derived nutrients to fresh water systems by salmon during their annual migrations, with the decomposition and consumption of salmon eggs and waste providing an important influx during an otherwise nutrient-scarce period (37,38).

It is important to bear in mind these ecosystem services in the management of sustainable fisheries, to ensure management practices do not interfere with key thresholds and ecological cycles. Ecosystem service trade-offs should also be considered, as, for example, enhancement stocking may provide beneficial regulating services, as well as increasing the number of fish available for harvest, but also decrease native biodiversity (39); determining which is the priority for a given location requires site-specific consideration.

Where waste is appropriately handled, and ecosystem trade-offs carefully considered, fish farming has the potential to provide food with relatively few negative environmental impacts while also providing important aquatic ecosystem services.

Negative environmental consequences of fish farming through the release of organic wastes which detrimentally affect ecosystem community structure and biodiversity (40,41) must also be taken into account when considering the net impact of fish production. This organic waste, however, while potentially dangerous when left as untreated and unprocessed effluent, can also potentially provide nutrients needed for other forms of food production. In integrated systems which have been in use in China for more than 1200 years, carp are co-produced in rice paddies, where they not only reduce the need for fertilizer (by 24% as compared with monocultures) through production of organic waste products, but also reduce pesticide inputs (by 68%) largely by disturbance of rice plants and causing insect pests to fall into the water below, where they are consumed (42). While such integrated production cannot, alone, solve the issues surrounding fish waste products at current levels of fish demand, multi-trophic aquaculture raises the possibility of co-producing aquatic organisms from different trophic levels in the same system, potentially reducing environmental impact without negatively impacting production (43, 44). A number of multi-trophic systems have been proposed including the use of bivalves around fish cages to recycle effluent (45); the use of plants as filtration agents (46); and those which combine both plant and bivalve filtration in multi-layered systems (47, 48) – in each case, such systems provide additional food products as well as environmental benefits. Fish effluents can also provide a nutrient rich fertilizer, which has been trialled and found to be a suitable replacement for inorganic nitrogen across a range of crops, including guineagrass (49), bell pepper (50), and wheat (51).

4) Current Importance of Aquatic Animals in the diet globally and nutritional benefits

Assessments of global consumption of fish have clearly shown an increasing trend in uptake as part of a balanced diet, supporting the importance of aquatic food within the human diet (52). There is however, a high level of heterogeneity between individual countries not only in terms of fish production but also in rates of consumption of fish products (53). The consumption rates are increasing in many high income countries (HIC) but still remain lower compared with the total percentage dietary protein intake for low to middle income countries (LMIC) (54). Farmed fish products have the larger share of the global market compared with capture fisheries where wild caught products are more commonly traded and consumed in low income countries (LIC) (54).

In the HIC, Government health initiatives promote the inclusion of 1-2 portions of oily fish per week, as part of a balanced diet, and in an effort to tackle the rise in diet-related noncommunicable diseases. It is the combination of high quality protein, micronutrients and essential fatty acids, all necessary for a range of human metabolic functions that a single portion of fish can provide that makes this such an attractive food staple in the diet (55). This has led to an increase in consumption of fish and fish products in HMICs, which is not mirrored in LMIC where fish are a more staple dietary source of protein and contribute a much higher percentage of the total animal protein consumed.

Thilsted et al (55) clearly showed the heterogeneity between selected LMI and HMI countries in terms of fish production and consumption. China was by far the largest producer of fish (59.82 million t/yr in total as compared with 3.41 in Bangladesh and 9.92 in Indonesia) and had the highest consumption of fish per capita in the LMICs (at 33.5 kg/capita/yr, as compared with 19.7 in Bangladesh and 28.9 in Indonesia), but the contribution of fish as a source of dietary protein was much higher per capita in Bangladesh and Indonesia (56.2% of total animal protein in Bangladesh, 54.8% in Indonesia, and 22.4% in China).

Published data on the importance of fish and fisheries products within the diet are usually linked to the percentage of dietary protein available, however, these products also provide an attractive mix of essential micronutrients and provides a more diverse diet compared with other food sources which can be more limited. This is particularly important to vulnerable members of the community within LMICs such as women and children (53). These products are more readily accessible to the impoverished as they are cheaper than alternatives, thus they are consumed at higher rates per person compared with HICs. Future global demand for fish and fisheries products are predicted to increase where the biggest demand may come from the rise in wealthy, urban middle classes, particularly in the MICs (56). The increase in life expectancy and need to tackle lifestyle diseases through better dietary habits is also likely to contribute to the future global demand for aquatic food in HICs.

5) Food safety

The principles of food safety are to prevent foodborne illness in people, and this scientific discipline has expanded over the years to accommodate changes reflected in our food production and supply chains. Food is a global commodity susceptible to emerging and re-emerging infectious diseases, where national and international surveillance programmes and regulations are applied to ensure the safety of the end product for consumers. The codes of practice, certification programmes e.g. ISO, HACCP and guidelines implemented through these surveillance programmes arose from the *Codex Alimentarius*, established through collaboration between FAO and WHO in 1960's. Each food type has its own hazards identified, but overall the purpose of all food safety regulation is to protect the health of the consumer. Through the globalisation of food production and supply, higher numbers of zoonotic infections have arisen, which are more prevalent in terrestrial farming practises that aquaculture or fisheries. Broadly, foodborne diseases in people are via direct contact with the infected food/animal product (zoonosis) or humans (e.g. food handler) or by ingestion of the contaminated food. For the purposes of this review only bacterial and viral foodborne infections of significance to seafood will be included.

If seafood is to play a pivotal role in food security then ensuring the safety of the end product is crucial. To be effective we must focus on the perception, regulations and rapid detection of foodborne microbes in our seafood products. Microbial pathogens can be part of the naturally occurring microflora on the fish/fisheries product or may come from contamination during processing and supply chain. Members of the bacterial genus *Vibrio* are common inhabitants of the marine environment. Both *V. parahaemolyticus* and *V. vulnificus* have been associated with seafood-associated illness in people, with *V. parahemolyticus* being the leading cause of seafood-associated bacterial illness in the US (58). Infections are often described as self-limiting, resulting in acute gastroenteritis with symptoms occurring 4-90h post consumption of contaminated seafood (59). Baker-Austin et al. (60) described the increased incidence of bacterial infections from non-cholera Vibrio species in people, where climate change and rising seawater temperature may influence the prevalence, spread and growth of these bacterial *Vibrios* in the marine environment.

Enteric bacterial and viral foodborne pathogens found in fish and fisheries products are all transmitted through the faecal-oral route, either by direct person-to-person contact or through ingestion of contaminated food. Determining the source of the infection however, can be more problematic with viruses, particularly human norovirus which is a member of the *Caliciviridae*, and is considered a major cause of acute gastroenteritis in people (61). Outbreaks of human norovirus and seafood poisoning have been implicated in cases of human gastroenteritis after consumption of shellfish contaminated with faecal pollution (62). Norovirus is described as highly contagious, prevalent and stable within the marine environment and has a long virus-shedding duration with a low infectious dose (63). These characteristics can promote the spread of the infection through the community and can contribute to high levels of viral burden in the shellfish farmed in coastal inland waters. Several strategies have been implemented to reduce the risk of enteric infections from shellfish including, farming in better quality waters, depuration and relaying of the animals in clean water prior to market.

Improved control measures over the last 20 years have reduced the prevalence of the bacterium *Listeria monocytogenes* which is a significant cause of foodborne illness (64). Exposure to *L. monocytogenes* often produced gastroenteritis symptoms which are usually self-limiting in healthy individuals but can become fatal in those who are immunocompromised e.g. elderly, pregnant women and children (65). A review by Jami et al (66) highlighted the increased risk of *L. monocytogenes* contamination in seafood products, particularly given the increased demand for lightly preserved e.g. smoked and ready-to-eat products. This raises the need for complete compliance on hygiene and sanitation practises within food processing sector and a greater emphasis on disinfection in the production line.

Social licence

Public and media perception is another issue which can cause problems for the aquaculture industry. In a recent paper Froehlich (67) analysed approx. 1500 newspaper headlines from 1984-2015 from both developed and developing countries and found an increasing positive trend in aquaculture coverage generally, but with developing countries producing proportionally more positive headlines than developed ones. An FAO report in 2015 (68) found that the rapid growth of aquaculture had caused concern about environmental impact, human health, including food safety, and social issues. However, it was also found that whilst most of the production is in Asia, the opposition to increased aquaculture development largely comes from the western world. The report from Bacher (68) found that the most significant consumer concern was the health and safety aspects of farmed fish. People's perceptions of environmental impact and animal welfare concerns varied geographically. However, most people were unaware whether the fish they bought was wild or farmed in origin. Overall the report concluded that the public perceptions of aquaculture focussed on risks and did not weigh up the costs and benefits. They went on to recommend ways of addressing these public concerns. One key conclusion was that it is important to put aquaculture in a wider perspective by comparing its costs and benefits with other animal production systems (69).

Consumer preferences

Despite the nutritional benefits, and the lower environmental impact of fish in comparison with other animal products, a number of socio-cultural barriers to fish consumption exist in western populations. Even within the EU fish consumption varies both within and between countries. Several of these barriers are linked to lack of experience with fish consumption, such as difficulty with fish bones (69, 70, 71), perceived high price (71, 72, 73, 74, 75), and distaste for presentation of the whole fish, particularly where the eyes are retained, as opposed to pre-cut filets, or terrestrial meat products (69). A number of sensory and physical factors are also important, such as disliking the smell (69, 70, 72, 74, 75) or taste (71) of fish, and a lack of satiety as compared to terrestrial meat (69, 74, 75). Both perceived food safety issues (71) and convenience (76) have also been highlighted as barriers to fish consumption. Cultural preferences can also play a role in consumption patterns, as regional differences in preferred seafood are evident; for example, the widespread consumption of cephalopods in Southern Europe and Southeast Asia, which is not mirrored in Northern Europe and North America (77).

However, studies have also shown that individuals who are more concerned with their health (71, 72,73, 74, 75, 78, 79) and who are older (71,72) are more likely to eat fish. Increased focus on fish as a healthy food, and on increasing convenience while reducing negative perceptions around price and safety, may therefore increase fish consumption.

Worldfish have been working to look at the use of fish products such as dried fish and fish chutney as food supplements in order to improve the nutritional content of diets (80) particularly in regions of the world where stunting and malnutrition is an issue. However, the impacts of this are not yet well understood.

Conclusion

Food and nutrition security is complex and involves many interacting factors. The issues and opportunities vary globally with, for example, a double burden of malnutrition meaning that some people still have too few calories, but at the other end of the scale people have access to high-fat, high-sugar, high-salt, energy-dense, and micronutrient-poor food many which can lead to obesity (22). Whilst obesity started out as a HIC problem it is now increasing in LMICs, particularly in urban areas. For example nearly half of the children under 5 who were overweight or obese in 2016 lived in Asia (22).

The role of aquatic food in nutrition and food security is further complicated by the wide range of different species that come from two very different production systems. Capture fisheries are very different to most of other sources of food, there are very few food sources in which wild food is caught and none which exist at the scale and volume of capture fisheries. In this case the ways in which we can influence the amount of food that we can catch are either through protecting fisheries resources by more sustainable fisheries management, which may include limiting fishing, or through creating marine protected areas. Aquaculture on the other hand shares many common features with other food production systems (both livestock and crops) including the need for sustainable feeds, the risks that come with disease outbreaks and issues around food safety. Aquaculture also uses similar technologies to other food production systems in order to improve production. Including genetic selection for disease resistance, genetic modification for improved growth and functional feeds. However, aquaculture has some unique benefits and challenges. Benefits include the fact that it is a relatively young production system and there is potential to increase yield in the same way that terrestrial systems have in the past. There are also more species which are farmed than for terrestrial animals. This can be both positive, because of the potential for diversification of species and to expand production by exploiting new species, and negative because each new species needs new research into efficient production, closure of the production cycle etc.. Challenges include the difficulties in observing and handling animals which live in water and the proximity to and interaction, including pathogen exchange, with wild fish which is closer than in many terrestrial animal systems.

When we consider the role of aquatic food in food security beyond production we have seen that there are currently significant contributions to livelihoods, particularly in rural areas and in LMICs. In addition, aquatic food can provide both protein and essential micronutrients and thus can contribute to a diverse and healthy diet, helping to tackle lifestyle diseases.

We know that the world is facing a number of challenges when it comes to feeding the population, these include population growth, increasing demands for animal protein and climate change all of which mean that our food supply will become more precarious. This is a complex problem which needs to be tackled from a number of different angles. The sustainable nutrition approach requires us to reduce our demands by wasting less and eating more sustainably. This means eating less red meat (particularly in developed, Western country's diets) and more fruit and vegetables, but can also mean eating more fish instead of meat which brings both environmental and health benefits. The sustainable intensification approach advocates producing more whilst protecting biodiversity and ecosystem services, this approach cannot be applied to fisheries, but there is certainly potential to grow aquaculture and to increase yield using many of the same techniques, such as genetic improvement and precision agriculture, which are used in terrestrial systems. It is essential then that aquatic foods take their place at the table when it comes to discussing nutrition and food security. We must recognise the significant benefits that aquatic food can bring, acknowledge and deal with the limitations across the supply chain and expend more effort exploiting the gains that could be made by considering aquatic foods alongside terrestrial systems.

References

1. FAO (1996). World Food Summit: Rome Declaration on World Food Security and World Food Summit Plan of Action. Rome, Italy. Available at: http://www.fao.org/docrep/003/w3613e/w3613e00.htm (accessed on 21/12/2018)
2. FAO (2017) - Fish and seafood snapshot. Available at: http://www.fao.org/3/a-BT091e.pdf (accessed on 21/12/2018)

3. Food and Agriculture Organization of the United States (FAO) (2016). – The State of World Fisheries and Aquaculture 2016. Contributing to food security and nutrition for all. Rome. 200 pp. Available at: http://www.fao.org/3/a-i5555e.pdf (accessed on 21/12/2018).
4. World Bank (2013). – FISH TO 2030: Prospects for Fisheries and Aquaculture. Worldbank report 83177-GLB. Available at: http://documents.worldbank.org/curated/en/458631468152376668/pdf/831770WP0P11260ES003000Fish0to02030.pdf (accessed on 21/12/2018).
5. Washington State Department of Health https://www.doh.wa.gov/CommunityandEnvironment/Food/Fish/HealthBenefits (accessed on 21/12/2018)
6. British Nutrition Foundation https://www.nutrition.org.uk/nutritionscience/nutrients-food-and-ingredients/653-fishreview.html%20 (accessed on 21/12/2018)
7. Hosomi, R., Yoshida, M & Fukunaga, K. (2012) – Seafood Consumption and Components for health. *Global Journal of Health Science* **4**(3) 72-86 doi: 10.5539/gjhs.v4n3p72.
8. FAO (2011)- The State of the Worlds land and water resources for food and agriculture. *Managing systems at risk*. ISBN 978-1-84971-326-9
9. Béné, C., Barange M., Subasinghe R., Pinstrup-Andersen, P. Merino, G., Hemre, G.I., Williams, M. (2015) - Feeding 9 billion by 2050 – Putting fish back on the menu. *Food Security*, **7**(2), 261–274. doi: 10.1007/s12571-015-0427-z.
10. Grafton, R. Q., Daugbjerg, C. and Qureshi, M. E. (2015) - Towards food security by 2050. *Food Security*, **7**(2), pp. 179–183. doi: 10.1007/s12571-015-0445-x.
11. O'Leary, B.C., Smart, J.C.R., Neale, F.C., Hawkins, J.P., Newman, S., Milman, A.C., Roberts, C.M. (2011) - Fisheries mismanagement. *Mar. Pollut. Bull*. **62**, 2642-2648 https://doi.org/10.1016/j.marpolbul.2011.09.032
12. Fernandes, P.G. and Cook, R.M. (2013) - Reversal of fish stock decline in the northeast Atlantic. *Current Biology*, **23**(15), 1432-1437. doi:10.1016/j.cub.2013.06.016
13. Bostock J., McAndrew B., Richards R., Jauncey K., Telfer T., Lorenzen K., Little D., Ross L., Handisyde N., Gatward I., Corner R. (2010)- Aquaculture: global status and trends. *Phil. Trans. R. Soc. B* **365**, 2897–2912 doi:10.1098/rstb.2010.0170
14. Hixon, S., Parrish, C.C., Anderson, D.M. (2014)- Full substitution of fish oil with camelina (Camelina sativa) oil, with partial substitution of fish meal with camelina meal, in diets for farmed Atlantic salmon (Salmo salar) and its effect on tissue lipids and sensory quality. *Food Chemistry* **157**, 51-61 doi: 10.1016/j.foodchem.2014.02.026

15. Bell, J.G., McEvoy, J., Tocher, D.R., McGhee F., Campbell, P.J., Sargent, J.R. (2001) - Replacement of fish oil with rapeseed oil in diets of Atlantic salmon (Salmo salar) affects tissue lipid compositions and hepatocyte fatty acid metabolism. *J. Nutrition* **131**, 1535-1543 doi: 10.1093/jn/131.5.1535
16. Bell J.G., Pratoomyot J., Strachan F., Henderson R.J., Fontanillas R., Hebard A.B., Guy D.R., Hunter D. & Tocher D.R. (2010) - Growth, flesh adiposity and fatty acid composition of Atlantic salmon (Salmo salar) families with contrasting flesh adiposity: effects of replacement of dietary fish oil with vegetable oils. *Aquaculture,* **306**, 225-232. http://dx.doi.org/10.1016/j.aquaculture.2010.05.021
17. Ryckebosch, E., Bruneel, C., Termote-Verhalle, R., Goiris, K., Muylaert, K., Foubert, I. (2014) - Nutritional evaluation of microalgae oils rich in omega-3 long chain polyunsaturated fatty acids as an alternative for fish oil. *Food Chemistry* **160**, 393-400 doi: 10.1016/j.foodchem.2014.03.087
18. Hemaiswarya, S., Raja, R., Kumar, R.R., Ganesan, V., Anbazhagan, C. (2011) - Microalgae: a sustainable feed source for aquaculture. *World Journal of Microbiology and Biotechnology* **27** (8), 1737-1746 https://doi.org/10.1007/s11274-010-0632-z
19. Crumlish M., (2015) - Aquaculture and Food Security pp71-83 *in Marine Oils from Seas to Pharmaceuticals* , Nova Science Publishers ISBN 978-1-63463-747-3
20. Glencross, B.D., Booth, M., Allan, G.L. (2007) - A feed is only as good as its ingredients – a review of ingredient evaluation strategies for aquaculture feeds. *Aquaculture Nutrition* **13**, 17-34 https://doi.org/10.1111/j.1365-2095.2007.00450.x
21. Leung, T. L. F. Bates, A. E. (2013) - More rapid and severe disease outbreaks for aquaculture at the tropics: implications for food security. *Journal of Applied Ecology* **50**(1), 215-222 https://doi.org/10.1111/1365-2644.12017
22. Nadimpalli, M., Delarocque-Astagneau, E., Love, D.C., Price, L.B., Huynh, B.T., Collard, J.M., Lay, K.S., Borand, L., Ndir, A., Walsh, T.R., Guillemot, D. (2018) - Combating Global Antibiotic Resistance: Emerging One Health Concerns in Lower- and Middle-Income Countries Clinical Infectious Diseases **66**(6), 963-969 doi.org/10.1093/cid/cix879
23. WHO factsheet 2018 http://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight accessed 22/8/2018
24. Monfort, M.C. (2015) - The role of women in the seafood industry. GLOBEFISH Research Programme Vol. 119, Rome, FAO. 67 pp. http://www.fao.org/3/a-bc014e.pdf

25. Williams, M.J. (1998) - Women do fish, report. www.mekonginfo.org/assets/midocs/0003434-biota-women-do-fish.pdf accessed 18/1/2019
26. Samina Shirajee, A., SAlehin, M.M. and Ahmed, N. (2010)– The changing face of women for small-scale aquaculture development in rural Bangladesh. Aquaculture Asia Magazine **XV**(2) 9-16 https://enaca.org/?id=392&title=aquaculture-asia-magazine-april-june-2010 accessed 18/1/2019
27. Worldfish report https://www.worldfishcenter.org/pages/why-gender-equality-matters-fisheries-aquaculture/ accessed 18/2/2019
28. Training of Trainers programme (2009) –Strengthening capacity of small holder ASEAN aquaculture farmers for competitive and sustainable aquaculture. library.enaca.org/inland/reports/asean-tot-manual-2010.pdf accessed 18/1/2019
29. Badjeck, M-C, Allison E.H., Halls A.S, Dulvy N.K, (2010) - Impacts of climate variability and change on fishery-based livelihoods. *Marine Policy*, **34**(3), 375-383 https://doi.org/10.1016/j.marpol.2009.08.007
30. Cheung, W.W.L., Lam, V.W.Y., Sarmiento, J.L., Kearney K., Watson R., Pauly D. (2009) - Projecting global marine biodiversity impacts under climate change scenario. *Fish and Fisheries*; doi: 10.1111/j.1467-2979.2008.00315.x.
31. Ripple W.J., Smith P., Haberl H., Montzka S.A., McAlpine C. & Boucher D.H. (2014). – Ruminants, climate change and climate policy. *Nature Climate Change*, **4** (1), 2-5. doi: 10.1038/nclimate2081
32. Fry J.P., Mailloux N.A., Love D.C., Milli M.C. & Cao L. (2018). – Feed conversion efficiency in aquaculture: do we measure it correctly? *Environ. Res. Lett.*, **13**, 024017. Doi: 10.1088/1748-9326/aaa273
33. Fry J.P., Mailloux N.A., Love D.C., Milli M.C. & Cao L. (2018). – Corrigendum: Feed conversion efficiency in aquaculture: do we measure it correctly? *Environ. Res. Lett.*, **13**, 079502. Doi: 10.1088/1748-9326/
34. Shepon A., Eshel G., Noor E. and Milo R. (2016) - Energy and protein feed-to-food conversion efficiencies in the US and potential food security gains from dietary changes. *Environ. Res. Lett*. **11** 105002 Environ. Res. Lett. doi:10.1088/1748-9326/11/10/105002
35. De Silva, S.S. and Soto, D. (2009) - Climate change and aquaculture: potential impacts, adaptation and mitigation. In K. Cochrane, C. De Young, D. Soto and T. Bahri (eds). *Climate change implications for fisheries and aquaculture: overview of current scientific*

knowledge. FAO Fisheries and Aquaculture Technical Paper. No. 530. Rome, FAO. pp. 151-212. http://www.fao.org/docrep/012/i0994e/i0994e00.htm accessed 18/1/2019

36. Holmlund, C. M. and Hammer, M. (1999) - Ecosystem services generated by fish population. *Ecological Economics*, **29**(2), pp. 253–268. doi: 10.1016/S0921-8009(99)00015-4.
37. Adámek, Z. and Maršálek, B. (2013) - Bioturbation of sediments by benthic macroinvertebrates and fish and its implication for pond ecosystems: A review. *Aquaculture International*, **21**(1), pp. 1–17. doi: 10.1007/s10499-012-9527-3.
38. Bilby, R. E., Fransen, B. R. and Bisson, P. A. (1996) - Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: evidence from stable isotopes. *Canadian Journal of Fisheries and Aquatic Sciences*, **53**(1), pp. 164–173. doi: 10.1139/f95-159.
39. Larkin, G. A. and Slaney, P. A. (1997)- Implications of Trends in Marine-derived Nutrient Influx to South Coastal British Columbia Salmonid Production. *Fisheries*, **22**(11), pp. 16–24. https://doi.org/10.1577/1548-8446(1997)022<0016:IOTIMN>2.0.CO;2
40. Pope, K. L., Pegg, M.A., Cole, N.W., Siddons, S.F., Fedele, A.D., Harmon, B.S., Ruskamp, R.L., Turner, D.R., Uerling, C.C. (2016) - Fishing for ecosystem services. *Journal of Environmental Management*. **183**, 408–417. doi: 10.1016/j.jenvman.2016.04.024.
41. Tsutsumi, H., Kikuchi, T., Tanaka, M., Higashi, T., Imasaka, K., Miyazaki, M. (1991)- Benthic faunal succession in a cove organically polluted by fish farming. *Marine Pollution Bulletin,* **23**(C), pp. 233–238. doi: 10.1016/0025-326X(91)90680-Q.
42. Vezzulli, L. Marrale, D., Moreno, M. and Fabiano, M. (2003) - Sediment organic matter and meiofauna community response to long-term fish-farm impact in the Ligurian Sea (Western Mediterranean). *Chemistry and Ecology*, **19**(6), pp. 431–440. doi: 10.1080/02757540310001609361.
43. Xie, J. Hu, L., Tang, J., Wu, X., Li, N., Yuan, Y., Yang, H., Zhang, J., Luo, S., and Chen, X (2011) - Ecological mechanisms underlying the sustainability of the agricultural heritage rice-fish coculture system. *Proceedings of the National Academy of Sciences*, **108**(50), E1381–E1387. doi: 10.1073/pnas.1111043108.
44. Chopin, T., Buschmann, A., Halling, C., Troell, M., Kautsky, N., Neori, A., Kraemer, G., Zertuche, J., Yarish, C., Neefus, C. (2001) - Integrating seaweeds into marine aquaculture systems: A key toward sustainability. *Journal of Phycology*. **37**. 975 - 986. doi: 10.1046/j.1529-8817.2001.01137.x.
45. Troell, M., Joyce, A., Chopin, T., Neori, A., Buschmann, A.H., Fang, J.G., (2009) - Ecological engineering in aquaculture - Potential for integrated multi-trophic aquaculture (IMTA) in

marine offshore systems. *Aquaculture*. **297,** 1–9. doi: 10.1016/j.aquaculture.2009.09.010.

46. Mazzola, A. and Sara, G. (2001) - The effect of fish farming organic waste on food availability for bivalve molluscs (aeta Gulf, Central Tyrrhenian, MED) : stable carbon isotopic analysis. *Aquaculture,* **192**, 361–379. doi: 10.1016/S0044-8486(00)00463-4.
47. Turcios, A. E. and Papenbrock, J. (2014) - Sustainable treatment of aquaculture effluents-What can we learn from the past for the future? *Sustainability (Switzerland)*, **6**(2), 836–856. doi: 10.3390/su6020836.
48. Shpigel, M. (2005) - Bivalves as Biofilters and Valuable Byproducts in Land-Based Aquaculture Systems. in Dame, R. F. and Olenin, S. (eds) *The Comparative Roles of Suspension-Feeders in Ecosystems*. Dordrecht: Springer Netherlands, pp. 183–197.
49. Nobre, A. M., Robertson-Andersson, D., Neori, A., Sankar, K. (2010) - Ecological-economic assessment of aquaculture options: Comparison between abalone monoculture and integrated multi-trophic aquaculture of abalone and seaweeds. *Aquaculture*. **306**, 116–126. doi: 10.1016/j.aquaculture.2010.06.002.
50. Valencia, E., Adjei, M. and Martin, J. (2001) - Aquaculture effluent as a water and nutrient source for hay production in the seasonally dry tropics. *Communications in Soil Science and Plant Analysis*, **32**(7–8), 1293–1301. doi: 10.1081/CSS-100104113.
51. Palada, M. C., Cole, W. M. and Crossman, S. M. A. (1999) - Influence of Effluents from Intensive Aquaculture and Sludge on Growth and Yield of Bell Peppers. *Sustainable Agriculture*, **14**, 85–102. doi: 10.1300/J064v14n04.
52. Al-Jaloud, A. A., Hussain, G. , Alsadon, A.A., Siddiqui, A.Q. and Al-Najada, A. (1993) - Use of aquaculture effluent as a supplemental source of nitrogen fertilizer to wheat crop. *Arid Soil Research and Rehabilitation*. **7**(3), 233–241. doi: 10.1080/15324989309381353.
53. FAOstat (2015) http://www.fao.org/3/a-i4691e.pdf accessed 31/8/2018
54. Belton, B., Thilsted, S.H. (2014) - Fisheries in transition: Food and nutrition security implications for the global South. *Global Food Security* **3**(1) 59-66 https://doi.org/10.1016/j.gfs.2013.10.001
55. Thilsted, S.H., Thorne-Lyman, A., Webb. P., RoseBogard, J., Subasinghe, R., Phillips, M.J., Allison, E.H. (2016) - Sustaining healthy diets: The role of capture fisheries and aquaculture for improving nutrition in the post-2015 era. *Food Policy* **61** 126-131 http://dx.doi.org/10.1016/j.foodpol.2016.02.005
56. Tacon, A.G.J., Metian, M. (2013) -Fish Matters: Importance of Aquatic Foods in Human Nutrition and Global Food Supply. *Reviews in fisheries science*. **21(**1), 22-38, DOI: 10.1080/10641262.2012.753405

57. Garcia, S.M. and Rosenberg, A.A. (2010) - Food security and marine capture fisheries: characteristics, trends, drivers and future perspectives. *Phil Trans Roy Soc B* **365**(1554) 2869–2880 https://doi.org/10.1098/rstb.2010.0171
58. Strom, M., Paranjpye, R.N., Nilsson, W.B., Turner, J.W. and Yanagida, G.K. (2013) - Pathogen Update: Vibrio species. 97-113. In *Advances in microbial food safety volume 1*. Ed J Sofos Woodhead Publishing Limited.
59. Morris, J.G. (2003) - Cholera and other types of vibriosis: A story of human pandemics and oysters on the half shelf. *Clinical Infectious Diseases* **37**(2): 272-280 doi: 10.1086/375600
60. Baker-Austin, C., Oliver, J.D., Alam, M., Ali, A., Waldor, M.K., Qadri, F. and Martinez-Urtaza, J. (2018) - Vibrio spp. infections. *Nature Reviews Disease* primers 4, number 8. doi: 10.1038/s41572-018-0005-8
61. Koopmans M. (2008) - Progress in understanding norovirus epidemiology. *Current opinion in infectious diseases* **21**(5): 544-552 doi: 10.1097/QCO.0b013e3283108965
62. Campos, C. J. A. and Lees, D. N. (2014) - Environmental transmission of human noroviruses in shellfish waters. *Applied and Envir. Microbiology* **80**(12): 3522-3561. 10.1128/AEM.04188-13
63. Ushijima, H., Fujimoto, T. Müller, W.E.G., Hayakawa, S. (2014). Norovirus and Foodborne Disease: A Review. *Food Safety*. **2**. 37-54. doi: 10.14252/foodsafetyfscj.2014027.
64. Buchanan, R.L., Gorris, L.G.M., Hayman, M.M., Jackson, T.C., Whitinge, R.C. (2017) - A review of Listeria monocytogenes: An update on outbreaks, virulence, dose-response, ecology, and risk assessments. *Food Control* **75** 1-13 https://doi.org/10.1016/j.foodcont.2016.12.016
65. Chen J., and Nightingale K., (2013) - Pathogen update: Listeria monocytogenes 47-60. In *Advances in microbial food safety volume 1*. Edited by John Sofos. Woodhead Publishing Limited.
66. Jami M., Ghanbari M., Zunabovic M., Domig K.J., Kneifel W. (2014) - Listeria monocytogenes in aquatic food products – a review. *Comprehensive reviews in food science and food safety*. **13**(5) 789-813 https://doi.org/10.1111/1541-4337.12092
67. Froehlich, H.E., Gentry, R.R., Rust, M.B., Grimm, D., Halpern, B.S. (2017) - Public Perceptions of Aquaculture: Evaluating Spatiotemporal Patterns of Sentiment around the World. *PLoS ONE* **12**(1): e0169281. https://doi.org/10.1371/journal.pone.0169281
68. Bacher, K. (2015) - Perceptions and misconceptions of aquaculture: a global overview. *GLOBEFISH Research Programme*, Vol. 120, Rome, FAO http://www.fao.org/3/a-bc015e.pdf accessed 18/1/2019
69. Leek, S., Maddock, S. and Foxall, G. (2000) - Situational determinants of fish consumption. *British Food Journal*, **102**(1), 18–39. doi: 10.1108/00070700010310614.

70. Prell, H., Berg, C. and Jonsson, L. (2002) - Why don't adolescents eat fish? Factors influencing fish consumption in school. *Scandinavian Journal of Nutrition/Naringsforskning*, **46**(4), 184–191. doi: 10.1080/110264802762225318.

71. Verbeke, W. and Vackier, I. (2005) - Individual determinants of fish consumption: Application of the theory of planned behaviour. *Appetite*, **44**(1), 67–82. doi: 10.1016/j.appet.2004.08.006.

72. Trondsen, T., Scholderer, J., Lund, E., Eggen, A.E. (2003) - Perceived barriers to consumption of fish among Norwegian women. *Appetite*, **41**(3), 301–314. doi: 10.1016/S0195-6663(03)00108-9.

73. Olsen, S. O. (2004) - Antecedents of Seafood Consumption Behavior. *Journal of Aquatic Food Product Technology*, **13**(3), 79–91. doi: 10.1300/J030v13n03.

74. Brunsø, K., Verbeke, W., Olsen, S.O., Jeppesen, L.F. (2009) - Motives, barriers and quality evaluation in fish consumption situations: Exploring and comparing heavy and light users in Spain and Belgium'. *British Food Journal*, **111**(7), 699–716. doi: 10.1108/00070700910972387.

75. European Commission (2017) EU consumer habits regarding fishery and aquaculture products. Available at: www.eumofa.eu. accessed 31/8/2018.

76. Olsen, S. O., Scholderer, J., Brunsø, K., Verbeke, W (2007) - Exploring the relationship between convenience and fish consumption: A cross-cultural study. *Appetite*, **49**(1), 84–91. doi: 10.1016/j.appet.2006.12.002.

77. Mouritsen, O.G. and Styrbaek, K. (2018) -Cephalopod Gastronomy—A Promise for the Future. *Front. Commun.* https://doi.org/10.3389/fcomm.2018.00038

78. Juhl, H. J. and Poulsen, C. S. (2000)- Antecendents and effects of consumer involvement in fish as a product group. *Appetite*, **34(**3), 261–267. doi: 10.1006/appe.2000.0314.

79. Pieniak, Z., Verbeke, W., Scholderer , J., Brunsø, K.,Olsen, S.O. (2008) - Impact of consumers' health beliefs, health involvement and risk perception on fish consumption: A study in five European countries. *British Food Journal*, **110**(9), 898–915. doi: 10.1108/00070700810900602.

80. https://www.worldfishcenter.org/content/bangladesh-fish-chutney-recipe-solve-malnutrition-and-stunting accessed 31/8/2018