Linking agroecosystems producing farmed seafood with food security and health status to better address the nutritional challenges in Bangladesh

Abstract

Objective: Aquaculture is one of the fastest growing food production sectors in many Low Income and Food Deficit Countries (LIFDCs) with aquatic eco-zones. Yet its specific impact on nutrition and livelihood in local communities, where commercial and/or export-orientated aquaculture activities are developed, is largely unknown.

Design: This narrative and argumentative review aims to provide an overview of our current understanding of connections between aquaculture agro-ecosystems, local and national fish production, fish consumption patterns and nutrition and health outcomes.

Results: The agro-ecological dynamic in a coastal-estuarine zone, where the aquatic environment ranges from fully saline to freshwater, is complex, with seasonal and annual fluctuations in freshwater supply creating a variable salinity gradient which impacts on aquatic food production, and on food production more generally. The local communities living in these dynamic aquatic eco-zones are vulnerable to poverty, poor diet and health, whilst these ecosystems produce highly valuable and nutritious aquatic foods. Policies addressing the specific challenges of risk management of these communities is limited by the sectoral separation of aquatic food production – the fisheries and aquaculture sector, the broader food sector - and public health institutions.

Conclusion: Here we provide an argument for the integration of these factors to improve aquaculture value chains to better address the nutritional challenges in Bangladesh.

Keywords: agrosystems, aquaculture, LIFDC, food security, nutritional status, Bangladesh

Introduction – the role of aquaculture production systems in food security and human health

Aquaculture represents a fast growing food production sector in many Low Income and Food Deficit Countries (LIFDCs). In certain southeast and south Asian countries, like Bangladesh and Vietnam, the contribution of aquaculture to gross domestic product (GDP) is now over 2.5%, indicating that aquaculture is an important contributor to the countries' economy performance [1,2]. In the ten leading aquaculture countries in the Global South, farmed fish is increasingly available and accessible to poor urban and rural consumers in these markets [3].Yet the specific impacts of commercial aquaculture on food security, nutritional status and livelihood in local communities where it is located are poorly understood. On a global scale, the importance of aquaculture in enhancing the reliance of the world food supply has been questioned [4], and aquatic products have often remain neglected in food security analyses, despite its important role in world trade, human nutrition and support for livelihoods [5]. Indeed, whilst its role in securing livelihoods of poor households through employment in fishery and aquaculture supply and value chains is well established [6,7], the contributions of fish to food security, but also to nutritional status as a consequence of increased fish consumption, has been largely ignored in international debate. A recent review found that fish consumption was absent from strategies for reduction of micronutrient deficiency [8]. The disconnect between nutrition and seafood continues - indeed, the recent Global Nutrition Report makes no mention of the role of seafood in human diets because the Sustainable Development Goal most linked to aquaculture (SDG14, Life under the water) has no 'nutritionally relevant' indicators [9]. The real importance of fish consumption occurs in LIFDC; in 2010, of the 30 countries where fish contribute more than one third of the total animal protein intake, 22 were LIFDCs [10].

The evidence that emergent commercial aquaculture in LIFDCs has had important effects on local livelihoods and the environment has not been matched with detailed studies of its direct impacts on peoples' nutritional status, health and well-being [11]. A review of the literature on the relationship between aquaculture and poverty, food security, food production sustainability and gender equality found that, although there were a number of studies identifying income benefits, these analyses were less relevant for consumption in poor households [12]. Recently, the impacts of deteriorating marine fish catches on human health was modelled using the decline in intake of critical nutrients as indicators [13]. However, this global model was limited to marine fisheries and cannot make predictions for highly complex agro-ecological food systems characterising many LIFDCs. This study reviews our current

understanding of connections between aquaculture agro-ecosystems, fish production and consumption patterns in relation to nutrition and health outcomes, and discusses how integration of such factors may improve impact on food security, nutritional status and well-being, in Bangladesh.

Methods

Here we present a narrative review discussing evidence from interdisciplinary research fields including agroecosystems producing farmed seafood, food security and nutritional status. The review was conducted by an interdisciplinary group of authors. This review contains argumentative elements to explore how integration of such interdisciplinary factors could improve future impact on food security, nutritional status and well-being in Bangladesh.

Aquaculture production systems in Bangladesh

The ecosystems

The geographical characterisation of Southeast and South Asian countries is diverse, and aquaculture systems vary according to position - coastal or inland - and salinity gradient. In Bangladesh, the agro-ecological dynamics of aquaculture are complex in a coastal zone ranging from saline to freshwater aquatic environments, with seasonal and annual fluctuations in freshwater availability. The variable salinity gradients impact on aquaculture specifically, and on food production more generally [14]. Local adaptation and risk management in terms of strategic cropping of rice and vegetables versus production of shrimp and finfish are common as people respond to changes to water regimes. For example, export–orientated shrimp aquaculture, that has developed to dominate land-use in estuarine flood plains of many coastal LIFDCs, causes a range of impacts on local livelihoods. Pressures from a growing human population and the quest for economic benefit are now transforming marginal agro-ecosystems in LIFDCs, including coastal wetlands that are vulnerable to climate change and salinization [14]. The livelihoods of the rural poor are increasingly dependent on alternative land use strategies and aquaculture has often become a key component of food production [7], mostly alongside continued exploitation of unstocked aquatic animals [15]. The impacts of such changes are not limited to the producers, or even producer

communities themselves, as the poor are often intrinsic members of associated value chains and/ or as consumers throughout a much broader geography [16]. Key drivers to this dynamic are both the declining harvests of wild aquatic stocks and growth in demand driven by increasing, often urban, populations consuming more nutritious diets [17,18].

Aquaculture in food systems

After three decades of sustained growth, aquaculture now accounts for 53% of reported fish production [19], although pathways to consumption are less well understood. Farmed seafood now contributes to nearly 50% of total direct human consumption globally, but in some countries such as Bangladesh, its rise has been comparatively more important [20], given the context of fish being the most accessible and also preferred choice of animal sourced foods. On the global level, significant diversity in consumption levels of seafood (total and as % of animal-sourced protein) and spatial importance of aquaculture production (as the contribution to gross domestic product) suggest some important mismatches. Indeed, although high consumption levels are met by high production in in Southeast and South Asia, demand for fish as a source of animal protein in West and Central Africa cannot be met by current levels of indigenous aquaculture, despite years of sector growth [5]. Moreover, on the local level, access of vulnerable individuals to farmed seafood within the community or even within the household is influenced by a range of social and individual factors.

Role of aquaculture in the sustainable development of Bangladesh

The challenge to meeting the sustainable agenda of the UN in Bangladesh is immense and linked to its poverty and estuarine environment [21]. The positive economic growth of Bangladesh in recent years has been based largely on the rise of 'non-traditional exports', garments and the mainly farmed shrimp and prawn [22]. Aquaculture, mainly practiced in southern coastal areas, has grown to constitute around 60% of primary product exports, but has given rise to considerable criticism on environmental and social grounds [23]. The well-publicised negative consequences of shrimp culture [23] include impacts related to general salinization of the environment, which can reduce terrestrial diversity, and possibly impoverish local diets and negatively impact on community social welfare. On the other hand, however, it has also been found that aquatic diversity can be enhanced in such environments, and a wide range of naturally-recruiting 'co-products' of indigenous fish are harvested from the commercial ponds, destined for local consumption [14]. This appears to be particularly the case in extensive and semi-intensive

production systems characteristic of Bangladesh. We recently showed that small homestead ponds, raising both fish and vegetables, can contribute to a wider food supply, reduced poverty and enhanced food security, which would be especially critical for food-vulnerable rural households compared with peri-urban households, and which would be most important during the lower income months [24]. But the role of aquaculture located in different agroecosystems also needs to be assessed. Recent research found that the hydrological forces in Southwest Bangladesh are actively displacing a zone of transition between fresh and brackish water southward despite a countervailing trend of rising sea level. Thus, the agro- and aquaculture systems in such a highly dynamic environments are continually being adapted to both environmental and market factors [14].

Role of aquaculture in economic development and poverty reduction

Previous attempts to explore the associations between commercial aquaculture and poverty as a measure of its impact on economic development have mainly focussed on the direct and indirect contribution to poverty reduction for the poor entering into paid employment [25]. A study in the Philippines used Gini decomposition of income due to employment generation and showed that commercial shrimp culture reduced economic inequality in several coastal villages [26]. The contribution of aquaculture to poverty reduction has been related to both the direct and indirect contributions of increased income and consumption in Bangladesh [11,16]. There is a lack of empirical studies that show the impact of indirect consumption through increased availability of fish in the markets and increased accessibility of fish due to reduced price. Household income and expenditure survey data can be used to demonstrate if aquaculture is "pro-poor", where pro-poor aquaculture growth is defined as the "quantity of fish eaten by poor consumers increases by a greater amount than the quantity of fish eaten by non-poor consumers" [11]. Better information on the specific nutritional, health and well-being outcomes that are related to changes in the 'foodscape' around aquaculture production, especially for the most vulnerable groups such as adolescent females, are required to inform future policy support for further transformation of rural landscapes and the livelihoods they support.

Fish consumption and health outcomes in Bangladesh

Fish consumption in Bangladesh

Fish consumption across Bangladesh is not well documented – the most recent and representative data evaluate fish consumption patterns based on 24-hour recall data collected as part of the

Bangladesh Integrated Household Survey (BIHS) between October 2011 and March 2012 [27]. The average intake of fish (fresh fish and dried fish converted to fresh weight) was 67 and 75 grams per person per day for adult women and men, respectively, across all wealth groups. Fish consumption amongst the poorest quintile wealth group was about half this amount, 35 versus 78 grams per person per day for adult women. Less than half of the children under the age of 2 years had been fed animal-source food the previous day, and the portions sizes were very small, despite the mothers' awareness of the importance of feeding their children fish or other animal-source food [27]. However, the period covered in this study includes the peak season for fish supply in Bangladesh, and therefore average fish consumption figures across the year may be lower.

In food system analysis, it is important that the relationship between fish intake and fish supply can be evaluated. Food balance sheets from the United Nations' Food and Agriculture Organization Statistical Database (FAOSTAT), providing data on quantities of food available to consumers based on production and trade between 2009-2011 [28], have shown the unique importance of fish availability in the food system in Bangladesh amongst 5 fish producing Asian LIFDCs countries, including China and India (Figure 1). While the total available food supply in terms of dietary energy per capita is relatively comparable between the 5 countries (A), in Bangladesh, the supply of animal-based foods (meat, egg, milk and seafoods) contributes significantly less to total available dietary energy (B, D), fat (E) and protein (F) compared with availability in the other countries. On the contrary, the contribution of animal-based food from fish and seafood (C, G-I), and particularly freshwater fish (J-L), to dietary energy, fat and protein intakes is amongst the highest across the countries investigated. The food system in Bangladesh is characterized by a generally sufficient – not alarming – per capita total supply of dietary energy and protein, but very low supply of fat and a very low total supply of animal-source food [28]. However, despite the very low availability of fat, a previous study also deriving data from FAOSTAT showed that Bangladesh did appear to have a relatively good supply of total n-3 PUFA compared to other LIFDCs [29]. In this context, the contribution from fish and seafood is significant, and therefore, any changes to the supply and accessibility of aquatic foods will impact on the dietary quality of the population.

Fish consumption and health outcomes

Consumption of seafood may be able to alleviate the often multiple micronutrient deficiencies that are highly prevalent in the Bangladeshi population [21]. In this country, fish is the most important nutrient-rich food in the diet across population groups and ages, being a valuable

contributor to the reference nutrient intakes for a range of micronutrients, in addition to being an important source of protein and energy [30]. Indeed, promotion of the consumption of mola carplet, a small indigenous fish high in vitamin A, appears a cost-effective approach increase vitamin A intake, reduce the prevalence of inadequate vitamin A intake and generally reduce the burden of micronutrient malnutrition in Bangladesh [31]. Furthermore, dietary LC n-3 PUFA from fish have well documented positive impacts on the brain development of infants and children [32]. In relation to this, it has been observed that birth weight and head circumference of babies at birth have been positively associated with seafood consumption in Norwegian mothers [33].

Between 1991 and 2010, fish consumption has increased by 30%, and, with fish being the major protein source of a typical Bangladeshi diet consisting of polished rice, fish and vegetables, this has also led to significant increases in average energy, protein and fat intake from fish, both nationally and for all poverty groups [30]. However, whilst protein levels vary little, micronutrient levels do vary across fish species [34] and, more generally, the nutritional quality of farmed species is known to be decreased for some species due to global changes in fish feed composition [35-37]. This may have contributed, for example, to a significant decrease in iron and calcium intakes from fish in the general Bangladeshi population, despite an increase in fish consumption in the past 20 years [30]. The impact of seafood consumption in populations in LIFDCs is, however, blurred by the multiple health impacts of poor living conditions, such as a high infectious disease burden and generally poor nutritional quality of diets. Whilst there exists a positive correlation between fish and seafood supply and male height (with low height being an indicator of stunted growth in early life) in Europe, this correlation is negative for fish and seafood supply, especially freshwater fish supply, and male height in populations in Asia and Africa [38]. This may indicate a higher dependency on fish, particularly freshwater fish, in LIFDC populations compared to high-income countries.

It was recently reported that obesity, hyperglycaemia and raised blood pressure are important but unrecognised health threats in rural Bangladesh, indicating a need for new treatment strategies to preventing the growing burden of non-communicable diseases (NCDs) like diabetes and cardiovascular disease [39]. Indeed, low-income and middle-income countries like Bangladesh suffer the largest burden of morbidity and mortality due to NCDs [40]. Therefore, the inverse relationship between fish consumption and risk for coronary heart disease and stroke, as established in two recent meta-analyses in mostly Western populations [41,42], may become

increasingly relevant for the treatment and prevention of NCDs in LIFDCs such as Bangladesh.

Linking aquaculture agro-ecosystems with nutritional health outcomes to address the nutritional challenges in Bangladesh

Current nutritional and health challenges in Bangladesh

Bangladesh has one of the worst rates of malnutrition in the world – 36% of children under 5 are stunted, 33% of children under 5 are underweight and millions of people have micronutrient deficiencies [43]. Deficiencies in folate, zinc, vitamins A, B_6, B_{12}, C, E and riboflavin, mainly resulting from inadequate dietary intake of animal source foods, fruit and vegetables, are highly prevalent and may occur concurrently among pregnant women [44], albeit that the prevalence of iron deficiency is low, contrary to the widely held assumption, possibly as a result of high levels of iron in groundwater [45]. Multiple nutrient deficiencies are generally observed in populations with low socioeconomic status [46]. However, despite many challenges, Bangladesh has made improvements in the health outcomes of its children. Stunting in children under 5 has declined by nearly 1.4 % a year between 1997 and 2011, with the key drivers for this change being multidimensional: improvements in parental education, household assets, sanitation and heath care use, for example [47]. The WHO currently recommends iron and folic acid supplementation for pregnant women to prevent maternal anaemia, puerperal sepsis, low birth weight, and preterm birth, and this is also implemented in Bangladesh. However, iron-folic acid supplementation often starts too late in the pregnancy to have impact on maternal nutrition and birth outcome. This supports the case for public health interventions to include nutritional interventions in addition to supplement regimes to improve nutritional status and thereby maternal and child health outcomes. Indeed, it has been argued, for example, that zinc bio-fortification of rice has the potential to markedly improve zinc adequacy in diets in rural Bangladeshi populations [48]. Moreover, a recent systematic review concluded that dietary interventions and fortified food products were effective in increasing birth weight and reducing the incidence of low birth weight [49].

Increasingly we acknowledge that improvements in nutritional and health status on the individual, local and national level depend on a complex network of interacting factors that drive food production, food availability and dietary intake, and by linking these we may be able to better address the nutritional challenges in Bangladesh (Figure 2). Currently, policies addressing the specific challenges of risk management of these communities are characterised by the sectoral

separation of aquatic food production – the fisheries and aquaculture sector and the broader food sector - and public health institutions. Indeed, a succession of national policies have acknowledged the importance of food security at the national, household and individual level in the agro-based economy of Bangladesh, stressing the importance of increasing production and processing in the fisheries sub-sectors in an environment-friendly and sustainable manner, without addressing the impact on human diet and health outcomes [50-52]. Likewise, several national policies have set out strategies to improve the overall health, nutritional status, survival, growth, development and productivity of the population by preventing and alleviating micronutrient deficiencies, as well as ensuring quality and equitable healthcare for all citizens of Bangladesh by gradually achieving Universal Health Coverage, without addressing the impact of food production and distribution [53,54]. It is therefore difficult to assess how government policies on fish production impact on nutritional status human health, and vice versa, in Bangladesh.

Cultural factors affecting dietary intake, nutritional status and health in Bangladesh

One main problem with linking factors like dietary intake, nutritional status and health (Figure 2) is that for the measurement of dietary intake, data are commonly collected at the household level. However, in Bangladesh, differential access to food within households, with a tendency of dis-favouring females, is a cultural norm [7]. This means that dietary intake data may not necessarily align with nutritional status and health outcomes, especially in adolescent girls and young women. Adolescent girls represent a vulnerable group in Bangladesh. They have lower access to food but at the same time have higher nutritional requirements: for their own growth, as well as – in case of early marriage and motherhood - for the inter-uterus growth of the child, and for breastfeeding the infant – the critical '1000 days' [55]. Indeed, in Bangladesh, for example, almost 30% of adolescent girls are married before 14 years of age, with almost 60% married by the age of 16; the country has been ranked third in the prevalence of child marriage globally [56]. Greater female autonomy, which has been found to confer improved food and resource allocation within the family, has been strongly linked to female employment, especially outside the home [57]. Given the large increase in female employment related to export-led processing of farmed seafood, a value chain approach, in which employment within entities involved in the forward and backward trade linkages with production are assessed, is critical to understanding the interactions of nutrition and health outcomes.

Aquaculture production factors affecting nutritional and health status

It is currently unclear how exactly aquaculture production systems contribute to the population

and individual health, and how this relationship may be affected by food availability, dietary intakes and nutritional status on the local level (Figure 2). Global Value Chain (GVC) frameworks containing information on product, process, functional and interchain categories [58-60] acknowledge the growing link between intensifying aquaculture in LIFDCs to global markets [9]. However typically, such frameworks do not include value add-ons such as food security, nutritional status, health and well-being outcomes. Despite the apparent lack of systematic approaches and methodologies to assess impact on health and related quality of life [61], these are necessary to create a better understanding of impacts of access to aquatic foods on health and nutrition – resulting in the development of more integrated policy models to evaluate the effectiveness and cost-effectiveness of interventions on lifetime health outcomes [62], as well as informing policy decisions for practice in the development of farmed aquatic systems. Analysis of global patterns in seafood reliance, malnutrition level and economic prospects have already indicated that island nations in Southeast Asia have the best opportunities for the farming of marine species [63]. However, frameworks and metrics for the linkages between terrestrial agroecosystems and nutritional and health outcomes, including Bangladesh, highlight the need for more research on in-country specific settings including dietary diversity and the role of women in food production and distribution [64]. Furthermore, the very specific complexity of the dynamic coastal ecosystems with fluctuating salinity, and the dependency of local communities on aquatic food resources, remain to be conceptualized for the aquaculture/fisheries and health sector. Monitoring of the consequences of natural and man-made developments in these extremely dynamic agro-ecological systems will be necessary to provide information on the nutritional, health and well-being outcomes of local residents that are related to the value chain and changes in the 'foodscape' relating to aquaculture production.

Conclusion

Establishing the relationships between aquaculture agro-ecosystems producing nutritious foods, and its impact on the health and nutritional status of local communities living in such dynamic aquatic eco-zones, is currently challenging for various reasons. These include the complex ecological dynamics of seasonal and annual fluctuations in freshwater supply and variable salinity gradients in aquatic environments, which is especially relevant for a country like Bangladesh. It also includes difficulties with the accurate assessment of fish consumption, and how this relates to individual health outcomes, as this relationship can be confounded by many factors, including the health impacts of poor living conditions, such as the high prevalence of infectious diseases generally poor nutritional quality of diets. Access to and availability of fish is another factor to

consider, including geographical locations, access to global and local markets, and household income. Populations in LIFDCs are more dependent on fish, particularly freshwater fish, to ensure sufficient intake of energy, protein and fat, and fish consumption may affect also growth and micronutrient status. Therefore, it is important that Global Value Chain (GVC) frameworks, which are currently mostly focussing on product, process, functional and interchain categories, include factors such as food security, nutritional status, health and well-being outcomes in the future. This will provide a better understanding of impacts of access to aquatic foods on health, resulting in a more integrated and relevant policies and practices when further developing farmed aquatic systems.

References

[1] Little DC, Newton RW and Beveridge MCM (2016) Aquaculture: a rapidly growing and significant source of sustainable food? Status, transitions and potential. *Proceedings of the Nutrition Society* 75, 274–286.

[2] Cai JN, Huang H and Leung PS (2019) Understanding and measuring the contribution of aquaculture and fisheries to gross domestic product (GDP). FAO Fisheries and Aquaculture Technical Paper No. 606. Rome, FAO. http://www.fao.org/3/CA3200EN/ca3200en.pdf

[3] Belton B, Bush S and Little DC (2018) Not just for the wealthy: Transforming farmed fish consumption in the Global South. *Global Food Security* 16, 85-92.

[4] Troell M, Naylor RL, Metian M, *et al*. (2014) Does aquaculture add resilience to the global food system? *PNAS* 111, 13257-13263.

[5] Little DC, Newton RW, Beveridge MCM (2016) Aquaculture: a rapidly growing and significant source of sustainable food? Status, transitions and potential. *Proc Nutr Soc* 75, 274-286.

[6] Allison EH (2011) Aquaculture, fisheries, poverty and food security. Penang, Malaysia. The WorldFish Center, 60pp. WorldFish Center Working Paper. p2011-2065.

[7] Béne C, Arthur R, Norbury H, *et al.* (2016) Contribution of fisheries and aquaculture to food security and poverty reduction: assessing the current evidence. *World Development* 79, 177-196.

[8] Allison EH, Delaporte A, Hellebrandt de Silva D (2013) Integrating fisheries management and aquaculture development with food security and livelihoods for the poor. Report submitted to the Rockefeller Foundation. Norwich: School of International Development, University of East Anglia.

[9] Little DC, Young JA, Zhang W, *et al*. (2018) Sustainable intensification of aquaculture value chains between Asia and Europe: a framework for understanding impacts and challenges. *Aquaculture* 493, 338-354.

[10] Kawarazuka N, Béné C (2010) Linking small-scale fisheries and aquaculture to household nutritional security: an overview. *Food Security* 2, 343–357.

[11] Toufique KA, Belton B (2014) Is Aquaculture Pro-Poor? Empirical Evidence of Impacts on Fish Consumption in Bangladesh. *World Development* 64, 609–620.

[12] Burns TE, Wade J, Stephen C, *et al.* (2014) A scoping analysis of peer-reviewed literature about linkages between aquaculture and determinants of human health. *EcoHealth* 11, 227–240.

[13] Golden C, Allison EH, Cheung WWL, et al. (2016) Fall in fish catch threatens human health. Nature, 534, 317-320.

[14] Faruque G, Hayat Sarwer R, Karim M, *et al.* (2016) The evolution of aquatic agricultural systems in Southwest Bangladesh in response to salinity and other drivers of change. *International Journal of Agricultural Sustainability* 15:185-207.

[15] Amilhat E, Lorenzen K, Morales EJ, *et al.* (2010) Fisheries production in Southeast Asian farmer managed aquatic systems (FMAS) II. Management impacts on diversity and productivity of aquatic resources. *Aquaculture* 298, 57-63.

[16] Mialhe F, Morales E, Dubuisson-Quellier S, *et al.* (2018) Global standardization and local complexity. A case study of an aquaculture system in Pampanga delta, Philippines. *Aquaculture* 493, 365-375.

[17] Bunting X, Stuart W, Little DC (2015) Urban aquaculture for resilient food systems. P312-335. In: de Zeeuw, Henk and Drechsel, Pay (Eds) Cities and Agriculture Developing Resilient Urban Food Systems. Earthscan Food and Agriculture . Taylor & Francis. ISBN 978-1-13-886058-2.

[18] HLPE (2014). Sustainable fisheries and aquaculture for food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. FAO Rome.

[19] FAO (2016) The State of World Fisheries and Aquaculture 2016. Contributing to Food security and nutrition for all. FAO Rome. 190 pp.

[20] Belton B, Thilsted SH (2014) Fisheries in transition: Food and nutrition security implications for the global South. *Global Food Security* 3, 59-66.

[21] Sack DA (2008) Achieving the Millennium Development Goals for Health and Nutrition in Bangladesh: Key Issues and Interventions—An Introduction. *J Health Population Nutr* 26, 253-260.

[22] Lewis, D.J. (2011) Bangladesh: Politics, Economy and Civil Society. Cambridge University Press 248pp.

[23] Stonich SC, Bailey C (2000) Resisting the blue revolution: contending coalitions surrounding industrial shrimp farming. *Hum Organ* 59, 23–36.

[24] Karim M, Little D (2018) The impacts of integrated homestead pond-dyke systems in relation to production, consumption and seasonality in central north Bangladesh. *Aquaculture research* 49:313–334.

[25] Belton B, Little DC (2011) Immanent and Interventionist Inland Asian Aquaculture Development and its Outcomes. *Development Policy Review* 29, 459-484.

[26] Xavier Irz, James R. Stevenson, Arnold Tanoy, *et al.* (2007) The Equity and Poverty Impacts of Aquaculture: Insights from the Philippines. *Development Policy Review* 25, 495-516.

[27] Bogard JR, Marks GC, Mamun A, *et al.* (2017) Non-farmed fish contribute to greater micronutrient intakes than farmed fish: results from an intra-household survey in rural Bangladesh. *Public Health Nutrition* 20, 702-711.

[28] AFSPAN (2014) Final workshop report: Aquaculture for Food Security, Poverty Alleviation and Nutrition (AFSPAN). Available from http://www.afspan.eu/publications/reports/afspan-final-project-workshop-report.pdf

[29] Michaelsen KF, Dewey KG, Perez-Exposito AB, *et al.* (2011) Food sources and intake of n-6 and n-3 fatty acids in low income countries with emphasis on infants, young children (6-24 months), and pregnant and lactating women. *Matern Child Nutr* 7:S124-140.

[30] Bogard JR, Farook S, Marks GC, *et al.* (2017) Higher fish but lower micronutrient intakes: Temporal changes in fish consumption from capture fisheries and aquaculture in Bangladesh. *PLoS One*, 6, 12(4):e0175098.

[31] Fiedler JL, Lividini K, Drummond E, *et al.* (2016) Strengthening the contribution of aquaculture to food and nutrition security: The potential of vitamin A-rich, small fish in Bangladesh. *Aquaculture* 452, 291-303.

[32] Lauritzen L, Hansen HS, Jorgensen MH, *et al.* (2001) The essentiality of long chain n-3 fatty acids in relation to development and function of the brain and retina. *Prog Lipid Res* 40, 1-94.

[33] Brantsæter AL, Birgisdottir BE, Meltzer HM, *et al.* (2012) Maternal seafood consumption and infant birth weight, length and head circumference in the Norwegian Mother and Child Cohort Study. *British Journal of Nutrition* 107, 436–444.

[34] Roos N, Wahab MA, Chamnan C, *et al.* (2007) The role of fish in food-based strategies to combat vitamin A and mineral deficiencies in developing countries. *J Nutr* 137, 1106-1109.

[35] Bogard JR, Thilsted SH, Marks GC, *et al.* (2015) Nutrient composition of important fish species in Bangladesh and potential contribution to recommended nutrient intakes. *J Food Comp Anal*, 42, 120-33.

[36] de Roos B, Sneddon AA, Sprague M, *et al.* (2017) The potential impact of compositional changes in farmed fish on its health-giving properties: is it time to reconsider current dietary recommendations? *Public Health Nutr*, 24, 1-8.

[37] Roos N, Wahab MA, Hossain MA, *et al.* (2007) Linking human nutrition and fisheries: incorporating micronutrient-dense, small indigenous fish species in carp polyculture production in Bangladesh. *Food Nutr Bulletin* 28, S280-293.

[38] Grasgruber P, Sebera M, Hrazdira E, *et al.* (2016) Major correlates of male height: A study of

105 countries. *Econ Hum Biol* 21, 172-195.

[39] Fottrell E, Ahmed N, Kumer Shaha S *et al.* (2018) Distribution of diabetes, hypertension and non-communicable disease risk factors among adults in rural Bangladesh: a cross-sectional survey. *BMJ Glob Health* 3:e000787.

[40] World Health Organisation. 2015. Non-communicable diseases fact sheet. Secondary non-communicable diseases fact sheet. Available from: http://www.who.int/mediacentre/factsheets/fs355/en/

[41] Zheng, J, Huang, T, Yu, Y *et al.* (2012) Fish consumption and CHD mortality: an updated meta-analysis of seventeen cohort studies. Public Health Nutr 15, 725–737.

[42] Xun, P, Qin, B, Song, Y *et al.* (2012) Fish consumption and risk of stroke and its subtypes: accumulative evidence from a meta-analysis of prospective cohort studies. Eur J Clin Nutr 66, 1199–1207.

[43] icddrb, UNICEF, GAIN, IPHN. National micronutrient status survey 2011-2012. Dhaka, icddr b (2013).

[44] Black RE, Allen LH, Bhutta ZA, *et al.* (2008) Maternal and child undernutrition: global and regional exposures and health consequences. *Lancet* 371, 243-60.

[45] Rahman S, Ahmed T, Rahman AS, *et al.* (2016) Determinants of iron status and Hb in the Bangladesh population: the role of groundwater iron. Public Health Nutr. 19, 1862-74.

[46] Arsenault JE, Yakes EA, Islam MM, *et al.* (2013) Very Low Adequacy of Micronutrient Intakes by Young Children and Women in Rural Bangladesh Is Primarily Explained by Low Food Intake and Limited Diversity. *Journal of Nutrition* 143:197–203.

[47] WHO (2005) Nutrition in Adolescences – Issues and Challenges for the Health Sector. WHO discussion papers on adolescence Nutrition in adolescence: issues and challenges for the health sector: issues in adolescent health and development. ISBN 92 4 159366 0.

[48] Arsenault JE, Yakes EA, Hossain MB, *et al.* (2010) The current high prevalence of dietary zinc inadequacy among children and women in rural Bangladesh could be substantially ameliorated by zinc biofortification of rice. *J Nutr* 140, 1683-90.

[49] Gresham E, Bisquera A, Byles JE, *et al.* (2016) Effects of dietary interventions on pregnancy outcomes: a systematic review and meta- analysis. *Maternal and Child Nutrition* 12, 5-23.

[50] National Food Policy 2006. Ministry of Food and Disaster Management. Bangladesh. [https://extranet.who.int/nutrition/gina/sites/default/files/BGD%202006%20National%20food%20policy.pdf].

[51] Bangladesh Country Investment Plan. A road map towards investment in agriculture, food security and nutrition. Government of the People's Republic of Bangladesh. 2011.

https://extranet.who.int/nutrition/gina/sites/default/files/BGD%202011%20Bangladesh%20Country%20Investment%20Plan.pdf

[52] Bangladesh Delta Plan 2100. Draft. Government of the People's Republic of Bangladesh, Bangladesh Planning Commission, General Economics Division. 2017. http://www.lged.gov.bd/UploadedDocument/UnitPublication/17/624/Bangladesh%20Delta%20Plan%202100%20Draft%20Report.pdf.

[53] National Strategy on the Prevention and Control of Micronutrient Deficiencies Bangladesh (2015-2024). Institute of Public Health Nutrition. Directorate General of Health Services, Ministry of Health and Family Welfare, Government of the People's Republic of Bangladesh. 2015. https://extranet.who.int/nutrition/gina/sites/default/files/BGD%202015%20National%20Strategy%20on%20prevention%20and%20control%20of%20micronutrient%20deficiency.pdf.

[54] Health, Nutrition and Population Strategic Investment Plan 2016-2021. Planning wing, Ministry of Health and Family Welfare. Government of the People's Republic of Bangladesh. 2016. https://extranet.who.int/nutrition/gina/sites/default/files/BGD%202016%20Health%20Nutrition%20and%20Population%20Strategic%20Investment%20Plan.pdf.

[55] WHO (2013) Essential Nutrition Actions. Improving maternal, newborn, infant and young child health and nutrition. https://www.who.int/nutrition/publications/infantfeeding/essential_nutrition_actions/en/

[56] Kamal SMM (2010) Pakistan Journal of Women's Studies: Alam-e-Niswan, 17, 37-57, ISSN: 1024-1256.

[57] Anderson S, Eswaran M (2009) What determines female autonomy? Evidence from Bangladesh. *Journal of Development Economics* 90, 179–191.

[58] Blazek J (2015) Towards a typology of repositioning strategies of GVC/GPN suppliers, the case of functional upgrading and downgrading. *Journal of Economic Geography* 16(4):1-21

[59] Kelling (2012) Knowledge is Power: A Market Orientation Approach to Global Value Analysis of Aquaculture: Two Cases Linking Southeast Asia and the EU. PhD Thesis. University of Stirling.

[60] Gereffi G, Fernandez-Stark K (2011) Global Value Chain Analysis: A Primer. Centre on Globalisation, Governance & competitiveness (CGGC), Duke University. 40pp. http://www.cggc.duke.edu/pdfs/2011-05-31_GVC_analysis_a_primer.pdf

[61] Gyles CL, Lenoir-Wijnkoop I, Carlberg JG, *et al.* (2012) Health economics and nutrition: a review of published evidence. *Nutrition Reviews*, 70: 693–708.

509 [62] Lewsey JD, Lawson DK, Ford I, *et al.* (2014) A cardiovascular disease policy model that
510 predicts life expectancy taking into account socioeconomic deprivation. *Heart* 101, 201-208.
511 [63] Liu OR, Molina R, Wilson M, *et al.* (2018) Global opportunities for mariculture development
512 to promote human nutrition. *PeerJ* 6, e4733.
513 [64] Yosef S, Jones AD, Chakraborty B, *et al.* (2015) Agricultural and Nutrition in Bangladesh:
514 Mapping evidence to Pathways. *Food and Nutrition Bulletin* 36, 387-404.

515 **Figure legends**

516

517 **Figure 1**. Quantities of foods and nutrients available to consumers based on production and trade.
518 Data obtained from food balance sheets from the United Nations' Food and Agriculture
519 Organization Statistical Database (FAOSTAT) 2009-2011 [28]. Panels A, B, D, E, F: availability
520 of animal-based foods and nutrients; panels C, G, H, I: availability of animal-based food and
521 nutrients from fish and seafood; panels J, K, L: availability of animal-based food and nutrients
522 from freshwater fish.

523

524 **Figure 2**. Schematic interpretation of links between aquaculture production systems, food
525 availability, dietary intakes, nutritional status and individual health.

Figure 1

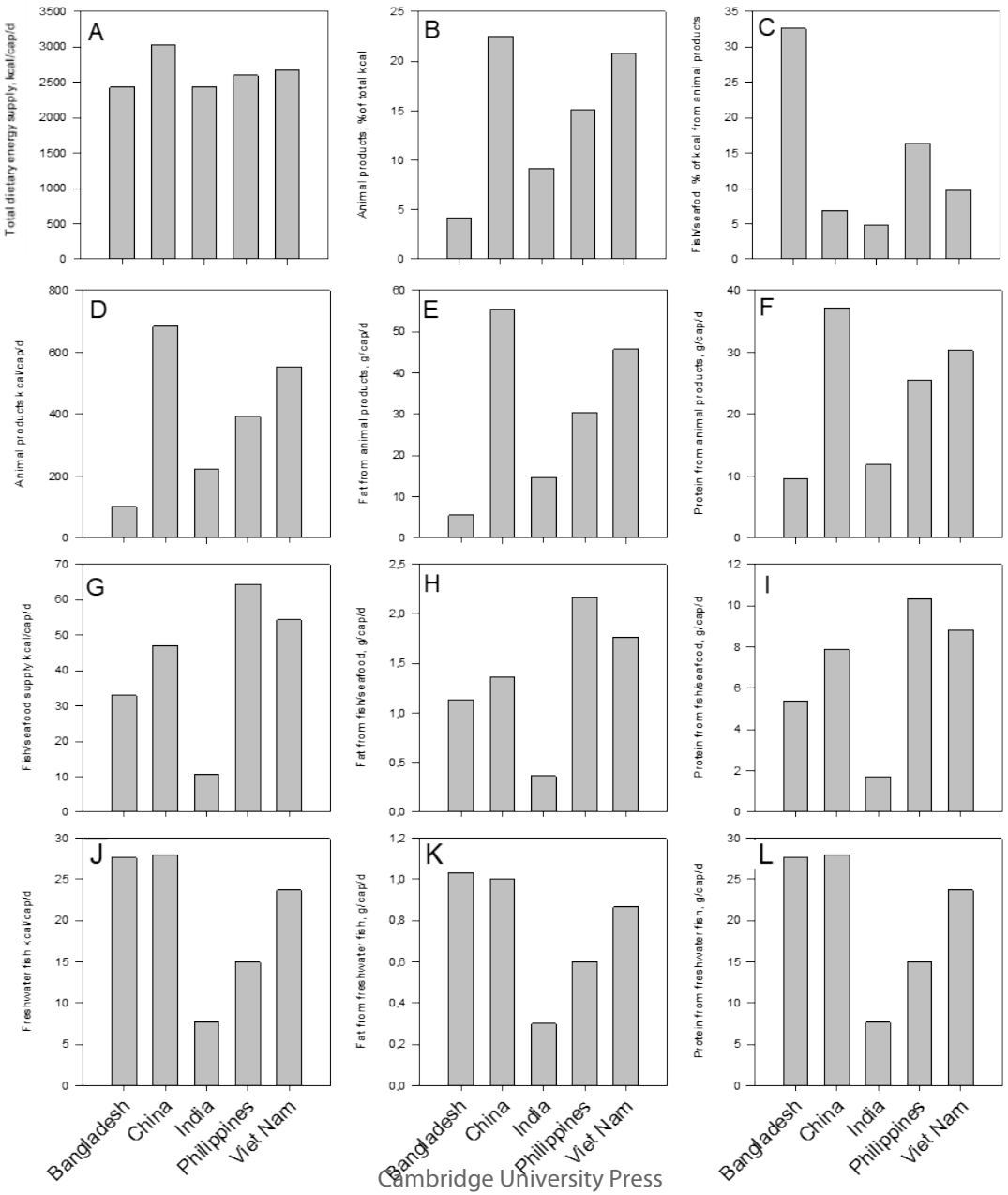
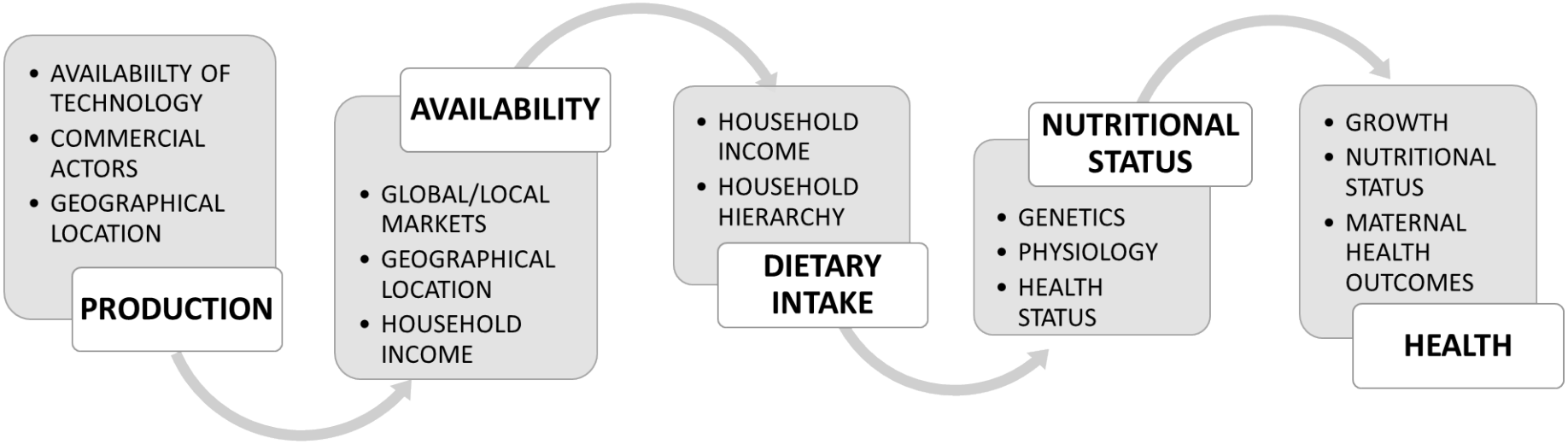


Figure 2


• AVAILABIILTY OF TECHNOLOGY
• COMMERCIAL ACTORS
• GEOGRAPHICAL LOCATION
PRODUCTION
AVAILABILITY
• GLOBAL/LOCAL MARKETS
• GEOGRAPHICAL LOCATION
• HOUSEHOLD INCOME
• HOUSEHOLD INCOME
• HOUSEHOLD HIERARCHY
DIETARY INTAKE
NUTRITIONAL STATUS
• GENETICS
• PHYSIOLOGY
• HEALTH STATUS
• GROWTH
• NUTRITIONAL STATUS
• MATERNAL HEALTH OUTCOMES
HEALTH