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# The contribution of fish to nutrition and food security: informing the evidence base for agricultural policy in Bangladesh

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# Abstract

## Background

Malnutrition and poor quality diets are the leading drivers of the global burden of disease, affecting one in three people globally. Pregnant and lactating women, and infants of complementary feeding age are particularly vulnerable. The fisheries sector is well-placed to contribute to improving malnutrition and food insecurity, particularly in the context of Bangladesh, yet is often overlooked.

## Aims

The broad aim of this research is to understand how fish contributes to nutrition and food security, how this is changing according to broader trends in aquatic food systems, and how fisheries might be better utilised to reduce malnutrition. The focus is on nutrients known to be significant causes of malnutrition in Bangladesh: iron, zinc, calcium, vitamin A and vitamin B12. This broad aim is addressed through five specific research questions (RQs):

RQ1: What is the nutritional value of commonly consumed fish in Bangladesh?

RQ2: How could local nutrient-rich foods including fish, be utilised to improve nutritional quality of diets?

RQ3: What does fish currently contribute to diets in terms of nutrient intakes?

RQ4: How has the transition in aquatic food systems (declining availability of species from capture fisheries, and rapid growth in aquaculture) impacted nutrient intakes?

RQ5: How could nutritional quality of fish production systems be measured and used in decision making?

## Methods

This research draws on a variety of different methods to address individual RQs. The nutritional value of fish (RQ1) was determined by primary analysis of 55 fish species for composition of protein, fat and selected minerals, vitamins and essential fatty acids using standard analytical methods. Raw, edible parts of individual samples were homogenised then analysed in duplicate. The use of fish to improve diets among vulnerable groups (RQ2) was informed by a review of local food-based approaches including food processing methods, and nutrient composition of local ingredients, followed by laboratory based trial

production of recipes. The role of fish in current diets (RQ3) was informed through secondary analysis of intra-household food consumption data (based on 24-hour recall) of a two-stage stratified nationally representative survey of rural Bangladesh (n=5,503 households, 24,198 individuals). Linear regression was used to estimate mean fish consumption, controlling for age, sex, wealth group and geographic region (adjusted by sampling weights). The impact of a shift in fish consumption away from non-farmed towards farmed fish, on nutritional quality of diets (RQ4) was estimated through secondary analysis of food consumption data from nationally representative household income and expenditure surveys in 1991 (n=5,745), 2000 (n=7,440) and 2010 (n=12,240). Linear regression, adjusting for sampling weights and clustering in survey design, was used to estimate mean fish consumption among different population groups. Measurement of nutritional quality of fish production systems (RQ5) was informed through a review of existing indicators and comparison of their strengths and limitations applied to common homestead pond aquaculture systems in Bangladesh.

**Main findings**

The nutrient composition of fish varies widely across species, particularly for micronutrients. Iron content ranged from 0.34-19 mg/100 g raw, edible parts; zinc from 0.6-4.7 mg/100 g; calcium from 8.6-1900 mg/100 g; vitamin A from 0-2503 µg RAE/100 g; and vitamin B12 from 0.50-14 µg/100 g. Non-farmed fish contribute between 6-35% of daily recommended nutrient intakes for iron, zinc, calcium, vitamin A and vitamin B12, *more* than farmed fish, despite being consumed in smaller portions (P<0.0001); and are therefore better placed to contribute to improved micronutrient intakes among vulnerable groups. Adaption of traditional recipes to include these nutrient-rich fish, combined with other local nutrient-rich foods and using simple processing methods, shows great potential to improve nutrient intakes. For example, consumption of the proposed complementary food product could meet >60% of the daily vitamin A and zinc needs for a child. However, such nutrient-rich species are not the current focus of production policies. Aquaculture systems are designed to maximise yields without considering nutritional quality. Growth in aquaculture has allowed fish consumption to increase nationally by 30% between 1991 and 2010, despite a 33% decline in availability of non-farmed fish. However, increased reliance on farmed fish of lower nutritional quality, has led to an overall decrease in micronutrient intakes from fish: iron significantly decreased by 15% (P<0.01), calcium by 14% (P<0.01), and zinc, vitamin A and

vitamin B12 remained unchanged despite an increase in total quantity of fish being consumed.

**Conclusions**

Fisheries make an important but undervalued contribution to nutrition and food security in Bangladesh. However, the current policy focus on maximising quantity of production from this sector, without considering quality, has had negative impacts on nutritional quality of diets. A nutrition-sensitive approach to fisheries policy is necessary. Such an approach would enable the fisheries sector to make a more substantial contribution to the reduction of malnutrition and food insecurity in Bangladesh. These findings are of great relevance to other countries experiencing this transition in aquatic food systems and malnutrition.

## Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, and any other original research work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my research higher degree candidature and does not include a substantial part of work that has been submitted to qualify for the award of any other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

I acknowledge that an electronic copy of my thesis must be lodged with the University Library and, subject to the policy and procedures of The University of Queensland, the thesis be made available for research and study in accordance with the Copyright Act 1968 unless a period of embargo has been approved by the Dean of the Graduate School.

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## Publications during candidature

### Peer-reviewed papers

1. **Bogard, J. R.**, Thilsted, S. H., Marks, G. C., Wahab, M. A., Hossain, M. A. R., Jakobsen, J., & Stangoulis, J. (2015). Nutrient composition of important fish species in Bangladesh and potential contribution to recommended nutrient intakes. *Journal of Food Composition and Analysis, 42*, 120-133.
2. **Bogard, J. R.**, Hother, A.-L., Saha, M., Bose, S., Kabir, H., Marks, G. C., & Thilsted, S. H. (2015). Inclusion of small indigenous fish improves nutritional quality during the first 1000 days. *Food and Nutrition Bulletin, 36*(3), 276-289.
3. **Bogard, J. R.**, Marks, G. C., Mamun, A., & Thilsted, S. H. (2016). Non-farmed fish contribute to greater micronutrient intakes than farmed fish: results from an intra-household survey in rural Bangladesh. *Public Health Nutrition, 20*(4), 702-711.
4. **Bogard, J. R.**, Farook, S., Marks, G. C., Waid, J., Belton, B., Ali, M., Toufique, K. A., Mamun, A., & Thilsted, S. H. (2017). Higher fish but lower micronutrient intakes: temporal changes in fish consumption from capture fisheries and aquaculture in Bangladesh. *PLOS ONE, 12*(4).
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8. Herrero, M., Thornton, P. K., Power, B., **Bogard, J. R.**, Remans, R., Fritz, S., Gerber, J. S., Nelson, G., See, L., Waha, K., Watson, R. A., West, P. C., Samberg, L. H., van de Steeg, J., Stephenson, E., van Wijk, M. T., & Havlík, P. (2017). Farming and the geography of nutrient production for human use: a transdisciplinary analysis. The Lancet Planetary Health, *1*, 33-42.

9. Thilsted, S. H., Thorne-Lyman, A., Webb, P., **Bogard, J. R.**, 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.

**Conference abstracts**

1. Oral presentation: *Reorienting food systems towards improving nutrition outcomes: measuring nutritional quality of agricultural production.* IUNS 21st International Congress of Nutrition. International Union of Nutritional Sciences, Buenos Aires, Argentina, 15-20th October, 2017.
2. Oral presentation: *The need for nutrition-sensitive policies in aquaculture and fisheries: a case study from Bangladesh.* Food Governance: The Role of Law, Regulation, and Policy in Meeting 21st Century Challenges to the Food Supply Conference. The University of Sydney, Sydney, 1-3rd November, 2016.
3. Conference abstract: *The contribution of fish food systems to nutrient intakes in Bangladesh.* World Public Health Nutrition Association Conference. Cape Town, 30th August – 1st September, 2016.
4. Poster presentation: *Quality over quantity: applying a nutrition lens to capture fisheries and aquaculture.* ANH (Agriculture Nutrition and Health) Academy Week Conference on Agri-Health Research. Addis Ababa, 20-24th June, 2016.
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6. Oral presentation: *Quality over quantity: applying a nutrition lens to fisheries and aquaculture in Bangladesh*. Nutrition Higher Degree Research Student Conference. Queensland University of Technology, Brisbane, 9th December, 2015.
7. Oral presentation: *The contribution of fish to nutrition and food security in Bangladesh*. School of Population Health Research Higher Degree Student Conference. UQCCR, Brisbane, 5th November, 2014.
8. Poster presentation: *Small indigenous fish and other local, nutrient-rich ingredients in food products for the first 1,000 days of life*. UQ Maternal and Child Health Research Networking Symposium, Brisbane, 4th November, 2014.

**Publications included in this thesis**

1. **Bogard, J. R.**, Thilsted, S. H., Marks, G. C., Wahab, M. A., Hossain, M. A. R., Jakobsen, J., & Stangoulis, J. (2015). Nutrient composition of important fish species in Bangladesh and potential contribution to recommended nutrient intakes. *Journal of Food Composition and Analysis, 42*, 120-133. doi:http://dx.doi.org/10.1016/j.jfca.2015.03.002 – **incorporated as Chapter 4**.

| Contributor | Statement of contribution |
|---|---|
| Jessica Bogard (Candidate) | Formulated the analysis (60%)<br>Analysis and interpretation of results (70%)<br>Wrote the paper (90%) |
| Shakuntala Thilsted (Associate Advisor) | Formulated the analysis (20%)<br>Analysis and interpretation of results (5%)<br>Wrote and edited paper (5%) |
| Geoffrey Marks (Principal Advisor) | Analysis and interpretation of results (5%)<br>Wrote and edited paper (5%) |
| Abdul Wahab | Formulated the analysis (5%)<br>Analysis and interpretation of results (5%) |
| Mostafa Hossain | Formulated the analysis (5%)<br>Analysis and interpretation of results (5%) |
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| James Stangoulis | Formulated the analysis (5%)<br>Analysis and interpretation of results (5%) |

2. **Bogard, J. R**., Hother, A.-L., Saha, M., Bose, S., Kabir, H., Marks, G. C., & Thilsted, S. H. (2015). Inclusion of small indigenous fish improves nutritional quality during the first 1000 days. *Food and Nutrition Bulletin, 36*(3), 276-289. doi:10.1177/0379572115598885 – **incorporated as Chapter 5**.

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| Geoffrey Marks (Principal Advisor) | Formulated the analysis (10%)<br>Interpretation of results (10%)<br>Wrote and edited paper (10%) |
| Jillian Waid | Prepared datasets for analysis (25%)<br>Advised on statistical analysis (50%) |
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| Abdullah Mamun (Associate Advisor) | Advised on statistical analysis (50%) |
| Shakuntala Thilsted (Associate Advisor) | Formulated the analysis (10%)<br>Wrote and edited paper (10%) |

## Contributions by others to the thesis

This thesis contains four published manuscripts and one submitted manuscript. I am the primary author of each of these manuscripts, and the contribution of other authors to each published manuscript is described in the previous section. I have full responsibility for the writing of all other chapters of this thesis with guidance and editing from my advisory team, particularly Geoff Marks and Shakuntala Thilsted.

## Statement of parts of the thesis submitted to qualify for the award of another degree

None.

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## Keywords

Nutrition, malnutrition, food security, fisheries, capture fisheries, aquaculture, Bangladesh, nutrition-sensitive, food systems, micronutrients

## Australian and New Zealand Standard Research Classifications (ANZSRC)

ANZSRC: 111799, Public Health and Health Services not elsewhere classified, (40%)

ANZSRC: 111706, Epidemiology, (30)

ANZSRC: 111104, Public Nutrition Intervention, (30%)

## Fields of Research (FoR) Classification

FoR code: 1117 Public Health and Health Services, (70%)

FoR code: 1111 Nutrition and Dietetics, (30%)

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[1] Figures within the main text of the thesis are labelled Figure T1, Figure T2 etc. as distinct from figures within published or submitted manuscripts which are labelled Figure 1, Figure 2 etc. to be consistent with published or submitted numbering and format for copyright purposes.

## List of Tables[2]

**Chapter 2:**



**Chapter 4 – Manuscript 1:**



**Chapter 5 – Manuscript 2:**



[2] Tables within the main text of the thesis are labelled Table T1, Table T2 etc. as distinct from tables within published or submitted manuscripts which are labelled Table 1, Table 2 etc. to be consistent with published or submitted numbering and format for copyright purposes.

**Chapter 6 – Manuscript 3:**



**Chapter 7 – Manuscript 4:**

**Chapter 8 – Manuscript 5:**

## List of Abbreviations

| | |
|---|---|
| AME | Adult male equivalent |
| ASF | Animal-source food |
| BBS | Bangladesh Bureau of Statistics |
| BDHS | Bangladesh Demographic and Health Survey |
| BIHS | Bangladesh Integrated Household Survey |
| BIRDEM | Bangladesh Institute of Research and Rehabilitation for Diabetes, Endocrine and Metabolic Disorders |
| BMI | Body mass index |
| CF | Complementary food |
| CFS | Committee on World Food Security |
| CGIAR | Consultative Group on International Agricultural Research |
| DFID | Department for International Development (United Kingdom) |
| DHA | Docosahexaenoic acid |
| FAO | Food and Agriculture Organization of the United Nations |
| FRSS | Fisheries Resources Survey System |
| FSANZ | Food Standards Australia and New Zealand |
| FSNSP | Food Security and Nutritional Surveillance Project |
| GDP | Gross domestic product |
| HFIAS | Household Food Insecurity Access Scale |
| HIES | Household Income and Expenditure Survey |
| HKI | Helen Keller International |
| HLPE | High Level Panel of Experts on Food Security and Nutrition |
| icddr,b | International Centre for Diarrhoeal Disease Research, Bangladesh |
| ICF | Inner City Fund |
| ICN | International Conference on Nutrition |
| ICN2 | Second International Conference on Nutrition |
| IFAD | International Fund for Agricultural Development |
| IFPRI | International Food Policy Research Institute |
| JPGSPH | James P. Grant School of Public Health |
| MCDA | Multi-criteria decision analysis |
| MDG | Millennium Development Goals |
| NIPORT | National Institute of Population Research and Training |

| | |
|---|---|
| NNS | National Nutrition Services |
| NFD | Nutritional functional diversity |
| NPNL | Non-pregnant non-lactating |
| PLW | Pregnant and lactating women |
| RAE | Retinol activity equivalents |
| REACH | Renewed Efforts Against Child Hunger and undernutrition |
| RNI | Recommended nutrient intake |
| RQ | Research question |
| SDG | Sustainable Development Goals |
| SIS | Small indigenous fish species |
| SUN | Scaling Up Nutrition |
| UN | United Nations |
| UNICEF | United Nations Children's Fund |
| UN SCN | United Nations Special Committee on Nutrition |
| WFP | World Food Programme |
| WHO | World Health Organization of the United Nations |

## Glossary

| | |
|---|---|
| Aquatic agricultural system | Food production system incorporating water based activities such as fish production, and often done in conjunction with land-based food production systems. |
| Baor | Oxbow (or U-shaped) lake created from rivers which change course and then become cut-off from the main water supply. |
| Beel | A static waterbody that forms in depressions in a floodplain area from surface and internal drainage channels, which usually contains water throughout the dry season, and so becomes a reservoir for fish. |
| Body mass index | A measure of a person's weight in relation to height, calculated by body weight (kg) divided by the square of a person's height (m). A BMI of <18.5 is considered underweight, a BMI from 18.5-24.9 is considered healthy, a BMI from 25-29.9 is considered overweight, and a BMI of ≥30 is considered obese. |
| Food-based approach | A public health nutrition intervention which promotes the production and consumption of foods that are either naturally rich in micronutrients, or improved through fortification. |
| Gher | Converted rice field where shrimp and prawn production take place. Ghers are usually connected to estuaries by sluice gates allowing control of flow of tidal water. |
| Blue Revolution | A phrase used to reflect the rapid expansion in aquaculture (fish farming) and its importance as an agricultural activity. |
| Green Revolution | An era of agricultural research and development from the 1940's-1970's and beyond, characterised by huge gains in global productivity due to the development of high yielding cereal grain varieties, introduction of irrigation, improved management techniques, and the wide-scale use of fertilisers and pesticides. |
| Haor | Bowl-shaped depressions between the natural levees of rivers. |
| Malnutrition | Physiological state of poor nutrition, including undernutrition, micronutrient deficiency and overnutrition (or overweight and obesity). |
| Micronutrient deficiency | Form of malnutrition related to inadequate intake of micronutrients (such as vitamins and minerals) to meet physiologic requirements. |
| Nutrition-sensitive (interventions) | Interventions or programmes that address the underlying determinants of malnutrition. |

| | |
|---|---|
| Nutrition-specific (interventions) | Interventions or programmes that address the immediate determinants of malnutrition. |
| Nutrition transition | The shift away from traditional diets high in cereals and fibre towards ‘Western diets’ high in saturated fat, sugar and refined or processed foods, also accompanied by a shift towards more sedentary lifestyles. |
| Overnutrition | Form of malnutrition related to excess consumption of dietary energy resulting in overweight and obesity. Can occur simultaneously with micronutrient deficiency. |
| Smallholder farmer | Marginal and sub-marginal farm households that own and or cultivate less than two hectares of land. Smallholder farmer households constitute a large proportion of the population in low and middle-income countries. |
| Small indigenous fish species | Local fish species in Bangladesh, less than 25 cm in length, and often consumed whole including head and bones. |
| Stunting | A measure of linear growth based on a child’s height-for-age. When a child’s height for age is more than two standard deviations below the median WHO reference population, this is defined as stunting and reflects the cumulative effects of chronic malnutrition. |
| Undernutrition | Form of malnutrition related to insufficient intake of dietary energy to meet physiologic requirements. |
| Underweight | A measure of nutritional status based on a child’s weight-for-age. When a child’s weight-for-age is more than two standard deviations below the median WHO reference population, this is defined as underweight and reflects acute and/or chronic malnutrition. |
| Wasting | A measure of nutritional status based on a child’s weight-for-height. When a child’s weight-for-height is more than two standard deviations below the median WHO reference population, this is defined as wasting and reflects acute or recent nutritional deficit. |
| 1,000 days | The period of time over the first one thousand days of life, including a woman during pregnancy and lactation, and the child up until two years of age. This time period represents an important window of opportunity to promote nutrition for healthy growth and development. |

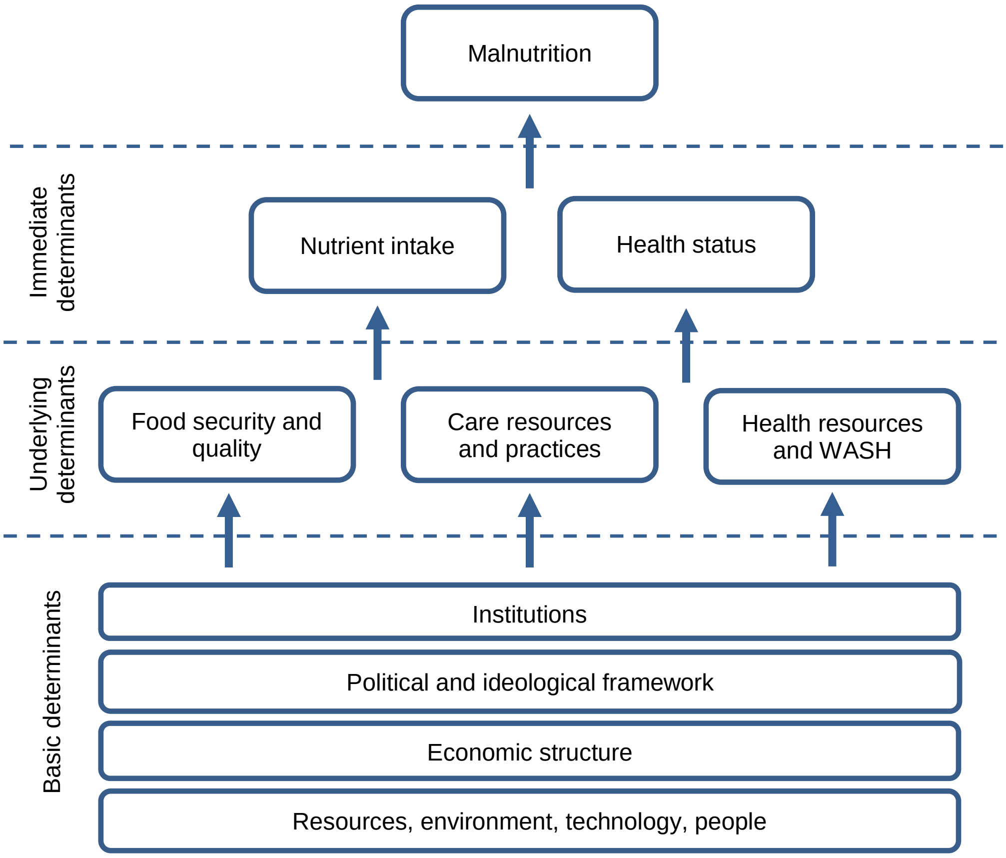
# 1. Introduction

## 1.1. Background

Malnutrition and poor quality diets are the leading drivers of the global burden of disease, affecting one in three people globally (IFPRI, 2016). Malnutrition is now more broadly understood to encompass three distinct forms; undernutrition (insufficient dietary energy); micronutrient malnutrition (insufficient micronutrients including vitamins and minerals); and overnutrition (excess dietary energy resulting in overweight and obesity). These forms of malnutrition can co-exist in communities, households and even individuals. For example, someone may suffer from obesity whilst also being deficient in certain micronutrients; or adult members of a household may suffer from overweight, whilst children in the same household may exhibit stunted growth, a chronic form of malnutrition. This is often described as 'the double burden' of malnutrition and is closely linked to the 'nutrition transition' occurring globally (Popkin & Gordon-Larsen, 2004). Nearly every country in the world suffers from malnutrition, though the burden of all forms of malnutrition are disproportionately felt in low and middle-income countries (IFPRI, 2016). The causes of malnutrition are multifactorial and operate at different levels, whereby immediate causes are related to dietary intake and general health status; underlying causes are related to food security, care resources and practices, and sanitation and hygiene; and structural or basic causes include the economic, political, institutional and physical environment. This multifactorial basis is outlined in the widely cited United Nations Children's Fund (UNICEF) framework for malnutrition (see Figure T1) (UNICEF, 1990). First published in 1990 and still highly relevant (Black et al., 2008), this framework denotes that solutions to malnutrition must also be multifactorial, requiring collaboration from a wide variety of disciplines working at the direct, underlying and basic levels.

The dominant focus of public health nutrition interventions to address malnutrition historically, has been on the immediate determinants of malnutrition. For example, food fortification and micronutrient supplementation, described as 'nutrition-specific interventions' (Ruel et al., 2013). However, modelling work has shown that even with the top ten most effective interventions successfully scaled to reach 90% of the population in the countries with the most significant undernutrition rates, nutrition-specific interventions, on their own, can only be expected to achieve a 15% reduction in child mortality (Bhutta et al., 2013). There is now a shift in momentum towards 'nutrition-sensitive interventions' (to complement evidence-based nutrition-specific interventions), defined as those interventions which address the underlying and basic determinants of malnutrition, to address the global challenge of malnutrition (Figure T1).

Figure T1: The UNICEF framework for malnutrition and its immediate, underlying and basic determinants.




WASH, water, sanitation and hygiene.
Source: (Herforth & Harris, 2014), originally adapted from (UNICEF, 1990).

One of the underlying drivers of malnutrition is food insecurity, defined as the lack of *physical, social or economic access to sufficient, safe and nutritious food, which meets dietary needs and food preferences for an active and healthy life* (FAO, 2009). Food security is underpinned by four domains; availability, referring to the quantity, quality and diversity of food; accessibility, referring to physical access to food in terms of purchasing power and physical access to functioning markets; utilisation, referring to appropriate absorption of nutrients consumed which is dependent on dietary quality, health, sanitation and care practices; and stability, which underpins the three above-mentioned pillars and refers to vulnerability to periodic food insecurity over time, for example, due to seasonal changes, price shocks or political instability. Inclusion of the phrase ‘food preferences’ in the definition is also noteworthy because it emphasises the importance of food that is socially and culturally acceptable in a given context.

In low-income countries, most attention by far has been paid to the first domain, increasing the quantity of food available, particularly staple grains. Agricultural development in the latter half of the 20th century (often described as the ‘Green Revolution’) was characterised by enormous increases in agricultural productivity through development of high-yielding varieties of cereal grains, improved management techniques such as irrigation, and the use of inorganic fertilisers and pesticides (IFPRI, 2002). Whilst this period is rightly credited with increasing per capita energy consumption and reducing undernourishment across low-income countries, it is also criticised for reducing the availability of, and increasing the price of micronutrient-rich vegetables, fruit and pulses, among other concerns (Gómez et al., 2013; IFPRI, 2002). Increased dietary energy consumption from staples has had the unintended consequence of reduced dietary diversity – one of the key drivers of micronutrient malnutrition. The concept of food security has since been broadened and is now widely described as ‘food and nutrition security’[3] – to emphasise the importance of stable availability, access and utilisation of micronutrient-rich foods, rather than energy-rich staple foods which do not provide the range of nutrients required for human health. The official definition of food and nutrition security also incorporates the other immediate and underlying determinants of malnutrition (Figure T1); *food and nutrition security exists when all people at all times have physical, social and economic access to food, which is safe and consumed in sufficient quantity and quality to meet their dietary needs and food preferences, and is supported by an environment of adequate sanitation, health services and care, allowing for a healthy and active life* (CFS, 2012).

Bangladesh is a lower-middle-income country in South Asia which experiences widespread malnutrition and food insecurity. The traditional diet is rice-based, complemented with small quantities of pulses, vegetables and fish[4]. Bangladesh has experienced many development successes; the per capita gross domestic product (GDP) has more than doubled since the country’s separation from Pakistan in 1971 (The World Bank, 2015), and the poverty rate has dropped from 83% in 1973-74 to 31.5% in 2010 (BBS, 1989, 2011). However, despite

[3] This thesis uses the terminology ‘nutrition and food security’, placing the emphasis on the contribution of fish to nutrient intakes and diets first and foremost, with the contribution to broader food security, second

[4] ‘Fish’ in this thesis is used to refer to the broad category of fish, shrimp and prawn species available for consumption in Bangladesh. It excludes aquatic plants and other aquatic animals such as turtles which may be consumed by minority groups in Bangladesh or other contexts. Note that aquatic animals in other contexts can make a significant contribution to diets and nutrient intakes.

some improvements, reductions in malnutrition have not kept pace. The most recent estimates are that 36% of children under five years of age are stunted, representing chronic malnutrition, 33% of children are underweight and 19% of adult women are undernourished (defined as having a body mass index (BMI) <18.5 kg/m$^2$) (NIPORT et al., 2015). Micronutrient deficiencies are also widespread (icddrb et al., 2013). Malnutrition also has profound economic impacts, estimated to cost the national economy around USD 1 billion per year in economic productivity alone, not to mention the costs to health care systems and societal costs (Howlader et al., 2012). A recent policy analysis of the development agenda in Bangladesh has highlighted the over-emphasis on increasing food availability, and lack of a coherent approach to the other pillars of food security, which may be contributing to the lack of significant progress in addressing malnutrition (Naher et al., 2014).

The fisheries sector of Bangladesh features prominently in the national development agenda (Government of the People's Republic of Bangladesh, 2005a, 2005b, 2006, 2011) for a number of reasons. Bangladesh possesses diverse and abundant aquatic resources, with nearly 400 aquatic animal species, a fast-growing aquaculture (fish farming) sector, a significant shrimp export sector, and annual fisheries production of over 3.5 million tonnes (FRSS, 2015; Hossain, 2010). This sector is also important for the national economy, contributing to the livelihoods of around 17 million people (FRSS, 2013), accounting for almost 4% of national GDP and 23% of the agricultural GDP (Government of the People's Republic of Bangladesh, 2015). Fish is also inextricably linked to the culture of Bangladeshi people, epitomised in the proverb ‘machee bhatee Bangali’ which translates as ‘fish and rice make a Bengali’ (Thompson et al., 2002).

The contribution of fish to nutrition and food security globally has received very little attention, with specialist fisheries discussions focused on aspects of biological sustainability or economic efficiency (HLPE, 2014). In Bangladesh, development policy has focused on the role of fish as a commodity; to provide employment, and to contribute to economic growth through increasing production and through expanding the export market. In fact, the national fisheries policy which has not been revised since 1998 contains no mention of nutrition (Naher et al., 2014). Nonetheless, with a focus on increasing production, the fisheries sector in Bangladesh has undergone rapid transformation over the last three decades. Total fish production in Bangladesh has been consistently increasing over time, from 0.8 million tonnes per year, in the early 1980s, to 3.5 million tonnes per year in 2013-2014 (FRSS, 1993, 2015). However, the nature and composition of production have undergone significant changes. Fish production has traditionally been dominated by the inland capture fisheries sub-sector, drawing from the extensive floodplains and vast river systems, including the Ganges, the Meghna and the Brahmaputra rivers. However, in recent years, the combination of environmental degradation of rivers and wetlands, and increased demand from a burgeoning population has led to a decline in production from this sub-sector, which now contributes less than a third of total fisheries production. At the same time, the aquaculture sub-sector has rapidly expanded. Pond aquaculture technology was introduced in the 1980's and by 2000, aquaculture production had overtaken that from capture fisheries. Bangladesh is now the world's sixth largest producer of aquaculture products (FAO, 2016d). This transition in the fisheries sector is generally assumed to have had a positive impact on nutrition and food security, with increased availability of fish, however, this has not been examined empirically, particularly from a nutrition-sensitive perspective.

## 1.2. Research aims and objectives

The broad aims of this research are to understand: how fish contributes to nutrition and food security; how this has changed according to broader trends in aquatic food systems; and how fisheries might be better utilised to reduce malnutrition. The focus is on nutrients known to be significant causes of malnutrition in Bangladesh: iron, zinc, calcium, vitamin A and vitamin B12. These broad aims are addressed through five specific research questions (RQs), each of which form an individual chapter in this thesis.

RQ 1: What is the nutritional value of commonly consumed fish in Bangladesh and how could fish potentially contribute to nutrient intakes among vulnerable groups?

RQ 2: How could local nutrient-rich foods including fish, be utilised to improve the nutritional quality of diets, particularly among vulnerable groups?

RQ 3: What does fish currently contribute to diets in terms of nutrient intakes, particularly among vulnerable groups?

RQ 4: How has the transition in aquatic food systems (declining availability of species from capture fisheries, and rapid growth in aquaculture) impacted nutrient intakes from fish, particularly among vulnerable groups?

RQ 5: How could nutritional quality of fish production systems be measured and used in decision making?

## 1.3. Significance of the research

Understanding the contribution of fish across all domains of nutrition and food security, particularly, accessibility, utilisation and stability domains, and how these interact to influence nutrition and health outcomes remains a significant knowledge gap. Without such knowledge, the ability of the fisheries sector to contribute meaningfully to reducing malnutrition is significantly impaired. This research will directly address this knowledge gap. Furthermore, the findings of this research are relevant to many other countries experiencing the burden of malnutrition and this transition in aquatic food systems. It is also noted that other related topics such as food safety and sustainability of fisheries are priority areas of research which are touched on briefly throughout the thesis, however, the main focus remains on the contribution to nutrition and food security.

# 2. Literature Review

## 2.1. The global momentum for improving nutrition

Malnutrition and poor quality diets are the leading drivers of disease globally, with 795 million people chronically undernourished, more than two billion people deficient in micronutrients, and around two billion people suffering from overweight or obesity (FAO et al., 2015; IFPRI, 2016). The vast majority of those suffering from malnutrition live in low and middle-income countries. The need to tackle malnutrition has been gaining prominence in the global development agenda, particularly in the new millennium. The global development agenda for low-income countries from 2000-2015, shaped by the United Nations (UN) Millennium Development Goals (MDGs), explicitly addressed hunger (goal 1), and implicitly addressed malnutrition in at least two other goals (goals 4 and 5) for improving child and maternal health (United Nations, 2015). Great progress was made during this period, with the *proportion* of hungry people throughout the world almost halved. However, progress was uneven, with *numbers* of hungry people increasing in some regions, and 'new' forms of malnutrition, particularly overweight and obesity rapidly rising across all regions (FAO, 2014). The new UN Sustainable Development Goals (SDGs) which are to shape the development agenda of all countries (not just low or middle-income countries) from 2016-2030, are more comprehensive and explicitly aim to address 'malnutrition in all its forms' (goal 2), and with improvements in nutrition pertinent to tracking progress among at least 12 of the 17 goals (IFPRI, 2016).

Political commitment to nutrition has expanded on a global scale since the food price crisis of 2007-2008, when staple food prices tripled in some regions, pushing an additional 40 million people into hunger and undoing much of the significant gains towards the MDG targets (UN SCN, 2009). This crisis served to heighten awareness of the volatility of food prices, and kick-started a number of high level regional and international meetings and commitments to increase investment in agriculture and food security.

The launch of the 'Lancet Series on Maternal and Child Undernutrition' in 2008 served to highlight the evidence for investment in nutrition. This series emphasised the importance of the first 1,000 days of life, from the start of pregnancy to a child's second birthday as the window of opportunity to reduce stunting and associated developmental and productivity losses (Bryce et al., 2008). The establishment of the Global Partnership for Agriculture and Food Security followed by the UN World Summit on Food Security in 2009, highlighted the need to invest in smallholder farmers. The Summit saw member countries become signature to the Rome Principles – five key principles for achieving sustainable global food security which emphasise (among others) a 'twin-track' approach to addressing the immediate and underlying causes of malnutrition (FAO, 2009). In 2010, the Scaling Up Nutrition (SUN) movement was launched, including a Framework for Action (SUN, 2014). The SUN movement is headed by the Special Representative for Food Security and Nutrition to the UN Secretary General and aims to bring together governments, civil society, the UN, donors, businesses and scientists in a united effort to improve nutrition. Membership now stands at 57 countries (and three Indian States) which have established country (or state) level goals which contribute to the global targets for improved nutrition, endorsed by the World Health Assembly in 2012, to be reached by 2025 (SUN, 2016). This movement too, adopts a twin-track approach to addressing the immediate and underlying determinants of malnutrition. Also in 2010, the '1,000 Days' partnership initiative was launched with the aim of triggering greater concerted global action and investment in improving nutrition through the 'window of opportunity' for mothers and children (1000 Days, 2017).

Recognising that economic growth alone is necessary but not sufficient to achieve adequate reductions in malnutrition (FAO, 2013b; Haddad et al., 2003), economists have also added momentum to the call for increased investments in nutrition. The Copenhagen Consensus, which brought together the world's leading economists in 2008 and again in 2012, listed nutrition amongst the top ten most cost-effective strategies to address the global development challenge (Hoddinott et al., 2012; Horton et al., 2008).

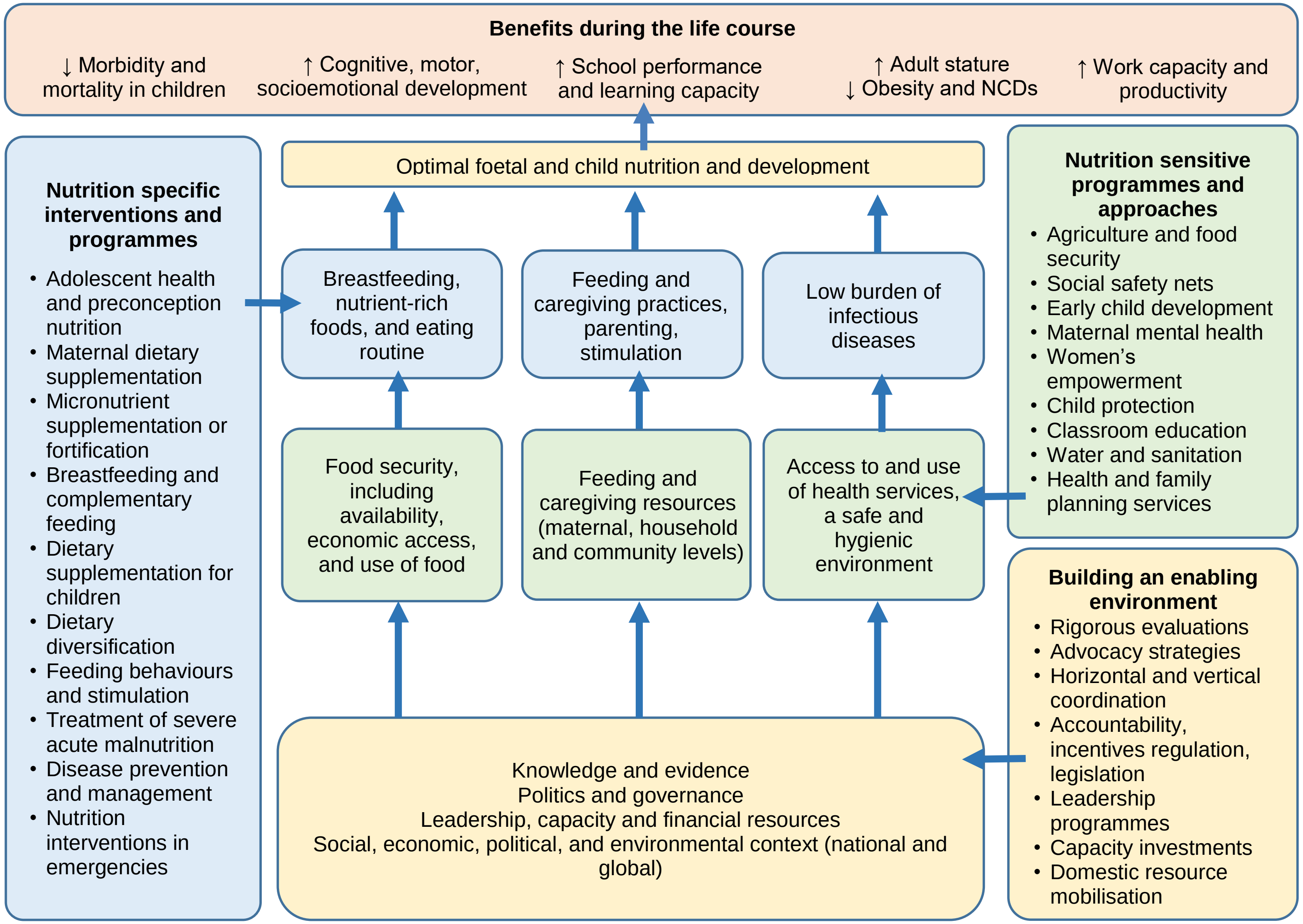
The Rio +20 Earth Summit in 2012 saw the launch of the Zero Hunger Challenge by UN Secretary General Ban Ki-Moon, in a call for scaled efforts on nutrition with an emphasis on family farming, sustainable and resilient food systems, and women's empowerment (United Nations, 2012b). The key project document from the summit, '*The Future We Want'* also points to the centrality of nutrition in sustainable development and global progress (United Nations, 2012a).

Later in 2013, The Lancet launched its second series on Maternal and Child Nutrition, bringing attention to the effectiveness of *nutrition-specific* interventions such as promotion of breastfeeding and micronutrient supplementation, which addresses the immediate causes of undernutrition; and *nutrition-sensitive* interventions such as agricultural diversification and education, which address the underlying causes of undernutrition (Ruel et al., 2013). It is noteworthy that whilst recognising the importance of nutrition-specific interventions, particularly in the short term, the series highlighted that their long-term sustainability and scope to achieve widespread results are limited. The Lancet series presented a core package of the ten most effective nutrition-specific interventions. Modelling of these interventions scaled to reach 90% of the population in 34 countries which are home to 90% of the world's undernourished children, revealed only a 15% reduction in current total mortality (Bhutta et al., 2013). This series, among many others, has called for strengthening of nutrition-sensitive programmes and strong multidisciplinary collaboration to address the underlying causes of malnutrition. The series also proposes a framework for action, highlighting a number of interventions and programmes to address the immediate, underlying and basic causes of malnutrition (see Figure T2).

Within days of publication of The Lancet series, the Nutrition for Growth high level meeting was held in London which resulted in pledges of USD 19 billion between 2013 and 2020, for the promotion of nutrition-sensitive interventions, and USD 4 billion for nutrition-specific interventions from the Group of Eight nations, businesses, foundations and civil society organisations (DFID, 2013a). This indicates that funding was directed in line with the growing evidence base regarding the need to address both immediate and underlying causes of malnutrition.

The second International Conference on Nutrition (ICN2) was a high level meeting held in Rome in 2014, in follow-up to the first ICN in 1992, with representatives from 170 governments, civil society and the private sector. There were three significant outcomes from this meeting relevant to the global nutrition agenda. First, the '*Rome Declaration on Nutrition*', and second the '*Framework for Action on Nutrition*', committed governments to implement national policies to transform food systems and alleviate malnutrition in all its forms. Third, this meeting put forward the recommendation to the UN General Assembly that 2016-2025 be declared the *Decade for Action on Nutrition*, a resolution that was endorsed in 2016. These events and commitments collectively demonstrate that improving nutrition is both a global imperative and priority.

Figure T2: Framework for action to achieve reductions in child malnutrition.




NCDs, non-communicable diseases.

Source: (Black et al., 2013).

## 2.2. The food and nutrition systems approach

Food systems can be conceptualised as consisting of all of the inputs and activities required to produce and distribute food for human consumption. Various conceptual models of food systems include several stages, including agricultural production, distribution, and consumption; each of which involves inputs, which undergo transformation and result in various outputs which continue their flow throughout the system (Global Panel on Agriculture and Food Systems for Nutrition, 2016; Ingram, 2011; National Health and Medical Research Council, 2013). This approach aligns with the concept that *the whole is greater than the sum of its parts*. Several authors propose a broader concept of food systems which incorporates nutrition and health outcomes. (Burchi et al., 2011; Nugent, 2011; Sobal et al., 1998). Sobal and colleagues (1998) define a food and nutrition system as '*the set of operations and processes involved in transforming nutrients into health outcomes, all of which functions as a system within biophysical and sociocultural contexts'.* This definition emphasises the interdependence of agricultural production, food consumption and nutritional status. An advantage of this conceptual approach is that an understanding of the drivers of, inputs to, transformations within, interactions between, and outputs at each stage of the system will allow more effective guidance of interventions at various points in the system to achieved desired nutrition and health outcomes. In line with this approach, several high level international reports have called for a paradigm shift in food systems thinking, away from feeding people to nourishing people (Global Panel on Agriculture and Food Systems for Nutrition, 2016; Jones, 2015).

Consistent with the food and nutrition systems approach, is recognition of the importance of considering dietary patterns holistically, as opposed to the traditional reductionist approach examining individual nutrients (Hoffmann, 2003). 'Feeding people' or producing sufficient dietary energy (calories), was the focus of the Green Revolution of the latter half of the 20$^{th}$ century. Heightened understanding of the complexities of malnutrition – specifically that malnutrition is more complex than simply inadequate energy intake – has slowly shifted food systems thinking towards considering micronutrients. This is seen, for example, in the significant global investment in staple crop biofortification initiatives such as vitamin A in maize and cassava; iron in peal millet and beans; and zinc in rice and wheat (Bouis et al., 2013). A limitation of such approaches is that they focus on single nutrients, when in fact nutritional status and health outcomes depend at a minimum on appropriate intakes of more than 40 nutrients. They are also limited in that they may mask how nutrients and other components of the diet interact empirically. This ‘reductionist’ approach, whilst an improvement on focusing on calories alone, still fails to capture all of the elements that are necessary for good health.

Some of the nutrition literature is therefore ‘transcending reductionism’ and moving towards examining the relationship between holistic dietary patterns and health outcomes (Hoffmann, 2003). This is the basis for the more recent interest in nutrition studies which examine whole dietary patterns, as is seen, for example, in the plethora of published literature examining the Mediterranean dietary pattern for prevention of chronic disease. There is still much to learn about how nutrients and other food components interact to influence nutrition and health outcomes in different contexts. What is clear however, is that diversity across and within food groups and individual foods is essential for achieving healthy diets (Global Panel on Agriculture and Food Systems for Nutrition, 2016).

### 2.2.1. Nutrition-sensitive agriculture

Within a food systems approach to improving nutrition, nutrition-sensitive agriculture has received particular attention as evidenced by its prominence in numerous high level strategic policy documents of the international community in recent years (see also Figure T2) (CGIAR, 2010; DFID, 2013b; FAO, 2013a; FAO et al., 2014; Ruel et al., 2013; The World Bank et al., 2013; UN SCN, 2013; Wiggins & Keats, 2013). A number of authors have articulated the various pathways through which agriculture and food production systems can influence nutrition and health. These depictions vary in detail, the level of emphasis placed on different pathways, connections between the pathways, and indeed, the number of pathways ranging from three (Herforth & Harris, 2014), five (Arimond et al., 2011; Berti et al., 2003; The World Bank, 2007), six (Meeker & Haddad, 2013) and seven (Gillespie et al., 2012). However, all of the various effects can be considered to be mediated through three predominant pathways; food production, income generation and women’s empowerment (Figure T3) (Herforth & Harris, 2014).

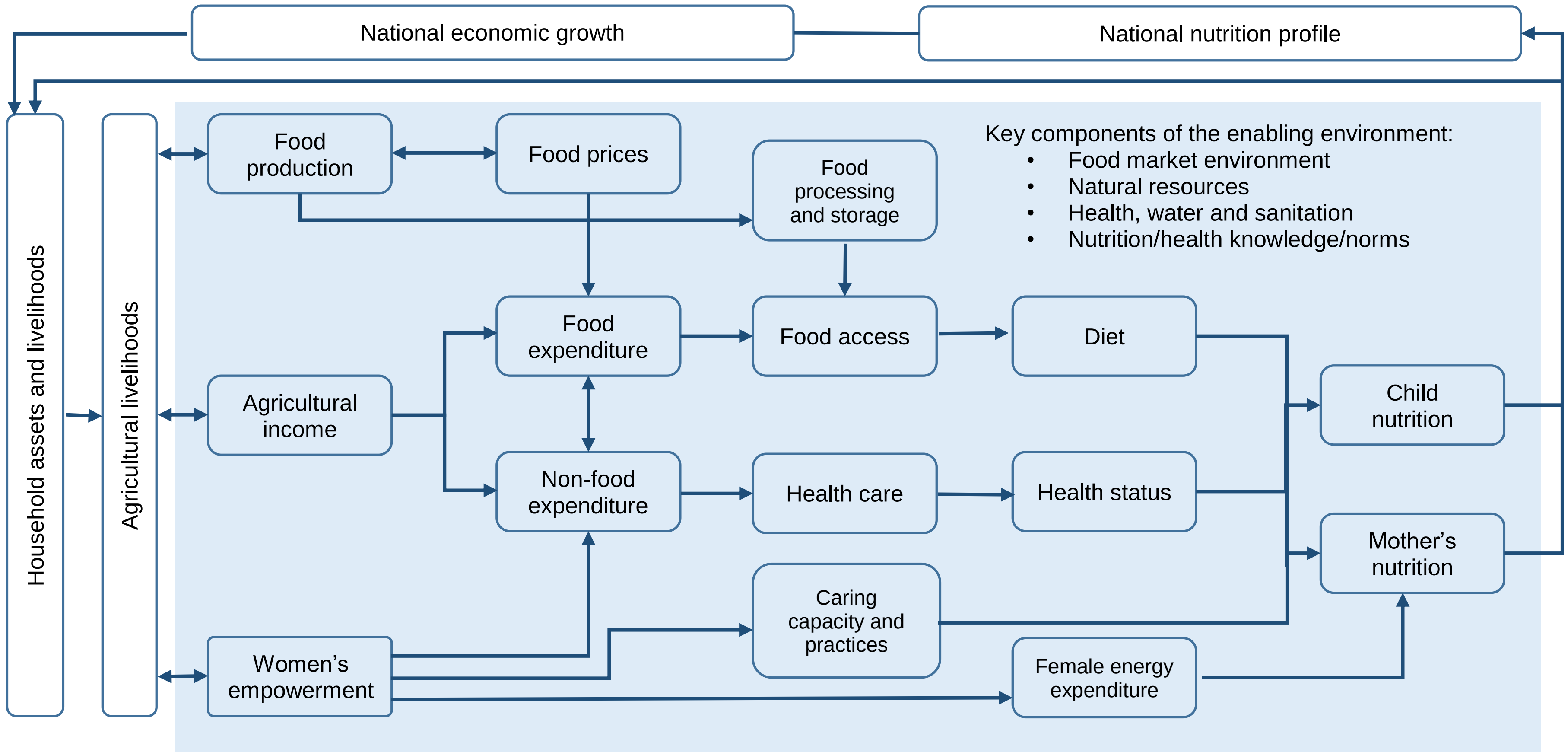
Agricultural interventions or programmes can influence food production directly, thereby influencing availability of foods both at the farm level and through markets. Food production, through supply and demand dynamics thereby directly influences food prices and physical and economic access to food. Agricultural interventions can also influence what type of foods are produced. For example, an agricultural intervention may promote production of nutrient-rich foods which therefore have an impact on nutritional quality of foods available.

Agriculture also influences nutrition outcomes through income generation for farmers, though the impact of this on nutrition outcomes is dependent on how that income is spent. When income is spent on accessing diverse and nutrient-rich foods, or other non-food determinants of nutritional status such as accessing health care services, the benefits are clear. However, increased incomes spent otherwise (e.g. alcohol and tobacco) may be detrimental. It is now broadly accepted that income generation on its own, is not sufficient to bring about improvements in nutrition (Haddad et al., 2003; UN SCN, 2011). In this sense, women are often considered as nutrition 'gatekeepers', as income in the hands of women has been shown to more likely be spent in ways that influence nutrition and health outcomes both of children and the family as a whole, compared to income in the hands of men (Smith et al., 2003).

Agricultural interventions and programmes can also influence nutrition outcomes through women's empowerment. Empowerment is a complex multidimensional concept, with multiple definitions in the literature (van den Bold et al., 2013). Broadly, it captures women's status, agency, their decision making power and control over resources. This is a crucial pathway, as more than half of the reductions in child stunting across the world between 1970 and 1995 has been attributed to improvements in women's status (Smith & Haddad, 2000). Figure T3 shows that women's empowerment can influence nutrition outcomes primarily through three pathways: firstly, through a woman's role in decision making on how income is spent, both on food and non-food purchases; secondly, through her level of knowledge, available time and skills to engage in care and feeding practices for herself and other family members, particularly children; and thirdly, through her workload and associated energy expenditure which influences her own nutritional status.

In an agrarian economy, in which a country's food production is characterised by small-scale agriculture, which employs a large proportion of the population, as is the case in Bangladesh, understanding of these pathways and linkages is particularly important. There is however, a lack of significant evidence of impact of agricultural programmes on nutrition (Webb & Kennedy, 2014). This is largely attributable to a lack of quality research design, rather than evidence of a lack of impact (Masset et al., 2012; The World Bank, 2007; Webb & Kennedy, 2014).

Figure T3: Conceptual framework of linkages between agriculture and nutrition.




Source: (Herforth & Harris, 2014), originally adapted from (Gillespie et al., 2012; Headey et al., 2011).

The extent of influence of each of these pathways, and thereby impact of interventions targeted at the different entry points are likely to be largely context specific. It is also clear that interventions to improve nutritional quality of food production are uniquely placed to influence nutrition outcomes, both by increasing access of producing households to nutritious foods, as well as increasing market supply of nutritious foods, available to the wider population with subsequent impacts on food prices. Such a framework provides a useful basis for examining the contribution of fisheries (as a sub-sector of agriculture) to nutrition.

### 2.2.2. Food-based approaches to micronutrient malnutrition

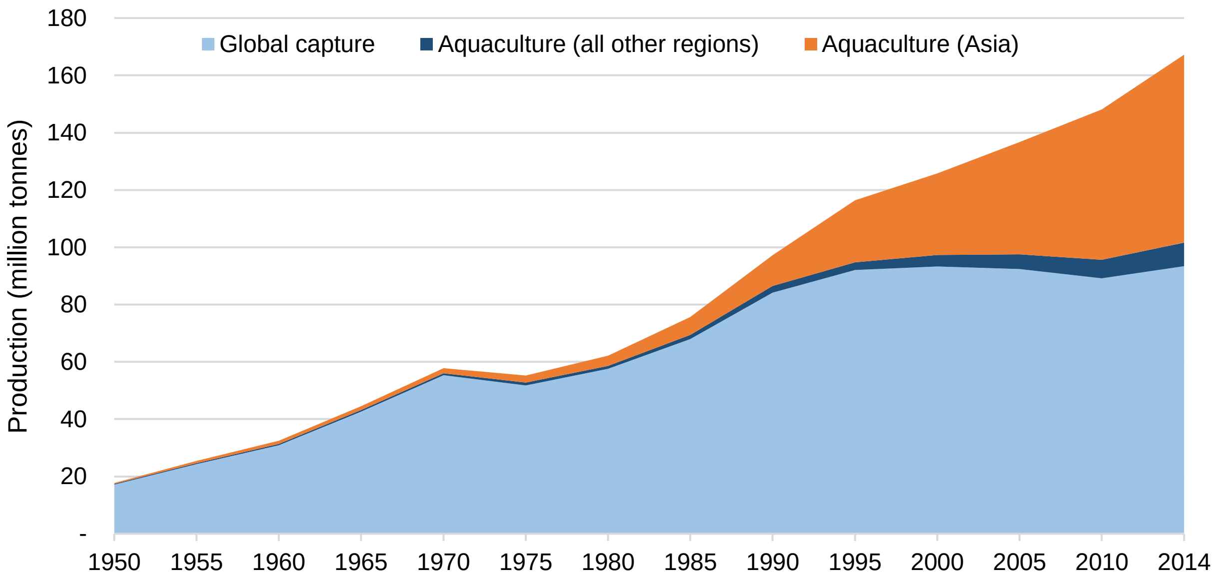
A related and perhaps more widely recognised approach to addressing malnutrition under the ‘food and nutrition systems’ umbrella, are ‘food-based approaches’, which promote the production and consumption of foods that are naturally rich in micronutrients, or improved through fortification. Food-based approaches have long been recognised as a key strategy for addressing multiple micronutrient malnutrition, and were a key recommendation to low-income countries at the initial ICN in 1992 (FAO & WHO, 1992). Despite strong evidence for their effectiveness, implementation of such approaches have not received sufficient attention, with governments often prioritising nutrition-specific interventions such as supplementation (Thompson & Amoroso, 2011). Whilst this is understandable, given that supplementation can often have a much quicker start-up time with measurable results, in a relatively short time frame, it cannot offer the sustainable social and economic benefits of food-based approaches in the long term (Gibson, 2011). A further advantage is that they offer potential to prevent or address multiple micronutrient deficiencies as opposed to focusing on a single nutrient, as is one of the common criticisms of supplementation approaches. They are also often more feasable in rural areas, particularly when focused on local foods and traditional preservation and processing methods (Ruel & Levin, 2000). Within food-based approaches, animal-source foods (ASFs) are worthy of particular attention as they offer a concentrated source of multiple micronutrients, generally with higher bioavailability compared to plant-based foods (Neumann et al., 2011). Consumption of ASFs is proven to improve growth and cognition in children, reducing micronutrient deficiencies, stunting and ultimately morbidity and mortality (Dror & Allen, 2011; Krebs et al., 2011; Neumann et al., 2011). However, much greater emphasis in the literature is given to milk, eggs and red meat; whilst fish has received far less attention, despite its high nutritional quality and importance in dietary patterns in many regions.

Food-based approaches have received some attention in Bangladesh, notably the homestead food production programme pioneered by Helen Keller International. This programme focused on training women to increase production of vitamin-A rich vegetables and fruit, combined with nutrition education and following pilot studies was successfully scaled to a national programme which has since been adopted by the Government of Bangladesh through the Department of Agricultural Extension (Talukder et al., 2000). The programme has been shown to increase production and consumption of vegetables and fruit, to increase household income, and to increase certain aspects of women's empowerment (Bushamuka et al., 2005). However, agricultural development in Bangladesh more broadly has been overly staple-centric, focused on achieving rice-self-sufficiency with considerably less attention to diverse and nutrient-rich food production (Naher et al., 2014). This is perhaps set to change in the near future, with the current draft Country Investment Plan 2016-2022 – a key national policy document that frames investment priorities – titled *'Towards Nutrition-Sensitive Food Systems'*.

## 2.3. Capture fisheries and aquaculture

Fisheries represent a large and important sub-sector of the global food system; fish provides more than three billion people with around 20% of their animal-source protein (HLPE, 2014), and annual global production in 2010 was more than double poultry production and triple global cattle production (Béné et al., 2016) (annual fish production was 167 million tonnes in 2014, (FAO, 2016d)). Global fisheries are also undergoing a period of transition. Global fish production continues to increase, with stagnating supply from capture fisheries and rapid expansion in aquaculture (see Figure T4). According to FAO statistics, the world's annual marine capture fisheries production peaked in 1996 at around 86 million tonnes, which, combined with inland capture fisheries, has since remained relatively stable at around 90 million tonnes per year (FAO, 2016d). Other estimates suggest that marine production peaked at a much higher level (around 130 million tonnes per year) and have since been in more rapid decline (Pauly & Zeller, 2016). Over-reporting of capture statistics by some countries for political reasons, as well as improved data collection methods compared to historical data (when under-reporting, particularly of artisanal or small-scale fisheries was potentially more common), are thought to have contributed to the 'stable' trend reported by FAO compared to the declining trend reported elsewhere (Pauly & Zeller, 2017). Nevertheless, unsustainable fishing practices continue to worsen, with 31% of global marine fish stocks overfished (up from 10% in 1974), and 58% of stocks at maximum fishing capacity (FAO, 2016d). Yet demand for fish products continues to rise with per capita annual consumption doubling from ten kilograms in the 1960s to 20 kilograms in 2013. This increased demand has largely been met through the rapid expansion in aquaculture, often referred to as the 'blue revolution'. The expansion in aquaculture is a global phenomenon, taking place in recognition of the biological limits of capture fisheries, the ever increasing demands of population growth and consumer preferences for fish, in increasingly affluent societies. Aquaculture is the fastest growing food production sector with an average annual growth of 8% (HLPE, 2014), and is estimated to produce half of all fish for human consumption (FAO, 2016d). Asia is by far the largest producing region, accounting for 93% of global aquaculture production, and China, on its own, accounting for 65% of global production.

Figure T4: Global capture fisheries and aquaculture production.

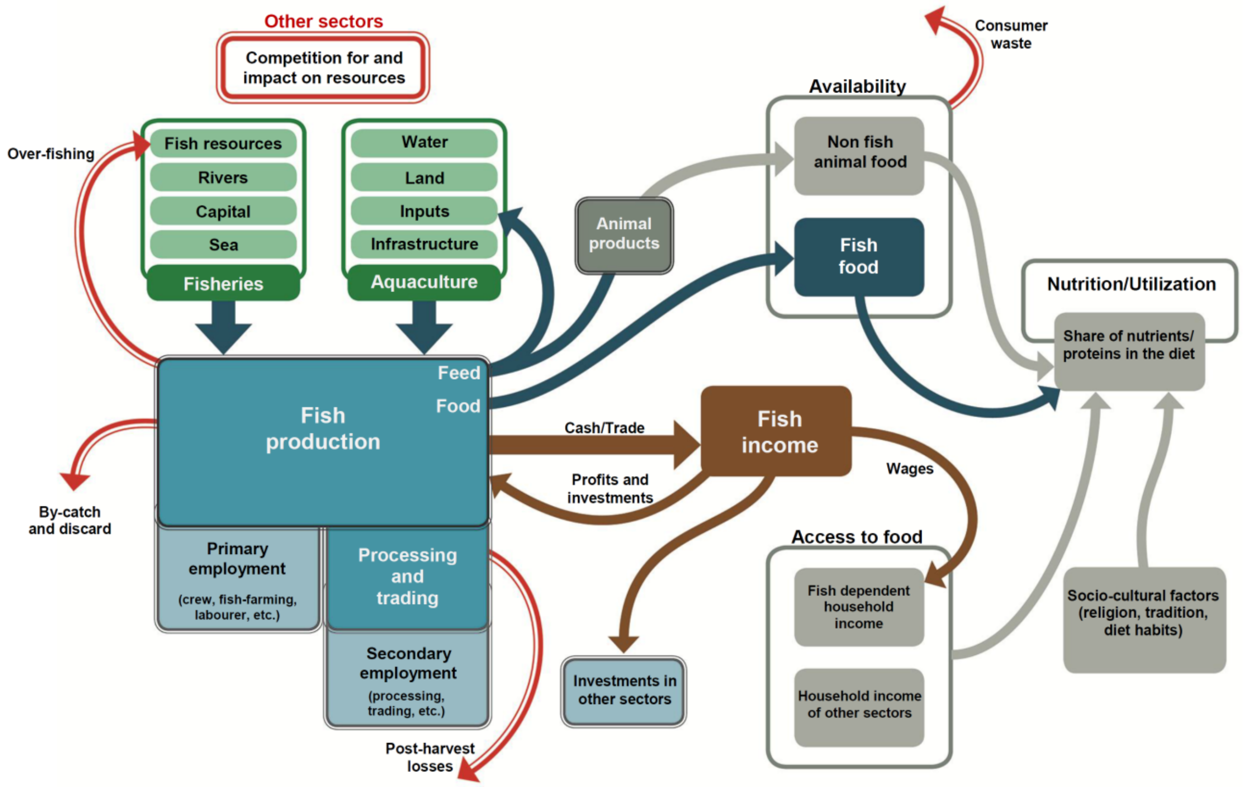



Source: Author's compilation from online dataset (FAO, 2017a, 2017b).

### 2.3.1. Fisheries links to nutrition and food security

The possible pathways through which capture fisheries and aquaculture influence nutrition and food security are shown schematically in Figure T5, which are also a reflection of the pathways described in Figure T3 on how agriculture influences nutrition. These pathways can be considered direct (e.g. fish as a direct source of food), or indirect (e.g. fish as a source of income which can be used to purchase food). The pathways also operate at different scales. For example, local fisheries may be a direct food source for local communities, or the fisheries sector may boost national economies through international trade in global markets. Some of these pathways are synergistic, for example, a local aquaculture system may provide income, in addition to being a direct food source; and others may entail trade-offs, for example, fish caught for non-human uses such as animal feed may provide employment but reduce availability of fish for direct human consumption. The pathways through which capture fisheries and aquaculture influence the different domains of nutrition and food security are summarised in the following sections.

Figure T5: Conceptual representation of the pathways through which fisheries and aquaculture influence nutrition and food security.




Source (HLPE, 2014).

#### 2.3.1.1. Availability

Global fish availability was described in section 2.3; and more detail is provided here. Fish availability around the world is not equal, with low-income countries having a much lower average apparent per capita annual consumption (7.6 kg/capita/year in low-income, food-deficit countries, and 12.4 kg/capita/year in least-developed countries) compared to industrialised countries (26.8 kg/capita/year) (FAO, 2016d). However, fish tends to make a larger contribution to total animal protein intake in 'developing'[5] countries (20%) compared to 'developed' countries (12%) (FAO, 2016d). Analysis of FAO food balance sheet data has shown that of the 30 countries in which fish is an important part of the diet (defined as more than a third of total animal protein from fish), 22 of these countries were considered low-income, food-deficit countries (Kawarazuka & Béné, 2011). This highlights the importance of fish in diets of the poor. Fish also makes an important contribution to consumption of other nutrients including vitamins, minerals and essential fats (described in more detail in section 2.7).

Fisheries also contribute to food availability indirectly, as an input to animal feed, thereby contributing to availability of other ASFs. Of global capture fisheries production in 2014, around 22% (21 million tonnes) was used for non-food purposes, largely as inputs to feed for aquaculture, livestock and poultry production systems (FAO, 2016d). Estimates from 2010 show that most fish destined for animal feed is used in aquaculture (73%), followed by pigs (20%) and poultry (5%) (Shepherd & Jackson, 2013). Increased availability of these other ASFs also contribute positively to food and nutrition security. However, a large proportion of species targeted as feed ingredients are nutrient-rich small pelagic fish (among other species) which is considered by some to make a more valuable contribution to food and nutrition security if used directly for human consumption (Tacon & Metian, 2009). This also raises equity questions where fish species may be directed away from direct consumption by poor consumers to be used to produce fish or livestock for export markets.

It is also important to note the factors which limit availability of fish (see red arrows in Figure T5). Not accounted for in global production statistics, is the large quantity of fish discarded at sea prior to landing. Statistics are difficult to estimate; the most recent from FAO in 2005 estimated discards at 8% of global marine catch, or 7.9 million tonnes in 2012 (HLPE, 2014; Kelleher, 2005). Discards are made up of by-catch (non-target species, or legally undersized fish) or fish of low quality that is damaged or spoiled. Of catch that is landed (and hence

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[5] 'Developing' and 'developed' country terminology is used to be consistent with the source, here and throughout the thesis, when considered appropriate. In this case, 'developing' country regions include Africa, Americas (excluding North America), Caribbean, Asia (excluding Japan), Oceania (excluding Australia and New Zealand); and 'developed' country regions include Northern America, Europe, Japan, Australia and New Zealand (United Nations Statistics Division, 2016). It is recognised that this terminology is increasingly outdated, and that more subjective groupings such as the World Bank income groups are generally preferred. These are used throughout this thesis, whenever possible.

included in global production figures), it has been estimated that a further 12 million tonnes were lost or wasted along the value chain in 2011 (Béné et al., 2015). Consumer waste is also difficult to estimate, but is suggested to be of importance, particularly in higher-income regions (FAO, 2011). All of these factors represent inefficiencies in the value chain which limit the potential contribution of fish to nutrition and food security.

#### 2.3.1.2. Access

Capture fisheries and aquaculture also make important contributions to livelihoods, particularly for the poor, and thereby contribute to economic access to food. It is estimated that 120 million people around the world depend directly on capture fisheries related activities (e.g. fishing, processing, trading), approximately 97% of whom live in ‘developing’ countries (Mills et al., 2011). Fish farming provides employment for a further 19 million people in primary production (FAO, 2016d), and an unknown number involved in aquaculture value chains. Perhaps surprisingly, nearly half of all fish workers in ‘developing’ countries are women, mostly in post-harvest activities, though participation varies widely across countries depending on fisheries practices and cultural and religious norms (Mills et al., 2011). If women’s engagement in the value chain increases women’s empowerment, this can have beneficial flow on effects via the determinants of malnutrition (see Figure T1 and Figure T3). For example, increased empowerment may improve a mothers childcare and feeding practices, which can then impact nutrition via improved dietary intake of the child and improved sanitation and hygiene (Kawarazuka, 2010). However, if women’s engagement in the value chain reduces their time available to contribute to care and feeding practices of children this may have detrimental impacts on nutrition. For example, a study in Tanzania attributed poor infant nutritional status to reductions in breastfeeding rates which occurred following an intervention which led women to become involved in fisheries activities soon after giving birth (Moshy et al., 2013).

It is also estimated that 88% of capture fisheries workers globally are engaged through the small-scale sector as opposed to large-scale fisheries (Mills et al., 2011). Small-scale fisheries are generally considered to make broader direct and indirect contributions to food and nutrition security compared to large-scale capture fisheries. This is due to large numbers employed or engaged in the small-scale sector, and the higher proportion of fish catch that is consumed locally from small-scale fisheries (higher proportions of large-scale fisheries are directed to international trade or non-food uses).

The scale of operation of aquaculture and links to food and nutrition security are less clear. Given its prominence on the global development agenda, aquaculture is broadly assumed to contribute to both poverty reduction and food security. However, evidence of the direct impacts, particularly for the poor, is lacking. There are some examples of aquaculture development in parts of Asia which have significantly reduced poverty rates (Béné et al., 2016). Aquaculture can also be credited with keeping down inflation of fish prices of both farmed species and species from capture sources, improving economic access (Belton & Thilsted, 2014). However, in other cases, it appears that from a livelihoods perspective, more affluent households which have the resources and opportunity to invest in aquaculture benefit most (Arthur et al., 2013).

#### 2.3.1.3. Utilisation

Fish is a nutrient-rich ASF which is irreplaceable in the diets of many, particularly the poor (Kawarazuka & Béné, 2011). In addition to being a source of high quality protein, it is also a rich source of essential fatty acids, particularly long chain omega-3 fatty acids. In many cases, the nutritional profile of fish is considered superior to other ASFs, having higher content of essential fatty acids, lower content of saturated fat, and higher content of several vitamins and minerals (Tacon & Metian, 2013).

The benefits of fish for human health are wide-ranging and well-documented. Fish consumption is protective against cardiovascular disease (Rimm & Mozaffarian, 2006), and all-cause mortality (Zhao et al., 2015). Omega-3 intake during pregnancy is associated with improved birth outcomes such as reduced risk of premature birth and low-birth weight (Imhoff-Kunsch et al., 2012); and fish consumption throughout pregnancy and breastfeeding is associated with improved child development outcomes (Oken et al., 2008). Low intake of seafood during pregnancy has also been shown to increase the risk of poor neurodevelopmental outcomes such as cognition and fine motor skills (Hibbeln et al., 2007).

On the other hand, there are also health risks linked to fish consumption due to the presence of contaminants from algae, bacteria, viruses and some chemical pollutants such as heavy metals in some regions. Methylmercury is a heavy metal which accumulates up the food chain, and can therefore be found in toxic concentrations in predatory species such as shark, billfish and tuna. Several high-income countries such as Australia recommend limited consumption of potentially contaminated species by vulnerable groups such as pregnant women and children (FSANZ, 2011). As with intensive livestock production systems, the expansion of aquaculture has also been accompanied by use of antibiotics and other chemicals with risks for human health through antibiotic resistance (HLPE, 2014). Many countries have strict regulations in place to prevent overuse of such substances; however, enforcement in some settings remains a challenge. Despite these risks, it is generally agreed that the positive health benefits of fish largely outweigh the risks (Hoekstra et al., 2013; Rimm & Mozaffarian, 2006).

#### 2.3.1.4. Stability

The contribution of fish to nutrition and food security is also subject to changes over time, across seasons and as with any food source, can be subject to vulnerability linked to political instability, extreme weather events and other shocks. Of significant global concern is the stability of certain marine fish stocks which are subject to overfishing. Despite global efforts to protect fish stocks, for example through establishment of the FAO Code of Conduct for Responsible Fisheries (FAO, 1995), the proportion of overfished fish stocks globally has continued to increase from 10% in 1974 to 31% in 2013 (FAO, 2016d).

The stability of fisheries over time also has implications for the temporal stability of nutritious diets. One analysis has modelled the dietary implications of future predicted declines in global fish stocks. The study finds that 845 million people are at risk of iron, zinc or vitamin A deficiency in the coming decades, directly attributable to declines in fish availability (Golden et al., 2016). In this sense, growth in aquaculture is crucial to maintaining fish availability. However, this is not without complications. For example, many aquaculture systems rely on capture fisheries resources (such as small pelagic fish) as an input for feed. The growing demand for fish feed, with growing pressure on capture sources and resultant increased prices have led aquaculture producers to look for alternative feed ingredients, which ultimately influence nutritional quality of the fish produced. A temporal analysis from Australia has demonstrated up to a 50% decline in omega-3 fatty acid content of farmed Atlantic salmon, linked to increasing substitution of fish oil with poultry fat in fish feed (Nichols et al., 2014).

Fisheries has also been shown to make an important contribution to economic stability both nationally and at the household level. For example, in Bangladesh, the world’s sixth largest producer of aquaculture products (FAO, 2016d), fisheries has contributed around 3.7% of national GDP for more than a decade (Government of the People's Republic of Bangladesh, 2015), with export earnings from prawn and shrimp farms alone at over USD 530 million per year, in 2013-14 (FRSS, 2015). At the community level, capture fisheries has been described as ‘the bank in the water’, a source of potential income that is available all year round as required (Béné et al., 2009). At the household level, whilst aquaculture may only contribute a small proportion of total household income, a homestead pond has been described as a type of insurance policy. Fish stocks can be sold for cash at times of shocks or vulnerability, potentially preventing declines into poverty for those on the cusp (Belton et al., 2011).

## 2.4. Malnutrition and food insecurity in Bangladesh

In Bangladesh, the most reliable source of nationally representative data on nutritional status is the Bangladesh Demographic and Health Survey (BDHS), the most recent results of which are from 2014 (NIPORT et al., 2015). This survey collects data on a range of health indicators; those relating to nutrition focus on women and children and include anthropometry, breastfeeding and complementary feeding practices, as well as estimated intake of certain micronutrients. The previous survey from 2011 also included anthropometric measures for adult men, anaemia among women and children, and some basic household food security indicators (NIPORT et al., 2013). A more comprehensive source of information on dietary practices and food insecurity in Bangladesh is the Food Security and Nutritional Surveillance Project (FSNSP) which collected nationally representative and seasonal data on women (including pregnant women) and children, from 2010-2015 (JPGSPH & NNS, 2016). This survey collected data on indicators of the different domains of nutrition and food security including dietary quality, care practices, complementary feeding and anthropometric measures of nutritional status[6]. The following section will outline what is known about the nutrition and food security situation in Bangladesh.

Some improvements have been made over the past decade with respect to childhood stunting and underweight, however, undernutrition in Bangladesh remains widespread. The most recent estimates are that 36% of children under five years of age are stunted (down

[6] Note that there is some variability in the indicators reported on in different survey rounds and associated survey reports. The most recent results are reported for indicators of interest here, or when comparisons of survey results are made to other data sources, survey rounds from the most similar time period are reported.

from 51% in 2004), 33% are underweight (down from 43%) and 14% are wasted (down slightly from 15%) (NIPORT et al., 2015). Among ever-married women aged 15-49 years, 19% are undernourished (down from 34% in 2004). These estimates are generally consistent with results from the FSNSP data from the same year, reporting prevalence of stunting in children under five years at 35%, and prevalence of undernourishment among women, aged 19-49 years at 17% (HKI & JPGSPH, 2016). In contrast, the proportion of women who are overweight or obese has more than doubled from 9% in 2004, to 24% in 2014 (NIPORT et al., 2015), a trend which is also reflected in the FSNSP data (HKI & JPGSPH, 2016). Interestingly, the rate of increase in prevalence of overweight in rural areas is almost double that in urban areas (Hoque et al., 2015). It is clear that Bangladesh suffers from the triple burden of malnutrition, with various sectors of the population suffering from undernutrition, micronutrient malnutrition and overweight and obesity.

In terms of food availability, national agricultural production continues to increase, particularly of ASFs. However the country is also increasingly reliant on food imports to keep pace with consumer demand from a growing population (HKI & JPGSPH, 2016). Economic access to food has also seemingly improved given real wage growth, resulting in a reduction in poverty from 57% in 1991-2 to 32% in 2010. However, food prices vary seasonally, and many are still unable to afford a diverse diet.

The perceived experience of food insecurity is measured by the Household Food Insecurity Access Scale (HFIAS) which provides an index score, based on survey responses to eight food-related behaviours, including worrying about food security, eating only staple foods (in this case, rice), reducing portion sizes and skipping meals (Coates et al., 2007). According to the HFIAS, 24% of households nationally were food insecure in 2014 (HKI & JPGSPH, 2016). This also varies seasonally and geographically, with rural households more prone to food insecurity, and the worst rates observed in the pre-monsoon season in the Northern Chars region, with 48% of households being food-insecure. Though unacceptably high, this is a remarkable improvement from 2011, when 69% of households nationally were food-insecure, linked to the global food price crisis that year (JPGSPH & HKI, 2012). Food insecurity is often not experienced uniformly within households. In Bangladesh, generally, adults will alter their eating patterns (for example, by reducing portion sizes, consuming only rice, or skipping meals) before children are affected, and female adults will do so before males. For example, if only one member of the household had to alter their eating patterns in response to food insecurity, it was nearly always the female adult (JPGSPH & NNS, 2016).

In terms of dietary quality, the FSNSP survey collected useful information on dietary patterns using a 24-hour recall methodology. In this survey, dietary inadequacy (a diet inadequate in macro and or micronutrients) is defined as consumption of fewer than five food groups in a 24-hour period. In 2015, 66% of women consumed inadequately diverse diets, up from 54% in 2014 (JPGSPH & NNS, 2016). Prevalence of inadequacy was much higher in rural areas (70%) compared to urban (51%), and also varied by income quintile (85% in the poorest wealth quintile), and geographic region. Seasonal variation in dietary diversity was not included in the most recent FSNSP report, though earlier reports show large variation in dietary diversity across seasons, whereby dietary inadequacy was higher in the post-monsoon dry season (HKI & JPGSPH, 2016). Another nationally representative survey of rural Bangladesh was conducted by the International Food Policy Research Institute (IFPRI) reports on food energy adequacy (Ahmed et al., 2013). Seemingly in contrast to FSNSP results, this survey showed that in 2011-12, the overwhelming majority of the rural population (88.4%) consumed diets adequate in energy. However, this simply exemplifies that whilst the majority may have sufficient access to staple foods such as rice to provide dietary energy, the overall dietary quality for the majority is likely to be poor and contribute to micronutrient deficiencies.

### 2.4.1. Micronutrients of public health significance

Micronutrient deficiency is a significant public health concern in Bangladesh. The most reliable and up-to-date source of information on the status of micronutrient deficiencies is the Bangladesh National Micronutrients Status Survey, conducted in 2011-12 by the International Centre for Diarrhoeal Disease Research, Bangladesh (icddr,b[7]) (icddrb et al., 2013). This survey collected serum samples from approximately 950 pre-school children, 950 non-pregnant, non-lactating (NPNL) women, and 1,500 school-aged children (actual numbers for each test vary) from rural, urban and slum dwelling populations and determined, iron, zinc, iodine, folate, vitamin A and vitamin B12 deficiency status, among other measures. The prevalence of deficiency of selected nutrients, according to national, urban, rural and slum population samples, are summarised in Table T1.

[7] Official acronym uses lowercase letters.

Table T1: National prevalence of selected micronutrient deficiencies in specific population groups in Bangladesh.

| Nutrient Deficiency and population group | Diagnostic criteria | National prevalence (%) | Rural prevalence (%) | Urban prevalence (%) | Slum prevalence (%) |
|---|---|---|---|---|---|
| *Anaemia* | Serum haemoglobin | | | | |
| Pre-school children | <110 g/L | 33.1 (51.3[a]) | 36.6 | 22.8 | 22.0 |
| 6-11 yo children | <115 g/L | 19.1 | 21.7 | 11.8 | 13.2 |
| 12-14 yo children | <120 g/L | 17.1 | 18.1 | 13.2 | 18.1 |
| NPNL women | <110 g/L | 26.0 (40.0[a]) | 27.4 (44.7[b]) | 21.4 (36.1[b]) | 20.1 |
| Pregnant women | <120 g/L | 49.6[a] | - | - | - |
| Lactating women | <110 g/L | 47.8[a] | - | - | - |
| *Iron deficiency* | Serum ferritin | | | | |
| Pre-school children | <12.0µg/L | 10.7 | 9.4 | 12.3 | 27.2 |
| 6-11 yo children | <15.0 µg/L | 3.9 | 4.1 | 3.6 | 3.4 |
| 12-14 yo children | <15.0 µg/L | 9.5 | 10.0 | 8.1 | 8.3 |
| NPNL women | <15.0 µg/L | 7.1 | 6.7 | 8.7 | 7.4 |
| *Iron deficiency anaemia* | Both serum | | | | |
| Pre-school children | haemoglobin and | 7.2 | 6.1 | 10.1 | 13.9 |
| 6-11 yo children | serum ferritin as | 1.3 | 1.1 | 2.1 | 1.3 |
| 12-14 yo children | defined above | 1.8 | 1.8 | 1.7 | 1.8 |
| NPNL women | | 4.8 | 5.0 | 4.1 | 4.1 |
| *Zinc* | Serum zinc | | | | |
| Pre-school children | < 9.9 µmol/L | 44.6 | 48.6 | 29.5 | 51.7 |
| NPNL women | <10.1 µmol/L | 57.3 | 57.5 | 54.5 | 66.4 |
| *Iodine* | Urinary iodine | | | | |
| School age children | <100 µg/L | 40.0 | 40.8 | 39.3 | 27.4 |
| NPNL women | <100 µg/L | 42.1 | 44.7 | 33.3 | 33.5 |
| *Vitamin A* | Serum retinol | | | | |
| Mild deficiency | | | | | |
| Pre-school children | ≥0.7-<1.05 mmol/L | 56.3 | 58.7 | 48.4 | 53.4 |
| School age children | ≥0.7-<1.05 mmol/L | 53.5 | 53.8 | 52.0 | 55.8 |
| NPNL women | ≥0.7-<1.05 mmol/L | | | | |
| Moderate and severe deficiency | | | | | |
| Pre-school children | <0.7 µmol/L | 20.5 | 19.4 | 21.2 | 38.1 |
| School age children | <0.7 µmol/L | 20.9 | 20.2 | 22.1 | 27.1 |
| NPNL women | <0.7 µmol/L | 5.4 | 5.4 | 4.9 | 6.9 |
| *Vitamin B12* | Serum B12 | | | | |
| Marginal deficiency | | | | | |
| NPNL women | 200-300 pg/ml | 15.9 | 15.8 | 16.0 | 18.1 |
| Deficiency | | | | | |
| NPNL women | <200 pg/ml | 6.1 | 5.7 | 7.5 | 6.5 |
| *Folate* | Serum folate | | | | |
| NPNL women | <6.8nmol/L | 9.1 | 8.6 | 11.4 | 7.9 |

All data sourced from (icddrb et al., 2013) unless otherwise specified.
yo, year old; pg/ml, picogram per millilitre; na, not available.
[a]Source, (NIPORT et al., 2013).
[b]Includes pregnant and lactating women in average. Source (NIPORT et al., 2013).

Vitamin A deficiency prevalence for all target groups were well above the WHO threshold to consider vitamin A deficiency as a public health concern (WHO & FAO, 2006). The prevalence of anaemia, according to WHO criteria, would be considered of moderate public health concern for pre-school aged children and NPNL women, and of mild public health concern among school aged children. It is worth noting that the prevalence of anaemia was also reported in the BDHS survey from 2011, and results were much higher than those reported in the icddr,b survey of 2012 (for example, 40.0% compared to 26.0% among NPNL women). This may be explained by slight differences in analytical methods (Rahman et al., 2016b). The icddr,b survey used venous blood samples, whereas the BDHS survey used capillary blood samples (NIPORT et al., 2013). Interestingly, the prevalence of iron deficiency and iron deficiency anaemia was found to be relatively low, despite the high prevalence of inadequate dietary iron intakes and the relatively high prevalence of anaemia (Rahman et al., 2016b). This has been attributed to the presence of highly bioavailable iron in groundwater in many regions of Bangladesh (Merrill et al., 2012; Rahman et al., 2016b). This challenges the widely held assumption that dietary iron inadequacy is the most common cause of anaemia. It is suggested by Rahman and colleagues, that in addition to dietary iron, vitamin A, folate and zinc may be important determinants of anaemia (2016b).

Iodine deficiency is defined as a public health concern when median urinary iodine is <100µg/L (WHO & FAO, 2006). The median urinary iodine concentration was above this cut-off based on national averages, though would be considered a public health concern among households of the two lowest wealth quintiles. The WHO has not established criteria for the public health significance of zinc or vitamin B12 deficiency due to limited high quality data on global prevalence. However, given the severe health consequences of deficiencies of these nutrients, and the high prevalence of deficiency in Bangladesh, they are considered here as nutrients of public health concern.

The icddr,b survey shows alarming rates of zinc deficiency, affecting 45% and 57% of pre-school aged children and NPNL women respectively. Inadequate dietary intake of zinc, particularly of highly bioavailable ASFs; and high phytate consumption (which inhibits zinc absorption) have been identified as the primary drivers of inadequacy (Rahman et al., 2016a). The prevalence of vitamin B12 deficiency is also of concern, affecting nearly one in four NPNL women. This is however, unsurprising given that vitamin B12 is found almost exclusively in ASFs (with the exception of bacteria-containing foods such as fermented products). Low consumption of ASFs has been identified as the likely primary cause of vitamin B12 deficiency in poor populations (Allen, 2009). This is of particular concern given the role of vitamin B12 in child development and cognitive function (de Benoist, 2008).

Furthermore, although national prevalence of calcium deficiency is unknown, it is considered here as a nutrient of public health significance for two reasons. Firstly, dairy foods are the predominant dietary source of bioavailable calcium in most high-income countries, whereas access to and consumption of dairy foods in Bangladesh is very low. Secondly, calcium deficiency has been implicated as the primary aetiological factor in the development of rickets in Bangladesh which was estimated to affect more than half a million children, in 2009 (icddrb, 2009).

There is a growing body of literature on the role for essential fatty acids in cognitive development, particularly during the first 1,000 days (Michaelsen et al., 2011). A small study amongst women of childbearing age in rural Bangladesh found low dietary intakes of essential fatty acids and low content in breastmilk, with potentially severe implications for infants during the first six months of life (Yakes et al., 2011). In light of the above information, specific nutrients of interest considered throughout this thesis include iron, zinc, calcium, vitamin A and vitamin B12, and where possible, essential fatty acids.

## 2.5. Capture fisheries and aquaculture in Bangladesh

Bangladesh has experienced a rapid transition in fisheries, described at the global level in previous sections, and further elaborated here. Fisheries in Bangladesh comprises three main sectors: inland capture, aquaculture and marine capture. Key characteristics of these three sectors are described in Table T2.

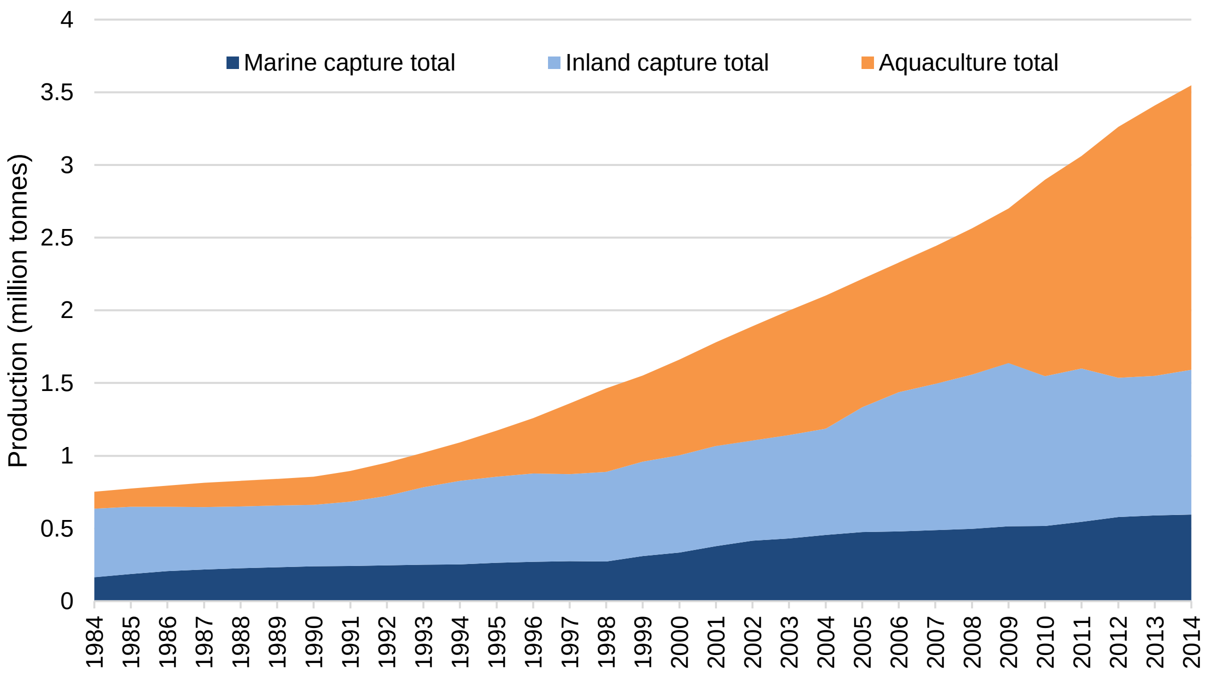
Table T2: Characteristics of the predominant fisheries sectors in Bangladesh.

| | Inland capture | Aquaculture | Marine capture |
|---|---|---|---|
| Description | Self-reproducing fish and prawn harvest from open inland waterbodies. | Synonymous with 'farming' and usually involves private ownership and some kind of intervention (such as feeding) to increase yields. | Self-reproducing fish and prawn harvest from the sea or ocean. |
| Annual production volume (2013-14) | 995, 895 tonnes per year<br>28% of total | 1,956,925 tonnes per year<br>55% of total | 595,385 tonnes per year<br>17% of total |
| Fishing industry structure | Small-scale, artisanal or community based management. Inclusive of the poor and landless. Some commercial fishing where water resources are leased by private owners or government to licensed fishers. | Approximately two-thirds of production volume from commercial activities. Homestead pond culture practised widely in varying levels of intensity (and usually forms only part of a household's livelihood strategy). | 87% artisanal or small-scale<br>13% industrial (trawling) |
| Production landscape[a] | Rivers<br>Floodplains and haors<br>Estuaries<br>Beels<br>Lakes<br>Mangrove forest | Commercial ponds<br>Homestead ponds and ditches<br>Baors<br>Gher culture<br>Cage culture (in open inland waterbodies)<br>Rice-fish culture<br>Coastal shrimp farms<br>Seasonal floodplain culture | Ocean (Bay of Bengal) |
| Dominant species in production | Nearly 300 species of finfish and prawns, including about 267 SIS<br>Hilsha[b]<br>Some indigenous carps | Dominated by 6-10 large species. Introduced species; Pangas, Silver carp, Tilapia<br>Indigenous major carps; Rui, Catla, Mrigal | Hilsha[b] (accounts for 43% of total marine production) and a large diversity of other species |

Adapted from (FRSS, 1993) with updated production figures (FRSS, 2015)
SIS, small indigenous fish species
[a]See glossary for definitions of production landscapes.
[b]Hilsha is the national fish of Bangladesh. It is a migratory fish and so contributes to both marine (77%) and inland capture fisheries (33%) production.

Total fish production in Bangladesh has been consistently increasing over the last 25 years from 0.8 million tonnes to more than 3.5 million tonnes per year in 2013-2014 (FRSS, 1993, 2015). However, the nature and composition of production has undergone significant changes. Fish production has traditionally been dominated by the inland capture fisheries sector until 2004, when aquaculture became the predominant source (see Figure T6). Since 2008-2009, inland capture fisheries have been in decline and now account for only 28% of national production, compared to 55% from aquaculture and the remaining 17% from marine capture (FRSS, 2015). Approximately 2.5% of total fisheries production is exported, the vast majority of which is prawn and shrimp from commercial aquaculture.

Figure T6: Fish production in Bangladesh by sector from 1984-2014.




Source: Author, based on data from (FRSS, 1993, 2002, 2015).

### 2.5.1. The decline of inland capture fisheries

Inland capture fisheries production is largely dominated by floodplain production. This is not surprising given that approximately two-thirds of the area of Bangladesh is considered floodplains, where agriculture and fisheries have traditionally operated to complement each other (Sultana, 2012). During the dry season (December to May), when water levels have receded, agriculture (particularly rice production) is conducted on the fertile soils and fish can be caught from beels and rivers. This type of fishing is often restricted to professional fishers working for leaseholders of government land. Then during the monsoon, the floodplain is inundated and fish populations thrive whilst deep water rice is often cultivated. At this time, fish can be caught by any member of surrounding villages. In this sense, capture fisheries are characterised by labour-intensive, small-scale or artisanal activities, usually managed at a household or community level rather than commercially (Sultana, 2012).

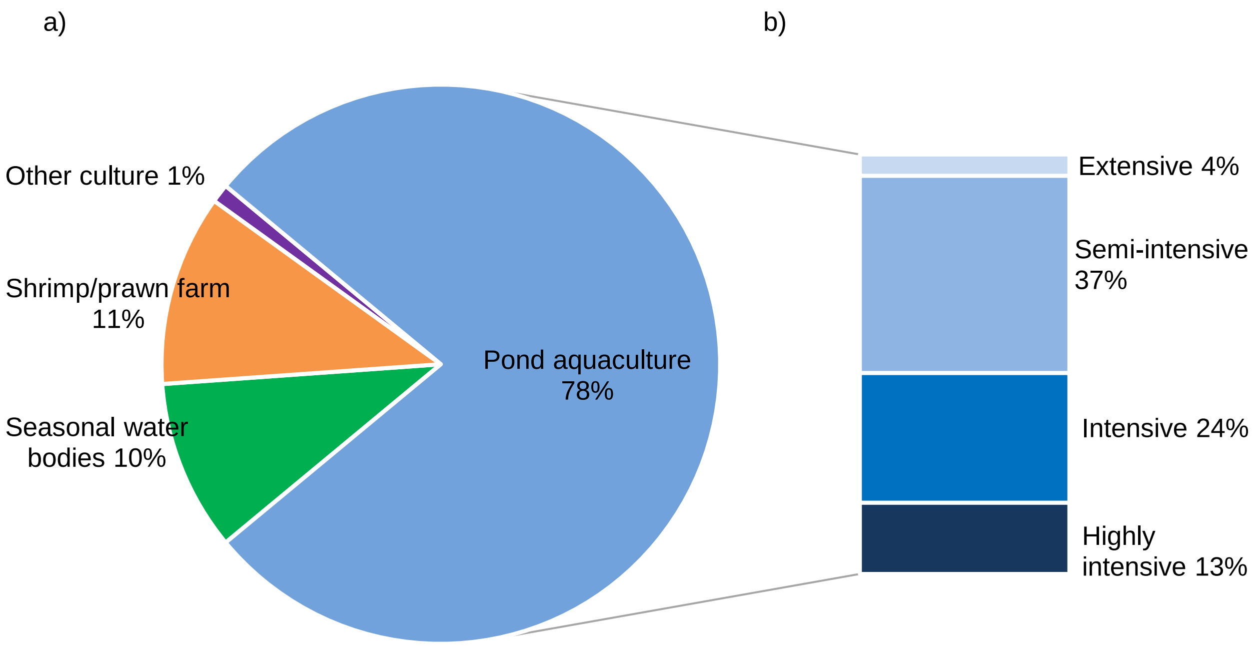
Whilst this system still operates, it has changed significantly over time. Floodplain fish production peaked in 2008-9 and has now decreased by nearly 20% (FRSS, 2015). The decline of capture fisheries (mainly from floodplain fisheries) is attributable to a combination of factors, including increased demand from a growing population resulting in overfishing, industrial pollution, water pollution, urban encroachment and expansion of transport infrastructure (Belton et al., 2011; Halls et al., 2008; Sultana, 2012). Most significant, however, are changes in water and land management practices introduced during the period of the Green Revolution for the purposes of increased rice production. The most significant effects are through a reduction in total area, where floodplains are drained for the purposes of land-based agriculture, and from the disruption caused by irrigation and construction of flood control embankments which prevent seasonal fish migration – a key step in the fish reproduction cycle. Whilst these management techniques (in combination with a number of other factors such as the introduction of high-yielding rice varieties, use of fertilisers and pesticides) have seen enormous increases in rice production, unfortunately, this has been at the expense of floodplain fisheries. Furthermore, since the 1980s, increasingly large areas of floodplains are being enclosed and restricted by private land owners for the purpose of aquaculture. This practice has had devastating impacts for the landless and poor, who previously had common access to the natural fisheries resources for their livelihoods (Sultana, 2012). Not only has total fish production declined, but these practices have led to severe losses of fish biodiversity, particularly of small indigenous fish species (SIS) (Hossain & Wahab, 2009; Mian et al., 2013). Despite the clear negative impacts of enclosure of floodplains for agriculture (including aquaculture), the current government policy on this practice remains unclear, and certain donor-funded development projects continue to promote this approach (Sultana, 2012).

### 2.5.2. The rise of aquaculture

The Government of Bangladesh, multi and bilateral donors, the private sector and non-government organisations have invested heavily in the development of the aquaculture industry in the last three decades. In addition to the extensive research on production techniques, this investment has seen rapid expansion of industry to support aquaculture, including hatcheries (where fish eggs are hatched under controlled conditions); nurseries (where young fish are raised prior to transfer to fish farms) and associated traders; and artificial feed production businesses. These developments have allowed for exponential growth in this sector, from virtually nothing prior to the 1980’s, to approximately 2 million tonnes fish per year in 2013-2014 (FRSS, 2015). Some researchers point out that this may even be an underestimate as current survey methods for official statistics are not designed to capture growth of innovations within the sector (Belton et al., 2011). Analysis of other datasets suggests that aquaculture production in 2005-2006 was 23% higher than official statistics.

Regardless of the total figures, whilst there are several forms of aquaculture, the sector is dominated by pond aquaculture, which produced 1.5 million tonnes per year in 2013-2014 (78% of total aquaculture, see Figure T7 a) (FRSS, 2015). Within pond aquaculture, there is considerable heterogeneity in the types of production systems operating, ranging from homestead ponds, with virtually no inputs, to intensively managed commercial systems. Official statistics from the Department of Fisheries categorise pond aquaculture systems according to productivity: extensive systems produce <1.5 tonnes/hectare (ha)/year; semi-intensive systems produce 1.5-4 tonnes/ha/year; intensive systems produce 4-10 tonnes/ha/year; and highly intensive systems >10 tonnes/ha/year (see Figure T7 b).

Figure T7: Aquaculture production in Bangladesh in 2013-14; a) contribution of the main aquaculture technologies to total production and b) contribution of sub-types of pond aquaculture production.




Source: Author based on data from (FRSS, 2015).

These categories are however, not necessarily standardised. For example, a recent WorldFish report considers broader categories: extensive systems producing <3 tonnes/ha/year (with very little active management), semi-intensive systems producing 4-20 tonnes/ha/year (requiring some use of external feeds and fertilisers) and intensive systems producing >20 tonnes/ha/year (total reliance on external feed inputs) (Murshed-e-Jahan et al., 2015).

Another WorldFish report categorises pond aquaculture systems as either homestead pond systems; entrepreneurial pond systems; or semi-intensive commercial systems, based on a broader set of criteria including size of the pond, management intensity, species produced and a number of other factors (Belton et al., 2011). Each of these systems was estimated to contribute about 30% of total national aquaculture production at the time of the review, though from a vastly different resource base; 265,000 ha of homestead ponds; 110,000 ha of semi-intensive commercial ponds; and 15,000 ha of entrepreneurial ponds.

Pond aquaculture systems also vary in terms of species produced. Homestead ponds tend to produce a polyculture of indigenous carp species such as Rui (*Labeo rohita*), Mrigal (*Cirrhinus mrigala*); and Catla (*Gibelion catla*), sometimes in combination with exotic species such as Silver carp, *Hypophthalmichthys molitrix*) or Tilapia (*Oreachromis niloticus*). Commercial systems are also often polyculture systems, though focused on target species such as Pangas (*Pangasius hypophthalmus*) or Koi (*Anabas testudineus*).

Two particularly promising production models, from a nutrition and food security perspective, promoted by WorldFish and partners, is the polyculture of carp species with SIS in stand-alone ponds, and ponds connected to rice fields (Thilsted & Wahab, 2014). These systems were originally developed at the Bangladesh Agricultural University in the late 1990s (Roos et al., 2007). Some of the benefits of these production systems are summarised in Table T3.

A cost-benefit analysis has demonstrated that inclusion of the vitamin A-rich SIS, Mola (*Amblypharyngodon mola*) fish, in carp-polyculture systems is a cost-effective strategy to alleviate vitamin A deficiency (Fiedler et al., 2016). However, widespread uptake of this simple technology has been limited by lack of availability of seed and any significant investment in technology transfer.

There is no convincing estimate of national production of SIS in pond aquaculture systems. A recent WorldFish survey found that around a quarter of homestead pond systems surveyed included SIS, which contributed an average of 13% of total pond yields, though this survey cannot be considered nationally representative (Murshed-e-Jahan et al., 2015).

Official statistics from the Department of Fisheries include no specific category for recording production of SIS in pond aquaculture.

Table T3: Benefits of two homestead pond aquaculture systems currently being promoted in Bangladesh.

| Inclusion of SIS in carp polyculture systems | Polyculture of carp species and SIS in ponds connected to rice fields |
|---|---|
| • Increased yields<br>• Increased nutritional quality of the food system (micronutrients such as Vitamin A, iron, calcium and zinc)<br>• Need only to be stocked once as long as a small amount of water is retained during the dry season<br>• Higher market price (for SIS)<br>• Culturally appropriate and well-liked<br>• Require partial harvesting which is conducive to household consumption (rather than production solely for income purposes) | • Increased yields of rice (10%) and straw (15%)<br>• Two crops produced from the same land at the same time, with relatively low costs and labour<br>• No need for application of insecticides as the fish feed on insects and pests in the rice fields<br>• Fish movement in the rice fields reduces the growth of weeds<br>• Promotes gender equality and women's empowerment, as most ponds connected to rice fields are close to homesteads, which is convenient for women who can be active in maintaining the pond and frequent and partial harvesting of fish for home consumption. |

Adapted from (Thilsted & Wahab, 2014).

Homestead ponds are used for a variety of purposes, including washing, bathing, cooking, as a water source for livestock, and fish culture. Excavation of land to raise houses as a flood prevention measure is common, resulting in a pond close to the homestead. One report estimates 4.27 million households in Bangladesh (around 20% of the rural population) operate a homestead pond (Belton et al., 2011). Fish culture in homestead ponds often supplements a larger farming system and/or other sources of income. A WorldFish review of six studies reports that income from aquaculture ranged from an average of 3-16% of total household income (Belton et al., 2011), whilst a more recent single survey, covering most major aquaculture-producing areas reports an average of 4-5% (Murshed-e-Jahan et al., 2015). In this recent survey, 55-70% of fish harvested from homestead ponds were used for direct household consumption.

## 2.6. Fish consumption in Bangladesh

In Bangladesh, fish is an irreplaceable ASF in the diet of millions, both in terms of quantity; accounting for approximately 60% of animal protein intake, and frequency of consumption; far exceeding that of any other ASF, including dairy, eggs, poultry and beef (Belton et al., 2014b). It's cultural significance is reflected in the old proverb, "machee bhatee Bangali", which translates to "fish and rice make a Bengali" (Thompson et al., 2002). Current fish consumption data is generally limited to the household level, and so it is not possible to assess the contributions of fish to nutrient intakes of individuals. However, several large surveys conducted in recent years, document fish consumption trends and are useful in broadly defining the dietary contribution of fish within different population groups (see Table T4 below).

Table T4: Summary of fish consumption from recent large surveys from Bangladesh.

| Reference | Survey Name | Data collection period | Location | Method of food consumption data collection | Form of fish consumption recorded in surveys |
|---|---|---|---|---|---|
| *General fish consumption* | | | | | |
| (IFPRI, 2013) | Bangladesh Integrated Household Survey (BIHS)[8] | Oct-Mar 2011-2012 | Nationally representative of rural Bangladesh | 7-day recall at household level, and 24-hour recall at household and intra-household level | *7 day household recall:* As purchased (mostly whole raw fish, or whole dried fish where applicable) *24-hour household recall:* Both raw weight of whole fish and cooked weight of dishes (e.g. fish curry) *24-hour intra-household recall:* Cooked weight of dishes (e.g. fish curry) |
| (Toufique & Belton, 2014) | Household Income and Expenditure Survey (HIES) | Year round, 2000, 2005 and 2010 | Nationally representative | 2-day recall, conducted on 7 alternate days over a 14 day period at household level | As purchased (mostly whole raw fish, or whole dried fish where applicable) |
| (Belton et al., 2014b) | Chronic Poverty and Long Term Impact Study (CPLTIS) | Oct-Dec 1996 Nov-Feb 2006-2007 | 4 districts: Mymensingh, Krishoreganj, Jessore and Manikganj | 3-day recall at household level | As purchased (mostly whole raw fish, or whole dried fish where applicable) |
| *Fish consumption in the first 1,000 days of life* | | | | | |
| (JPGSPH & NNS, 2016) | Food Security Nutritional Surveillance Project (FSNSP) | 3 survey rounds over 12 months Conducted each year from 2010-2015 | Nationally representative (children and women) | 24-hour recall for women including pregnant women, and survey of mother for information on complementary feeding practices | Not quantitative (e.g. only asks whether or not fish was consumed, not how much or in what form fish was consumed) |

[8] A repeat of the BIHS has since been conducted in 2015 and datasets published online in December 2016, however the results of this more recent survey have not yet been published in a report.

| | | | | | |
|---|---|---|---|---|---|
| (Saha et al., 2011) | Alive and Thrive Baseline Survey[9] | Apr-Aug 2010 | 20 sub-districts across the whole country | 7-day recall at household level 24-hour recall (infants and young children) | *7-day household recall:* As purchased (mostly whole raw fish, or whole dried fish where applicable) *24-hour recall:* Not quantitative (e.g. only asks whether or not fish was consumed, not how much or in what form fish was consumed) |

None of the surveys are directly comparable as they either examine different population groups, use different methods of data collection or are conducted in different seasons of the year. Data on per capita fish consumption from the Bangladesh Integrated Household Survey (BIHS) and the Household Income and Expenditure Survey (HIES) differ; although they do reflect some similar trends; fish consumption largely varies by income group and geographic location. The BIHS conducted in 2011-2012 reported average fish consumption was 21.1 g/person/day of small fish, and 43.3 g/person/day of large fish (total 64.2 g/person/day)[10]. This is significantly higher than data from the nationally representative HIES 2010, which reported annual fish consumption of 16.71 kg/person/year (equivalent to 45.8 g/person/day) (Toufique & Belton, 2014). This difference may be attributable to the fact that the BIHS data was collected in October-March, which includes the post-monsoon period when fish availability tends to be high, whereas the HIES data represent annual consumption. The BIHS survey is also nationally representative of rural Bangladesh, whereas the HIES is representative of both rural and urban Bangladesh, which may account for some differences. The Chronic Poverty and Long Term Impact Study (CPLTIS), conducted by IFPRI in 2006-2007 reported per capita fish consumption in the mid-range of the above surveys, 54.0 g/person/day, however, this is not directly comparable, as the survey was only conducted in four districts (Belton et al., 2014b).

Fish consumption in the BIHS varied by household expenditure quintile, with the lowest group consuming about half the national average, both in terms of quantity and frequency of intake. This trend is consistent with data from the HIES which reported 9.8 kg/person/year

[9] The endline survey for the Alive and Thrive study has since been published (Menon et al., 2016), however these more recent consumption patterns are linked to a behaviour change intervention and so are not discussed further here. The study did not include a control group.
[10] Fish consumption in Bangladesh, rather than an aggregate total, is often further categorised as either; 'small fish' which refers to consumption of SIS of less than 25 cm in length; or 'large fish' which refers to indigenous or exotic species that grow to a size larger than 25 cm in length.

(26.8 g/person/day) among the extreme poor, compared to more than double among the non-poor, consuming 20.9 kg/person/year (57.3 g/person/day). In the BIHS, amongst the lowest expenditure quintile, frequency of fish consumption was 2.4 days in the preceding 7 days, compared to 4.7 days in the highest expenditure quintile, with a national average of 3.6 days.

Consumption in the BIHS also varied by geographic location, with the lowest consumption in Rangpur district in the North-west, with 13 and 20.9 g/person/day of small and large fish respectively (total 33.9 g/person/day). The highest consumption of small fish was in Sylhet in the North-east, with 29.2 g/person/day and the highest consumption of large fish, 52.1g/person/day was in Dhaka district. This is not surprising given that Sylhet is characterised by extensive wetlands area where capture of SIS dominates availability, compared to Dhaka district where pond aquaculture is more common (and hence production of large fish species such as carp). This variation was also reflected in the frequency of consumption which was lowest in Rangpur (2.1 days in the preceding 7 days), and highest in Sylhet and Khulna, both at 4.3 days. The Western region, including Rangpur is known as the ‘rice belt’ where dietary diversity tends to be lower than other regions, so Rangpur having both the lowest quantity and frequency of consumption is unsurprising. It is noteworthy however, that across all wealth groups and geographic locations, fish was by far the most frequently consumed, and consumed in the greatest quantity, compared to all other ASFs, including dairy, eggs, poultry and meat.

Consumption according to geographic districts was not disaggregated in either the HIES study or the CPLTIS study. However, the HIES did report significant differences in fish consumption between rural and urban households, with urban households consuming an average of 13.9 g/person/day *more* than rural households (Toufique & Belton, 2014). This is possibly a reflection of the greater proportion of rural people who are poor, compared to the urban population.

### 2.6.1. Temporal trends in fish consumption

A temporal analysis of fish consumption based on data from the HIES from 2000, 2005 and 2010 was recently published (Toufique & Belton, 2014). This provides a very useful analysis of fish consumption disaggregated by poverty status (extreme poor, moderate poor and non-poor), geographic location (rural and urban), and by fish production sector (aquaculture, inland capture, marine capture). The survey data were collected over 12 month periods, to control for seasonal variations in consumption. Some key messages from this analysis emerge. First, annual per capita fish consumption has grown, although, predominantly within urban areas rather than rural, and most significantly amongst the non-poor compared to the moderate and extreme poor. Second, the proportionate composition of fish consumption from inland capture fisheries (predominantly SIS) declined amongst all income groups, and fish consumption from aquaculture increased amongst all income groups. The same trend emerges for frequency of consumption, decreasing from capture fisheries and increasing for aquaculture (note that data was not disaggregated by income group). Third, fish price trends were significantly different in the period from 2000-2005 and 2005-2010, attributable to the lasting effects from the food price crises of 2007-2008. Real fish prices from capture fisheries fell by 2% from 2000-2005, then increased by 6% in 2005-2010. In contrast, the real price of farmed fish fell by 9% in 2000-2005 and remained steady in 2005-2010, despite a 54% growth in supply.

Similar consumption trends were also documented in the CPLTIS in 1996-1997 and 2006-2007 (Belton et al., 2014b). Over the period, total fish consumption increased by 5.3%, but when disaggregated by source, consumption of non-farmed fish fell by 32.5% compared to an increase of 79.9% in farmed fish.

This trend is supported by a review of studies from 1991-1999 showing the relative contribution of small fish was much higher than large fish (Thompson et al., 2002), compared to cross-sectional data from 2011-2012 which showed that large fish made a more significant contribution to quantity of fish consumed by all expenditure quintiles and districts, compared to small fish (IFPRI, 2013). This review is limited in that the various consumption surveys employ a variety of different methods, sample sizes, seasons and geographic locations of data collection. However, the results are likely to be broadly reflective of temporal shifts in consumption patterns, with growing availability of large species (mostly from aquaculture) and declining availability of SIS from capture fisheries.

### 2.6.2. Fish consumption in the first 1,000 days of life

Several sources report *briefly* on fish consumption within the first 1,000 days; however, the information is often limited to complementary feeding practices (thereby excluding the dietary intake of pregnant or lactating women). The BIHS is the first nationally representative study (of rural Bangladesh) which collected data on intra-household food distribution, including data on consumption in the first 1,000 days of life (for both women and infants).

However; to date, only summary statistics have been published (IFPRI, 2013). The following sections will describe what is currently known about fish consumption in the first 1,000 days of life.

#### 2.6.2.1. Fish consumption of older infants and young children

The age of introduction of particular nutritious food groups is an indicator of appropriate complementary feeding practices, and the introduction of nutritious foods, including ASFs, at 6-8 months of age is considered optimal (Dewey, 2001). The BIHS reported that 65% of rural households had *introduced* fish to infants at age 6-8 months, which is significantly more than the 41% reported in the Alive and Thrive baseline survey (note that the Alive and Thrive survey was conducted in all districts of the country but it was not statistically nationally representative). It is important to make the distinction that 'age of introduction' of foods, as reported in the above two surveys, does not reflect how often these foods are fed or in what quantities. The FSNSP survey conducted in 2011, reports that only 10% of children 6-8 months of age had been fed fish[11] (JPGSPH & HKI, 2012). Similarly, The BIHS survey reported that although the majority of infants aged 6-8 months had been introduced to fish in their diets, only 5.3% of rural households had actually *fed* infants aged 6-8 months flesh foods (including fish) in the last 24 hours. This is very similar to results from the Alive and Thrive study, reporting 5.7% of infants at age 6-8 months, but increasing to 35.2% for infants and young children aged 6-23 months (Saha et al., 2011). This may reflect that whilst it may be desirable to feed ASFs such as fish at this age, the frequency and quantity may be limited. If fish is to be fed to infants, it must first be affordable and available in the family home (Rasheed et al., 2011).

#### 2.6.2.2. Fish consumption of women of childbearing age

Data on fish consumption patterns of women of childbearing age in Bangladesh are relatively limited. The FSNSP survey conducted in 2015 reported that on the day preceding the survey, 50% of women had consumed small fish and 39% had consumed large fish. However, this also varied considerably by district, with the lowest prevalence of consumption in Rangpur (31% had consumed small fish and 32% had consumed large fish) (JPGSPH &

[11] More recent rounds of the FSNSP survey report on consumption of the broader category of 'flesh foods' and do not specifically refer to fish.

NNS, 2016). In terms of quantity of fish consumed, in a smaller study of food consumption patterns of 474 women of reproductive age in Northern Bangladesh (data collected from October 2007-June 2008), average fish consumption was 12.8 g/day, which is significantly lower than averages reported for the region in the BIHS data (IFPRI, 2013; Yakes et al., 2011).

Consumption of aquatic foods by women of childbearing age has been identified as the most important determinant of docosahexaenoic acid (DHA) composition of breastmilk (Michaelsen et al., 2011). Accordingly, breastmilk and fish have been identified as the most important sources of omega-3 fatty acids for children under two years. Given the growing body of literature on the important role of essential fats in cognitive development in children, fish consumption by women of childbearing age is an important area for further research.

### 2.6.3. Intra-household distribution of fish

As mentioned previously, the BIHS is the first nationally representative survey which has collected data on intra-household food distribution; however, to date, only summary statistics have been published and so far this does not include data on the intra-household distribution of food (IFPRI, 2013). It does, however, report on energy adequacy (energy intakes relative to estimated requirements). Adult women (aged 18-64) had consistently lower energy intakes relative to requirements than males across all income groups, in rural Bangladesh. Interestingly, school-aged and adolescent females appeared to have higher energy adequacy compared to their male counterparts.

There is much evidence from smaller studies that adult males, followed by male children are given priority with regard to food portions, particularly of ‘high value’ foods such as fish, and that women often eat last (Chen et al., 1981; Hossain, 2004; Razzaque et al., 2011; Roos et al., 2003a). Whilst not specific to fish, the FSNSP survey captured food insecurity coping behaviours within households, finding that women and girls across all age groups overwhelmingly practise food insecurity coping strategies such as reducing meal size or skipping meals, in comparison to their male counterparts (JPGSPH & NNS, 2016). The most notable discrepancy between females and males was in the adult group (>17 years of age). The proportion of adult women that practised specific coping strategies is around double that of adult men.

## 2.7. Nutritional value of fish

Some initial work in Bangladesh in 2001 analysed the mineral content of raw, edible parts of 13 species, and the vitamin A content of raw, edible parts of 20 species (Roos, 2001). This work revealed some important findings in relation to several SIS being very rich sources of vitamin A, in the forms of de-hydroretinol and retinol, and several SIS being very rich sources of minerals, including iron, zinc and bioavailable calcium. In contrast, the large species analysed, which are often those produced in aquaculture, were not found to be important sources of any of these micronutrients. The predominant explanation for this difference is variability in what is considered to be the edible parts of different species. For example, for most large fish species, normally only the flesh of the fish is consumed, whereas for many SIS, they are often consumed whole, with head, bones and sometimes viscera. Analysis of the distribution of nutrients within anatomical areas of fish, indicate that indeed the composition is not uniform, and often micronutrients are concentrated in areas other than the fish flesh (Roos et al., 2002).

These findings suggest that fish (particularly SIS) are well placed as a food source to contribute to increased nutrient intakes and to prevent micronutrient deficiencies. However, analyses of the nutritional value of fish species in Bangladesh to date have been limited, and do not reflect the large diversity of species available for consumption. No data were available on the vitamin B12 content of fish in Bangladesh, though as an ASF, it is likely to be a rich source. Furthermore, very little data on vitamin D content of fish in Bangladesh were available. This reflects a significant omission given that fish are one of the few known natural dietary sources of vitamin D globally.

The micronutrient content of fish is also of significance for several reasons relating to bioavailability. Nutrient bioavailability refers to the proportion of nutrient ingested that is absorbed from the gastrointestinal tract; which is determined by the chemical structure in which it is found in different food sources as well as several other processes that occur during digestion. Firstly, minerals such as iron and zinc in fish are considered to be highly bioavailable, in comparison to these nutrients in plant-source foods. Relatedly, fish have been identified as the only dietary source (along with animals that eat fish) of a particular form of vitamin A, 3,4-didehydroretinol, also known as vitamin $A_2$, which has been found to have 119-127% of the biological activity of retinol (La Frano et al., 2017; Riabroy et al., 2014). Secondly, recent evidence from Bangladesh has also shown that the haem iron content in fish (the more bioavailable form of iron compared to non-haem iron) may be much higher than that in other ASFs (Wheal et al., 2016). Furthermore, the absorption of these minerals from fish is not inhibited by other compounds in the diet such as phytate which can inhibit absorption of iron and zinc from plant-source foods. Fish also has an important enhancing effect on the bioavailability of non-haem iron and zinc from other foods in the diet, although the biological mechanisms of this effect remain unclear (Gibson et al., 2010; Michaelsen et al., 2009; Sandström et al., 1989). There is also some evidence to suggest that vitamin A may have an enhancing effect on iron absorption from other foods (Andersen et al., 2016; Garcia-Casal et al., 1998); however this has not been confirmed in other studies (Chen et al., 2014; Walczyk et al., 2003). Calcium from fish has also been found to be highly bioavailable, contrary to the common assumption that calcium from bone sources is unavailable for dietary absorption (Hansen et al., 1998).

As is the case globally, fish can also be a source of health risk in Bangladesh through contamination (Ahmed et al., 2016). Water pollution is extensive in Bangladesh, particularly in the rivers surrounding Dhaka where industries are centred (Kibria et al., 2016). Chemical pollutants from the garment, tannery and other industries, and sewage and waste water, are dumped unfiltered into waterways, posing a risk for contamination of fish (Kibria et al., 2016). Contamination of fish with heavy metals is therefore highly location-specific and several studies have analysed content of various heavy metals across the country with variable results (Ahmad et al., 2010; Ahmed et al., 2016; Begum et al., 2013). A recent study of four SIS and one large fish from the Buriganga river concluded that concentrations of individual heavy metals did not pose a health risk, but that their combined effect may be potentially hazardous (Ahmed et al., 2016). This is, however, a complex issue affecting the whole food supply (not only fish) (Islam et al., 2015). Contamination of fish with methylmercury is of particular interest given the known negative effects of contaminated fish consumption by pregnant women on neurodevelopment of their infants (FAO & WHO, 2010). However, other research has shown very low contamination of mercury in fish in Bangladesh (Holsbeek et al., 1997; Sharif, 2007).

## 2.8. Summary of literature review

Despite progress nationally and regionally, malnutrition remains a significant development challenge in Bangladesh. Capture fisheries and aquaculture make an important contribution to nutrition and food security in many fish-consuming countries, including Bangladesh, and represent an important opportunity for further progress in reducing malnutrition. Global trends in growth of aquaculture in recent decades have been successful in stabilising fish prices, allowing relative affordability of fish to increase for many. However, the growth in aquaculture has come at the expense of capture fisheries, in some cases, and can have a tendency to exclude the most vulnerable population groups. The implications of this transition on nutrition and health are largely unknown.

The benefits of the nutritional value of fish in relation to nutrients of public health significance are three-fold. Firstly, some species of fish are rich sources of important nutrients, including animal protein, iron, zinc, calcium and vitamin A. Secondly, iron, zinc and calcium found in fish is highly bioavailable, and unaffected by inhibitory factors that affect absorption of those nutrients from plant-source foods. Relatedly, fish is the only dietary source of vitamin $A_2$, (3,4-didehydroretinol), which has higher biological activity than retinol. Thirdly, fish has an enhancing effect on absorption of iron and zinc from other foods in the diet. Fish is therefore well placed to contribute to improved nutrient intakes and in prevention of micronutrient deficiencies.

In reference to Bangladesh, fish consumption is highly variable and dependant on economic status, geographic location and season, and varies within the household. It is clear that fish consumption has increased over time, although more markedly for the urban and non-poor. It is also clear that consumption of species from capture fisheries has declined in recent decades, and consumption of species from aquaculture has increased. However, given the known variability in nutritional value of different fish species, these shifts in consumption are likely to have impacted nutrient intakes, particularly of important nutrients during the first 1,000 days of life such as iron, zinc, calcium and Vitamin A.

Knowledge of the nutrient composition of commonly consumed foods at a population level is an invaluable and basic tool for understanding the links between food production, access and nutrient intakes. However, despite the clear importance of fish in the Bangladeshi diet, existing composition data do not reflect the large diversity of species available for consumption and have only focused on a few select nutrients rather than comprehensive nutrient profiles. There is also a lack of information on fish consumption at species level and thereby a lack of knowledge on the contribution of fish to nutrient intakes. Furthermore, most data available reflects fish consumption at household level, and little is known about intra-household distribution of fish. These knowledge gaps are a significant impediment to planning of policies and programmes which aim to improve nutrition and food security, and reduce malnutrition.

# 3. Research strategy and methods

This thesis draws on a variety of different methods to address individual RQs. Four common themes link the focus and methodological approaches of each individual RQ addressed in Chapters 4 – 8, as follows:

1. Each study focuses on understanding the current and/or potential contribution of fish to nutrition and food security in Bangladesh.
2. Each study focuses on vulnerable population groups including poor households; pregnant or lactating women; infants and young children of complementary feeding age.
3. Each study focus on micronutrients identified as being of public health concern in the context of Bangladesh: iron, zinc, calcium, vitamin A and vitamin B12. Where appropriate these nutrients are also considered relative to recommended nutrient intakes (RNIs).
4. Where relevant, comparisons are made between fish species from two primary production sectors; capture fisheries (non-farmed fish) and aquaculture (farmed fish). This was essential in making links to policy implications of the research findings, given that the two sectors are managed and governed in Bangladesh in unique ways.

The nutritional value of fish (RQ1) was determined by primary analysis of fish samples for composition of protein, fat and a selection of minerals, vitamins and essential fatty acids according to standard analytical methods. The inclusion of nutrients in addition to those identified as of public health concern was important for consistency with those normally included in national and regional food composition tables. Samples of 55 species of fish were analysed based on fish species commonly available in markets. Geographic variability in fish species consumed was accounted for by collecting samples from fish markets in five distinct regions of the country[12]. Samples were cleaned to obtain raw, edible parts, as determined by local fisher-folk according to local practices. For example, some species are commonly consumed whole, including bones, with only the viscera removed, whereas with

[12] This refers to geographic variability in the *availability* of species collected for analysis, and does not refer to variability in nutrient composition within species.

other species, only the flesh is normally consumed. Samples were homogenised then analysed in duplicate and the nutrient content presented as the mean.

The potential of fish and other local nutrient-rich foods to improve diets among vulnerable groups (RQ2) was informed by a review of food-based approaches including food processing methods, and nutrient composition of local ingredients. A laboratory-based trial production of recipes was then conducted, employing ‘trial and error’, to produce two improved food products, based on traditional recipes; one for pregnant and lactating women, and one for infants and young children of complementary feeding age. These products were then tested for acceptability among the target groups and final products were then analysed for nutrient composition using standard analytical procedures. Samples were analysed in duplicate and the results presented as the mean. The potential contribution of these nutrient-rich food products to diets was then estimated based on analysed nutrient composition data compared to daily RNIs for the target groups. From a policy perspective, the approach employed in this study, though theoretical in nature (describing the *potential* contribution of such foods to RNIs) was important in highlighting the value of fish as a local nutrient-rich food.

Until now, data on the role of fish in diets have been limited by very small sample sizes and distinct geographic locations or population target groups. To answer RQ3, a detailed recently conducted nationally representative survey of rural Bangladesh, including data on intra-household food consumption (based on 24-hour recall) was analysed (BIHS). This survey permitted detailed exploration of consumption patterns of fish and other ASFs among different age, gender and wealth groups, in different geographic regions of the country, to clearly elucidate the current role of fish in diets. The survey undertaken by IFPRI employed a two-stage stratified sampling design of 5,503 households (24,198 individuals). Linear regression was used to estimate mean fish consumption, controlling for age, sex, wealth group and geographic region, and adjusted using sampling weights. Consumption data were positively skewed and so sensitivity analyses were conducted by log-transforming outcome variables where possible, or using quantile regression.

The impact of a shift in fish consumption away from non-farmed towards farmed fish on nutritional quality of diets (RQ4) was based on secondary analysis of nationally representative HIES apparent food consumption data, in 1991 (n= 5,745 households), 2000 (n= 7,440 households) and 2010 (n= 12,240 households). The three independent cross-sectional survey sample designs were based on a two-stage stratified sampling technique;

primary sampling units were selected with probability proportional to size in the first stage and households were selected by systematic random or circular sampling in the second stage (BBS, 1995, 2003, 2011). The survey years were chosen to capture the period from when aquaculture was in its early phase of introduction (1991) up until the most recent dataset that was available. The focus on vulnerable groups was maintained through disaggregating results by rural and urban location, and household wealth groups, consistent with the 'cost of basic needs' method employed by the Bangladesh Bureau of Statistics (BBS). In the absence of intra-household food consumption data capturing this timeframe, the adult male equivalent (AME) method was used to account for different age and sex composition of households over time (Fiedler et al., 2012). This allows for a more accurate estimate of consumption patterns rather than per capita averages (often used in other disciplines when reporting on household level data). Detailed methods on calculation of AMEs used in the analyses presented in this thesis are included in Chapter 7 and also published in detail elsewhere (Waid et al., 2017). Regression analyses were used to estimate mean fish consumption and mean nutrient intakes from fish, at each time point, adjusted using sample weights provided by BBS and for clustering in survey design. All primary outcome variables (fish consumption and nutrient intakes from fish, per AME/day) were positively skewed in distribution and log transformation did not produce a Normal distribution. Therefore, a sensitivity analysis was conducted, using quantile regression which is suitable for non-parametric analyses and is also not sensitive to the presence of outliers (Koenker, 2005).

Measurement of the nutritional quality of fish production systems (RQ5) was informed through a review of potentially relevant indicators, pertaining to the stages of the food and nutrition system (production, distribution, consumption and nutrition). Indicators relevant to the agricultural production stage were then applied to 18 selected fish production sub-systems in the context of Bangladesh to yield insights into the different aspects of nutritional quality captured by different indicators, and their various strengths and limitations.

More detailed descriptions of the methodologies used are found in each manuscript, constituting Chapters 4-8 of this thesis. A schematic overview of the thesis research questions, methodologies and relevant thesis chapters and published or submitted manuscripts is shown in Figure T8.

Figure T8: Schematic overview of research questions, methodology, relevant thesis chapters and published or submitted manuscripts.

| Research Question (RQ) | Relevant Food Security Pillar | Methodology | Output |
|---|---|---|---|
| 1. What is the nutritional value of commonly consumed fish in Bangladesh | Utilisation | Laboratory analysis of nutrient composition of fish species | Chapter 4: manuscript published in *Journal of Food Composition and Analysis* |
| 2. How could local nutrient-rich foods, including fish be utilised to improve nutritional quality of diets? | Utilisation | Review of local food-based-approaches; laboratory-based trial production of recipes; laboratory analysis of nutrient composition of products | Chapter 5: manuscript published in *Food and Nutrition Bulletin* |
| 3. What does fish currently contribute to diets in terms of nutrient intakes? | Access, utilisation | Secondary analysis of nationally representative intra-household food consumption data from BIHS, combined with primary data from RQ1. | Chapter 6: manuscript published in *Public Health Nutrition* |
| 4. How has the transition in aquatic food systems (declining availability of species from capture fisheries, and rapid growth in aquaculture) impacted nutrient intakes? | Access, utilisation, stability | Temporal analysis of secondary data from nationally representative HIES, combined with primary data from RQ1. | Chapter 7: manuscript published in *PLOS ONE* |
| 5. How could nutritional quality of fish production systems be measured and used in decision making? | Availability, access, utilisation | Review of indicators capturing nutritional quality of production; comparative analysis of indicators nutritional quality of different fish production systems, drawing on primary data from RQ1 | Chapter 8: manuscript submitted to *Global Food Security* |

BIHS, Bangladesh Integrated Household Survey; RQ, research question; HIES, Household Income and Expenditure Survey.

# 4. Nutritional value of fish

## 4.1. Forward to manuscript

A basic requirement for understanding the contribution of a particular food or food group to nutritional quality of diets, is knowledge of the nutrient composition of that food. In Bangladesh it is known that fish is widely consumed, and that there are hundreds of species available for consumption, however, very little is known about the nutrient composition of those species. This chapter specifically addresses this knowledge gap by answering RQ 1: What is the nutritional value of commonly consumed fish in Bangladesh and how could fish potentially contribute to nutrient intakes among vulnerable groups? The data presented here forms an essential input to all analyses presented in the remaining chapters of this thesis and underpins the overall contribution of the thesis in elucidating the contribution of fish to nutrition and food security in Bangladesh. In particular, analysis of vitamin B12 and vitamin D in fish samples is a significant contribution to the literature.

Key findings of this analysis are that the content of micronutrients of public health significance in fish, are highly variable across species. Several species, all from capture fisheries, could make a large contribution to RNIs for both pregnant or lactating women, and infants of complementary feeding age, across three or more micronutrients of importance.

Analysis of contaminants such as heavy metals in fish is recognised as an important area of research relevant to health outcomes. In addition to nutrient composition presented here, the content of arsenic, cadmium and lead was analysed for a sub-set of fish samples (24 species of fish, one prawn species and one shrimp species) and published elsewhere (Wheal et al., 2016). Low concentrations of cadmium and lead were found in most samples, and all were below acceptable limits. Low concentrations of arsenic were detected in all samples; further analysis of content of organic versus inorganic arsenic is required to determine the potential health impacts. Due to resource constraints, it was not possible to analyse methylmercury content in fish samples. Previous analyses have found very minimal levels of mercury in fish, attributed to limited industrial input, and the ‘sweeping’ effect of the annual monsoon which prevents accumulation of mercury in sediment of waterbodies (Holsbeek et al., 1997; Sharif, 2007). Particularly for SIS, given their relatively short life cycle, they are also at low risk of accumulation of heavy metals (Ahmed et al., 2016).

This same sub-set of samples was also analysed for content of haem and non-haem iron and published elsewhere (Wheal et al., 2016). Haem iron content of these samples ranged from 18% to 93% of total iron, and in 18 out of the 26 samples, the haem iron proportion was 50% or higher. These results indicate that earlier estimates of haem iron in fish may have underestimated their importance as a richsource of bioavailable dietary iron.

## 4.2. Formal citation and published manuscript

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# Nutrient composition of important fish species in Bangladesh and potential contribution to recommended nutrient intakes

Original research article.

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## Highlights

- We analyse comprehensive nutrient profiles of 55 fish species from Bangladesh
- Results are compared to recommended nutrient intakes in the first 1000 days of life
- Inland capture species are more nutritious compared to cultured species
- Seven species could contribute ≥25% RNIs for 3 or more nutrients simultaneously
- A balanced approach to sustainable capture fisheries and aquaculture is desirable

## Abstract

Fish, in Bangladesh where malnutrition remains a significant development challenge, is an irreplaceable animal-source food in the diet of millions. However, existing data on the nutrient composition of fish do not reflect the large diversity available and have focused on only a few select nutrients. The purpose of this study was to 'fill the gaps' in existing data on the nutrient profiles of common fish in Bangladesh by analysing the proximate, vitamin, mineral and fatty acid composition of 55 fish, shrimp and prawn species from inland capture, aquaculture and marine capture fisheries. When comparing species, the composition of nutrients of public health significance was diverse. Iron ranged from 0.34-19 mg/100 g, zinc from 0.6-4.7 mg/100 g, calcium from 8.6-1900 mg/100 g, vitamin A from 0-2503 µg/100 g and vitamin B12 from 0.50-14 µg/100 g. Several species were rich in essential fatty acids, particularly docosahexaenoic acid in capture fisheries species (86-310 mg/100 g). The potential contribution of each species to recommended nutrient intakes (RNIs) for pregnant and lactating women (PLW) and infants was calculated. Seven species for PLW and six species for infants, all from inland capture, and all typically consumed whole with head and bones, could potentially contribute ≥25% of RNIs for three or more of these nutrients, simultaneously, from a standard portion. This illustrates the diversity in nutrient content of fish species and particularly, the rich nutrient composition of small indigenous species, which should guide policy and programs to improve food and nutrition security in Bangladesh.

## Key words

Small indigenous fish species, capture fisheries, aquaculture, Bangladesh, nutrient composition, 1,000 days, mineral, vitamin, fatty acids, biodiversity

# 1 Introduction

In Bangladesh, fish is an irreplaceable animal-source food in the diet of millions, both in terms of quantity; accounting for approximately 60% of animal protein intake at 18.1 kg consumed per person per year, and frequency of consumption; far exceeding that of any other animal-source food (Belton et al., 2014). The country possesses diverse and abundant aquatic resources with 267 freshwater fish species (Thilsted, 2010), and an annual production of 3.1 million tonnes (Belton and Thilsted, 2014). Bangladesh is also one of many lower-middle income countries to experience the proliferation of aquaculture, now the world's fastest growing food production sector, during a period of decline in capture fisheries (Belton and Thilsted, 2014). Whilst remaining largely successful in increasing supply to meet the demand of a growing population, the extent to which the growth of aquaculture, focusing on only a few select large species, has been able to mitigate reduction in dietary diversity and micronutrient intake from the diverse but waning capture fisheries sector, is questionable (Belton et al., 2014). Despite improvement in some food and nutrition security indicators (JPGSPH and HKI, 2012), malnutrition, largely caused by inadequate micronutrient intake remains widespread with 41% of children under five years suffering from stunted growth (NIPORT et al., 2013). The fisheries and aquaculture sector has been recognised as a key resource in tackling food and nutrition security issues and features prominently in the national development agenda (Government of the Peoples Republic of Bangladesh, 2005a, b, 2006, 2011).

Knowledge of the nutrient composition of important foods is an invaluable tool in understanding the links between food production, access and nutrient intakes, and in devising policies and programs such as development of improved production technologies (Thilsted and Wahab, 2014a), to ensure food supply optimally fulfils population nutrient requirements. However, despite the clear importance of fish in the Bangladeshi diet, existing composition data do not reflect the large diversity of species available for consumption and have only focused on a few select nutrients rather than comprehensive nutrient profiles. The recently published Food Composition Table for Bangladesh is a useful compilation of existing composition data on important foods (including a number of fish and fish products), however, the data come from a large number of sources including regional databases with varying sampling and analytical methods, some of which are now several decades old (INFS, 2013).

The primary objective of this study was to document comprehensive nutrient composition profiles of important fish, shrimp and prawn species in Bangladesh with a specific focus on small indigenous species (SIS). Species and nutrient components selected for analyses were chosen to 'fill the gaps' in existing data (Roos et al., 2002), using rigorous sampling and analytical methods, as well as to extend the data to include more species diversity. The secondary objective was to estimate the potential contribution of fish, shrimp and prawn species to recommended nutrient intakes (RNIs) during the first 1,000 days of life; that is, for women throughout pregnancy and lactation; and for infants from age 7-23 months. Specific nutrients considered are iron, zinc, calcium, iodine, vitamin A and vitamin B12, which are of known public health concern in Bangladesh (Craviari et al., 2008; Fischer et al., 1999; ICDDRB et al., 2013). Data presented in this paper are the most comprehensive collection on the nutrient composition of important fish, shrimp and prawn species in Bangladesh, both in terms of the number of species and the nutrient components analysed, to date.

# 2 Materials and methods

## 2.1 Sampling protocol

The sampling method was constrained by the nature of rural fish markets in this context, largely dependent on the activities of small-scale fishermen whereby supply is unpredictable. As a result, single pooled samples of 54 fish, shrimp and prawn species commonly available during the monsoon season, were collected at local markets and fish landing sites in Mymensingh, Sylhet, Khulna and Cox's Bazar districts in Bangladesh as shown in Figure 1, from July - September 2012. Additionally, one small fish species (*Amblypharyngodon mola*) was sampled both from the market (assumed to be from an inland capture source) and from a homestead pond in Dinajpur district (referred to as $\text{Mola}_{\text{(cultured)}}$). The number of fish collected for each sample was dependent on the average size of each fish species but was a total of approximately two kilograms for each sample. For small fish species (<500 g per fish), a single pooled sample of up to several hundred individual fish (to make a total sample of approximately two kilograms) was collected, for medium fish (500 g – 750 g per fish), a single pooled sample of four individual fish, and for larger fish (>750 g per fish), a single pooled sample of two individual fish. Samples were packed in polyethylene bags at the collection site and transported in an insulated ice box lined with ice chips and away from direct sunlight, to a nearby laboratory facility.


Figure 1: Fish sampling locations in Bangladesh.
Adapted from (Center for Intercultural Learning, 2012).

## 2.2 Sample preparation

The identification details of each sample including common Bangla name, scientific name, location of sample collection and sample preparation details are shown in Table 1. In this paper, samples are referred to by the common Bangla name and are grouped according to the three dominant fish production sectors: inland capture, inland aquaculture and marine capture fisheries. Samples were cleaned by local fisher-folk to obtain raw, edible parts according to traditional practice. Depending on the fish species, edible parts may or may not include the head, viscera, scales, bones and other parts (Table 1). To avoid contamination of samples, non-metal equipment such as plastic cutting boards, buckets and strainers; and ceramic cutting knives were used to obtain raw edible parts. Fish samples were washed with deionised water after cleaning and before being packed in polyethylene bags and stored in a deep freezer at -18°C. Frozen samples were transported in an insulated box, lined with dry ice to laboratories in New Zealand and Denmark for nutrient composition analysis. The temperature of fish samples was measured upon receipt at the testing facilities to ensure that the samples had remained frozen during transportation. Fish species were homogenised as per raw edible parts prior to analysis and subsamples of the homogenate were taken, with size appropriate for individual analytical tests (10-100 g). For several species, the homogenate included bones, and for others, bones were removed prior to homogenisation if they are typically discarded as plate waste, as shown in Table 1.

Table 1: Identification details of fish, shrimp and prawn samples and anatomical parts removed prior to analysis.

| Common Bangla name | Scientific name | Collection district | Anatomical parts excluded prior to analysis |
|---|---|---|---|
| Inland capture | | | |
| *Small indigenous fish species (SIS)* | | | |
| Baim | *Mastacembelus armatus* | Mymensingh | Bones, viscera, fins, skin, dorsal spine, snout |
| Bele, Bailla | *Glossogobius giuris* | Mymensingh | Viscera, fins, scales |
| Boro Kholisha | *Colisa fasciata* | Mymensingh | Viscera, fins, scales |
| Chanda | *Pseudambassis ranga* | Khulna | Viscera, fins |
| Chapila | *Gudusia chapra* | Mymensingh | Viscera, fins, scales |
| Chela | *Chela cachius* | Mymensingh | Viscera, fins, scales |
| Darkina | *Esomus danricus* | Mymensingh | Viscera, scales |
| Dhela | *Osteobrama cotio* | Mymensingh | Viscera, fins, scales |
| Ekthute | *Hyporhamphus limbatus* | Khulna | Viscera, fins |
| Foli | *Notopterus* | Mymensingh | Bones, viscera, fins, scales, operculum |
| Golsha | *Mystus cavasius* | Mymensingh | Bones, viscera, fins, barbell |
| Guchi | *Mastacembelus pancalus* | Mymensingh | Viscera, fins |
| Gutum | *Lepidocephalichthys guntea* | Mymensingh | Viscera, fins |
| Jat Punti | *Puntius sophore* | Sylhet | Viscera, fins, scales |
| Kachki | *Corica soborna* | Mymensingh | No parts removed |
| Kajuli, Bashpata | *Ailia coila* | Sylhet | Bones, viscera, fins, scales |
| Kakila | *Xenontedon cancila* | Mymensingh | Bones, viscera, fins, snout |
| Koi | *Anabas testudineus* | Mymensingh | Bones, viscera, fins, scales, gills |
| Kuli, Bhut Bailla | *Eleotris fusca* | Khulna | Viscera, fins, scales |
| Magur | *Clarias batrachus* | Mymensingh | Bones, viscera, gills, barbell |
| Meni | *Nandus nandus* | Mymensingh | Viscera, fins, scales, gills, operculum |
| Modhu Pabda | *Ompok pabda* | Mymensingh | Bones, fins, viscera |
| Mola | *Amblypharyngodon mola* | Mymensingh | Viscera, fins, scales |
| Mola (cultured)[a] | *Amblypharyngodon mola* | Dinajpur | Viscera, fins, scales |
| Rani, Bou | *Botia dario* | Sylhet | Viscera, fins |
| Shing | *Heteropneustes fossilis* | Mymensingh | Bones, viscera, barbell, gills |
| Taki | *Channa punctatus* | Mymensingh | Bones, viscera, fins, scales |
| Tara Baim | *Macrognathus aculeatus* | Mymensingh | Viscera |
| Tengra | *Mystus vittatus* | Mymensingh | Viscera, barbel |
| Tit Punti | *Puntius ticto* | Mymensingh | Viscera, fins, scales |
| *Large fish species* | | | |
| Gojar | *Channa marulius* | Sylhet | Bones, viscera, fins, scales, gills |
| Ilish | *Tenualosa ilisha* | Khulna | Bones, viscera, fins, scales |
| Jatka Ilish | *Tenualosa ilisha (juvenile)* | Sylhet | Bones, viscera, fins, scales |
| Shol | *Channa striatus* | Sylhet | Bones, viscera, scales, gills, fins |
| Shrimp/prawn | | | |
| Harina Chingri | *Metapenaeus monoceros* | Khulna | Viscera, shell, legs, tail |
| Najari Icha | *Macrobrachium malcolmsonii* | Mymensingh | Viscera, shell, legs, tail |
| Inland aquaculture | | | |
| *Indigenous major carps* | | | |
| Catla | *Catla catla* | Mymensingh | Bones, viscera, fins, scales, gills |
| Mrigal | *Cirrhinus mrigala* | Mymensingh | Bones, viscera, fins, scales, gills |
| Rui | *Labeo rohita* | Mymensingh | Bones, viscera, scales, fins, gills, snout, operculum |
| *Introduced fish species* | | | |
| Common Carp | *Cyprinus carpio* | Khulna | Bones, viscera, fins, scales, gills, operculum |

| | | | |
|---|---|---|---|
| Grass Carp | *Ctenopharyngodon idella* | Mymensingh | Bones, viscera, fins, scales, gills, operculum |
| Silver Carp | *Hypophthalmichthys molitrix* | Mymensingh | Bones, viscera, gills, fins, operculum |
| Thai Pangas | *Pangasianodon hypophthalmus* | Mymensingh | Bones, viscera, gills, fins, operculum |
| Majhari Thai Pangas | *Pangasianodon hypophthalmus (juvenile)* | Sylhet | Bones, viscera, fins, barbel |
| Thai Sarpunti | *Barbonymus gonionotus* | Mymensingh | Bones, viscera, fins, scales, gills, operculum |
| Tilapia | *Oreochromis niloticus* | Mymensingh | Bones, viscera, fins, scales, gills |
| Majhari Tilapia | *Oreochromis niloticus (juvenile)* | Mymensingh | Bones, viscera, fins, scales, gills |
| Marine capture | | | |
| Foli Chanda | *Pampus argenteus* | Khulna | Bones, viscera, fins |
| Kata Phasa | *Stolephorus tri* | Cox's Bazar | Viscera |
| Lal poa | *Johnius argentatus* | Cox's Bazar | Viscera, fins, scales |
| Maita | *Scomberomorus guttatus* | Cox's Bazar | Bones, viscera, fins, scales |
| Murbaila | *Platycephalus indicus* | Cox's Bazar | Bones, viscera, fins, scales |
| Parse | *Liza parsia* | Khulna | Bones, viscera, fins, scales, gills |
| Tailla | *Eleutheronema tetradactylum* | Cox's Bazar | Bones, viscera, fins, scales |
| Tular Dandi | *Sillaginopsis panijus* | Cox's Bazar | Bones, viscera, fins, scales |

[a] Mola is a SIS typically sourced from inland capture fisheries; however, Mola is now included in homestead pond polyculture with carps (Thilsted and Wahab, 2014c).

## 2.3 Analytical methods

The analytical methods for each nutrient component, and corresponding limits of quantitation (LOQ) and reproducibility are summarised in Table 2.

### 2.3.1 Analyses completed at AsureQuality Limited Laboratory, Auckland, New Zealand

For proximate components (protein, fat, moisture, ash), vitamin B12 and folate, standard analytical methods as per the Association of Official Analytical Chemists (AOAC) were used, as listed in Table 2. Minerals (except iodine and selenium) were analysed using the inductively coupled plasma optical emission spectrometry (ICP-OES) method (APA et al., 2012). Iodine and selenium were analysed using the inductively coupled plasma mass spectrometry (ICP-MS) method (APA et al., 2012). Vitamin D and E were analysed using high performance liquid chromatography (HPLC) (Brubacher et al., 1985). Fatty acid composition was analysed using gas liquid chromatography (GLC) (Bannon et al., 1985).

### 2.3.2 Analyses completed at the National Food Institute, DTU, Denmark

Analyses of vitamin A, B12, D, E and folate in 29 species were carried out in Denmark where all tests were conducted in accordance with standard ISO17025 of the International Organization for Standardization, as summarised in Table 2 (ISO, 2005). Vitamin A, D and E were analysed using HPLC. Quantification of vitamin A activity included all-*trans*-retinol, 13-*cis*-retinol, all-*trans*-3,4-dehydroretinol and 13-*cis*-3,4-dehydroretinol. Dehydroretinol is expected to demonstrate 40% of the biological activity of retinol (Shantz and Brinkman, 1950) and possibly up to 110% (Riabroy and Anumihardjo, 2011). For vitamin D, the CEN-method was modified to include quantitation of 25-hydroxy vitamin D3 (Jakobsen et al., 2007). Vitamin B12 was determined by microbiological assay using *Lactobacillus delbrueckii* as the test organism (Nord, 1960), and folate was determined using *Lactobacillus casei* as the test organism (CEN, 2003).

Table 2: Analytical methods used for nutrient composition analysis of fish, shrimp and prawn samples.

| Analyte | Units | Method reference[a] | LOQ[b] | Reproducibility |
|---|---|---|---|---|
| Analyses conducted at *AsureQuality*, New Zealand | | | | |
| Proximate components | | | | |
| Protein | g/100 g | Block digestion (AOAC 981.10) | 0.1 | 0.2√Result |
| Fat (total) | g/100 g | Acid hydrolysis (AOAC 948.15) | 0.1 | 0.5% |
| Moisture | g/100 g | Air drying (AOAC 950.46) | 0.1 | 0.8% |
| Ash | g/100 g | Direct method (AOAC 920.153) | 0.1 | 0.8% |
| Minerals | | | | |
| Iron | mg/kg | Acid Digest, ICP OES (APA et al., 2012) | 0.62 | 7% |
| Zinc | mg/kg | Acid digest, ICP OES (APA et al., 2012) | 1.5 | 7% |
| Calcium | mg/kg | Acid Digest, ICP OES (APA et al., 2012) | 2.8 | 8% |
| Iodine | µg/kg | TMAH Digestion, ICP MS (APA et al., 2012) | 0.02 | 10% |
| Selenium | mg/kg | TMAH Digestion, ICP MS (APA et al., 2012) | 0.02 | 7% |
| Phosphorus | mg/kg | Acid Digest, ICP OES (APA et al., 2012) | 3.3 | 8% |
| Magnesium | mg/kg | Acid digest, ICP OES (APA et al., 2012) | 0.74 | 7% |
| Sodium | mg/kg | Acid Digest, ICP OES (APA et al., 2012) | 2.7 | 8% |
| Potassium | mg/kg | Acid Digest, ICP OES (APA et al., 2012) | 3.3 | 8% |
| Manganese | mg/kg | Acid digest , ICP OES (APA et al., 2012) | 0.05 | 7% |
| Sulphur | mg/100 g | Acid digest, ICP OES (APA et al., 2012) | 0.02 | 7% |
| Copper | mg/kg | Acid digest, ICP OES (APA et al., 2012) | 0.1 | 8% |
| Chromium | mg/kg | Wet Oxidation, ICP MS (APA et al., 2012) | 0.05 | 10% |
| Vitamins | | | | |
| Vitamin B12 | µg/100 g | Surface plasmon resonance (AOAC 2011.16) | 0.2 | 12% |
| Vitamin D3 | IU/100 g | HPLC (Brubacher et al., 1985) | 20 | 16% |
| Vitamin D2 | IU/100 g | HPLC (Brubacher et al., 1985) | 20 | 16% |
| Vitamin E (α-tocopherol) | IU/100 g | HPLC (Brubacher et al., 1985) | 0.11 | 10% |
| Vitamin E, γ, δ tocopherols) | IU/100 g | HPLC (Brubacher et al., 1985) | 0.01 | 10% |
| Folate | µg/100 g | Optical biosensor assay (AOAC 2011.05) | 8 | 12% |
| Fatty Acids | mg/100 g | GLC (Bannon et al., 1985) | 10 | 12% |
| Analyses conducted at *National Food Institute, DTU*, Denmark | | | | |
| Vitamins | | | | |
| Vitamin A (all components) | µg/100 g | HPLC (Roos et al., 2007a) | 10 | 19%[c] |
| Vitamin B12 | µg/100 g | Microbiological assay (Nord, 1960) | 0.03 | 13%[c] |
| Vitamin D3 | µg/100 g | HPLC (CEN, 2009) | 0.05 | 10%[c] |
| 25OHD3 | µg/100 g | HPLC (CEN, 2009) | 0.1 | -[d] |
| Vitamin E (α-tocopherol) | mg/100 g | HPLC (CEN, 2000) | 0.02 | 9.9%[c] |
| Folate | µg/100 g | Microbiological assay (CEN, 2003) | 0.2 | 18%[c] |

[a] AOAC, Association of Official Analytical Chemists, http://www.aoac.org; ICP OES, inductively coupled plasma optical emission spectrometry; TMAH, Tetramethylammonium hydroxide; ICP MS, inductively coupled plasma mass spectrometry; HPLC, high performance liquid chromatography; GLC, gas liquid chromatography.
[b] LOQ, limit of quantitation.
[c] Values are based on analyses of fish samples in this data set.
[d] Not applicable as no result returned a detectable quantity.

## 2.4 Presentation of results

All proximate components and minerals were analysed in duplicate and presented here as the mean, reported to the same number of significant figures as per original analytical results. For some samples a result of 'none detected' is given when a quantifiable result was found for one replicate but the corresponding duplicate returned a result below the LOQ. All minerals (except sulphur) were reported in metric units per kg of raw, edible parts but are presented here as metric units per 100 g raw, edible parts for ease of use. Energy was calculated using Atwater factors from assayed proximate components (Merill and Watt, 1973). Due to resource limitations, vitamins and fatty acids were analysed singly and presented here as per analytical results. Vitamin A components are presented as µg/100 g of 13-*cis*-retinol, 13-*cis*-3,4-dehydroretinol, all-*trans*-retinol, all-*trans*-3,4-dehydroretinol and β-carotene and then total vitamin A in retinol activity equivalents (µg RAE/100 g) has been calculated according to the following conversion factors: 1 µg all-*trans*-retinol = 1 µg RAE, 1 µg 13-*cis*-retinol = 0.75 µg RAE (Ames et al., 1955), 1 µg all-*trans*-3,4-dehydroretinol = 0.4 µg RAE, 1 µg 13-*cis*-3,4-dehydroretinol = 0.4 µg RAE (Shantz and Brinkman, 1950), 1 µg β-carotene = 0.08 µg RAE (Ottin et al., 2006). Species analysed for vitamin D and E at *AsureQuality* were reported in International Units per 100 g of raw edible parts (IU/100 g) and were converted to *International System of Units* (SI) units (µg/100 g) using the following conversion factors: vitamin D2 (µg/100 g) = vitamin D2 (IU/100 g) x 0.025, vitamin D3 (µg/100 g) = vitamin D3 (IU/100 g) x 0.025 and vitamin $E_{(tocopherol)}$ (mg/100 g) = vitamin $E_{(tocopherol)}$ (IU/100 g) x 0.67 (FAO/INFOODS, 2012). Fatty acid components are presented here as per analytical results and total n-6 polyunsaturated fatty acids (PUFA) and n-3 PUFA were calculated from the fatty acid profile. All results are presented as per 100 g raw, edible parts. The composition of nutrients of public health significance, vitamins and fatty acids, in relation to RNI's have been discussed in the results section.

### 2.4.1 Previously published data on nutrient composition of fish species

Data on the mineral content of 13 species and vitamin A content of 20 species had previously been published using similar sampling methods and therefore these analyses were not repeated but have been included in the presentation of results here for completeness. In this pre-existing data, minerals (except selenium) were analysed by atomic absorption spectrometry (AAS), selenium was analysed using inductively coupled plasma atomic emission spectrometry (ICP-AES), and vitamin A was analysed using HPLC (Roos, 2001). Due to slight differences in methodology for mineral analysis in previous data and newly presented data, care should be taken in making comparisons across species.

### 2.4.2 Statistical analyses of results

Descriptive statistics of the data are presented including the range and mean, rounded to the same number of significant figures as original analytical results. Pearson's correlation coefficients were calculated using STATA (version 12.1, Statacorp, Texas, USA), to describe the linear dependence of fat, moisture and energy for all 55 species; and ash and various minerals for 41 species for which all mineral compositions were analysed.

## 2.5 Calculation of potential contribution to recommended nutrient intakes

The potential contribution of each species to RNIs of nutrients of interest during the first 1,000 days was calculated first by assigning an average RNI target for each nutrient as shown in Table 5, for pregnant and lactating women (PLW) to account for variations in requirements throughout the three trimesters of pregnancy and first 12 months of lactation, and for infants to account for variations in requirements throughout the period from age 7-23 months (FAO/WHO, 2004); then by calculating the contribution from a standard portion of each species (50 g/day for PLW and 25 g/day for infants) as a percentage of the average RNI. The nutrients of interest considered here are iron, zinc, calcium, iodine, vitamin A and vitamin B12. The RNIs for iron and zinc further vary according to estimated overall dietary bioavailability which is dependent on a number of factors including the presence of animal-flesh foods, phytates and other factors; and are therefore provided according to four and three dietary bioavailability categories, respectively. The typical Bangladeshi diet based on polished rice, fish and vegetables is assumed to fit best with criteria used to define the '10% bioavailability' category for iron, and 'moderate bioavailability' category for zinc (FAO and WHO, 2004).

# 3 Results and discussion

## 3.1 Proximate composition

The energy, protein, fat, moisture and ash composition of all 55 species are shown in Table 3. The total energy content varied greatly with a range of 267-1020 kJ/100 g which is related to variation in fat content in the different species, as evidenced by a correlation coefficient of 0.98. The total protein content in fish species ranged from 11.9-20.6 g/100 g and can be assumed to be of high dietary quality, being an animal-source protein (WHO, 2007). The fat content ranged from 0.3-18.3 g/100 g. Fat generally varies much more widely than other proximate components of fish, and usually reflects differences in the way fat is stored in particular species but may also be affected by seasonal/lifecycle variations and the diet/food availability of the species at the time of sampling (Ababouch, 2005). For example, bottom dwelling species such as the indigenous major carps are typically lean fish, storing fat in the liver (Ababouch, 2005), whereas, migratory fish such as Ilish have a higher content of dark muscle which tends to be rich in fat (Alam et al., 2012). The moisture content of fish species ranged from 60.2-85.4 g/100 g and, as expected was negatively correlated with fat and energy content (correlation coefficient of -0.91 and -0.95 respectively). Ash content ranged from 0.7-5.3 g/100 g and is positively correlated with mineral content, particularly calcium, phosphorus, magnesium and zinc, with correlation coefficients of 0.98, 0.95, 0.85, and 0.74 respectively. The large variation in ash content is likely related to inclusion of bones as edible parts in some species, which would lead to higher ash content in these.

Table 3: Energy, protein, fat, moisture and ash content of fish, shrimp and prawn species[13].[a]

| | Nutrient content per 100 g raw edible parts | | | | |
|---|---|---|---|---|---|
| | Energy kJ | Protein g | Fat g | Moisture g | Ash g |
| Inland capture | | | | | |
| *Small indigenous fish species (SIS)* | | | | | |
| Baim | 381 | 17.9 | 1.7 | 78.6 | 1.0 |
| Bele, Bailla | 292 | 16.6 | 0.4 | 80.3 | 3.1 |
| Boro Kholisha | 354 | 15.2 | 2.5 | 77.0 | 5.2 |
| Chanda | 400 | 15.5 | 3.8 | 76.2 | 4.7 |
| Chapila | 385 | 15.5 | 3.8 | 78.4 | 3.4 |
| Chela | 349 | 15.2 | 2.4 | 79.4 | 2.9 |
| Darkina | 384 | 15.5 | 3.2 | 77.1 | 4.2 |
| Dhela | 387 | 14.7 | 3.8 | 78.1 | 3.7 |
| Ekthute | 360 | 17.9 | 1.7 | 76.7 | 4.1 |
| Foli | 384 | 20.5 | 0.6 | 76.7 | 1.4 |
| Golsha | 479 | 16.8 | 5.1 | 76.8 | 1.0 |
| Guchi | 394 | 17.9 | 2.6 | 77.7 | 2.2 |
| Gutum | 431 | 17.2 | 3.9 | 76.7 | 2.6 |
| Jat Punti | 541 | 15.7 | 7.2 | 73.2 | 3.5 |
| Kachki | 267 | 11.9 | 1.9 | 85.4 | 1.7 |
| Kajuli, Bashpata | 751 | 17.1 | 12.6 | 70.0 | 0.7 |
| Kakila | 329 | 17.1 | 1.2 | 80.2 | 1.8 |
| Koi | 737 | 15.5 | 12.8 | 70.5 | 1.0 |
| Kuli, Bhut Bailla | 330 | 16.9 | 1.2 | 78.9 | 3.1 |
| Magur | 326 | 16.5 | 1.3 | 81.3 | 1.1 |
| Meni, Bheda | 338 | 16.7 | 1.7 | 78.5 | 3.6 |
| Modhu Pabda | 619 | 16.2 | 9.5 | 73.9 | 0.9 |
| Mola | 445 | 17.3 | 4.5 | 75.6 | 3.5 |
| Mola (cultured) | 412 | 14.7 | 4.6 | 77.3 | 4.0 |
| Rani, Bou | 654 | 14.9 | 10.6 | 70.8 | 3.2 |
| Shing | 374 | 19.1 | 1.9 | 79.2 | 1.0 |
| Taki | 306 | 18.3 | 0.6 | 80.7 | 2.1 |
| Tara Baim | 387 | 17.2 | 2.6 | 79.4 | 2.3 |
| Tengra | 428 | 15.1 | 4.6 | 76.6 | 3.7 |
| Tit Punti | 385 | 15.4 | 3.4 | 77.5 | 3.8 |

[13] The edible parts of each species are listed in Table 1.

| | | | | | |
|---|---|---|---|---|---|
| *Large fish species* | | | | | |
| Gojar | 286 | 17.1 | 0.3 | 82.6 | 1.0 |
| Ilish | 1020 | 16.4 | 18.3 | 60.2 | 1.4 |
| Jatka Ilish | 618 | 19.0 | 7.7 | 71.8 | 2.5 |
| Shol | 310 | 18.7 | 0.3 | 81.0 | 1.2 |
| Shrimp/prawn | | | | | |
| Harina Chingri | 333 | 17.6 | 1.0 | 79.5 | 2.2 |
| Najari Icha | 364 | 15.7 | 2.2 | 77.9 | 3.3 |
| Inland aquaculture | | | | | |
| *Indigenous major carps* | | | | | |
| Catla | 267 | 14.9 | 0.7 | 84.1 | 1.0 |
| Mrigal | 363 | 18.9 | 1.1 | 78.9 | 1.1 |
| Rui | 422 | 18.2 | 3.0 | 77.7 | 1.0 |
| *Introduced fish species* | | | | | |
| Common Carp | 381 | 16.4 | 2.9 | 80.0 | 1.0 |
| Grass Carp | 341 | 15.2 | 1.1 | 80.2 | 1.1 |
| Silver Carp | 435 | 17.2 | 4.1 | 77.8 | 1.5 |
| Thai Pangas | 925 | 16.0 | 17.7 | 65.5 | 0.9 |
| Majhari Thai Pangas | 360 | 18.6 | 1.4 | 79.2 | 1.4 |
| Thai Sharpunti | 466 | 18.4 | 4.4 | 76.2 | 1.6 |
| Tilapia | 390 | 19.5 | 2.0 | 77.6 | 1.8 |
| Majhari Tilapia | 412 | 19.0 | 2.6 | 77.5 | 1.3 |
| Marine capture | | | | | |
| Foli Chanda | 320 | 17.2 | 0.9 | 82.1 | 0.7 |
| Kata Phasa | 357 | 17.6 | 2.1 | 77.4 | 4.1 |
| Lal Poa | 381 | 18.1 | 2.4 | 75.2 | 5.3 |
| Maita | 405 | 20.5 | 1.1 | 76.5 | 1.0 |
| Murbaila | 310 | 18.8 | 0.3 | 80.6 | 1.6 |
| Parse | 813 | 16.1 | 14.3 | 67.8 | 1.2 |
| Tailla | 425 | 20.6 | 2.2 | 76.5 | 1.1 |
| Tular Dandi | 345 | 19.3 | 0.6 | 78.8 | 1.6 |

[a] All data are newly reported values.
n = 1 pooled sample.

## 3.2 Mineral composition

The iron, zinc, calcium, iodine, selenium, phosphorus, magnesium, sodium, potassium, manganese, sulphur and copper composition for all species are shown in Table 4.

Table 4: Mineral composition of fish, shrimp and prawn species[14].

| | Nutrient content per 100 g raw edible parts | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Iron | Zinc | Calcium | Iodine | Selenium | Phosphorus | Magnesium | Sodium | Potassium | Manganese | Sulphur | Copper |
| | mg | mg | mg | µg | µg | mg | mg | mg | mg | mg | mg | mg |
| Inland capture | | | | | | | | | | | | |
| *Small indigenous fish species (SIS)* | | | | | | | | | | | | |
| Baim | 1.9 [a] | 1.1 [a] | 449 [a] | 13 | 12 [a] | - | 35 [a] | 47 [a] | 322 [a] | - | - | - |
| Bele, Bailla | 2.3 | 2.1 | 790 | 25 | 31 | 520 | 38 | 56 | 210 | 2.3 | 200 | 0.030 |
| Boro Kholisha | 4.1 | 2.3 | 1700 | 20 | 26 | 910 | 44 | 61 | 210 | 2.0 | 190 | 0.046 |
| Chanda | 2.1 [a] | 2.6 [a] | 1153 [a] | 24 | 22 [a] | - | 45 [a] | 61 [a] | 206 [a] | - | - | - |
| Chapila | 7.6 [a] | 2.1 [a] | 1063 [a] | 13 | 13.4 [a] | - | 41 [a] | 57 [a] | 281 [a] | - | - | - |
| Chela | 0.84 | 4.7 | 1000 | 19 | 32 | 590 | 39 | 28 | 85 | 0.60 | 170 | 0.052 |
| Darkina | 12 [a] | 4.0 [a] | 891 [a] | 81 | 12 [a] | - | 38 [a] | 110 [a] | 200 [a] | - | - | - |

[14] The edible parts of each species are listed in Table 1.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dhela | 1.8 | 3.7 | 1200 | 9.5 | 29 | 660 | 39 | 37 | 110 | 0.60 | 170 | 0.046 |
| Ekthute | 1.5 | 3.6 | 1300 | 11 | 28 | 770 | 51 | 52 | 140 | 0.73 | 240 | 0.030 |
| Foli | 1.7 | 1.6 | 230 | nd | 22 | 270 | 34 | 53 | 280 | 0.078 | 260 | 0.058 |
| Golsha | 1.8 | 1.3 | 120 | 13 | 41 | 180 | 26 | 33 | 210 | 0.22 | 220 | 0.039 |
| Guchi | 2.7 [a] | 1.3 [a] | 491 [a] | 19 | 45 [a] | - | 34 [a] | 52 [a] | 294 [a] | - | - | - |
| Gutum | 3.3 | 2.5 | 950 | 16 | 36 | 650 | 57 | 45 | 240 | 0.46 | 190 | 0.054 |
| Jat Punti | 2.2 [a] | 2.9 [a] | 1042 [a] | 20 | 9.5 [a] | - | 39 [a] | 53 [a] | 203 [a] | - | - | - |
| Kachki | 2.8 [a] | 3.1 [a] | 476 [a] | 6.0 | 7.5 [a] | - | 26 [a] | 38 [a] | 134 [a] | - | - | - |
| Kajuli, Bashpata | 0.82 | 1.2 | 110 | 7.1 | 27 | 140 | 22 | 26 | 130 | 0.17 | 200 | 0.059 |
| Kakila | 0.65 | 1.9 | 610 | 37 | 29 | 450 | 35 | 49 | 190 | 0.47 | 240 | 0.046 |
| Koi | 0.87 | 0.60 | 85 | nd | 19 | 160 | 21 | 31 | 260 | 0.052 | 190 | 0.052 |
| Kuli, Bhut Bailla | 0.79 | 2.0 | 980 | 31 | 49 | 580 | 39 | 55 | 190 | 0.29 | 210 | 0.030 |
| Magur | 1.2 | 0.74 | 59 | 22 | 22 | 210 | 26 | 61 | 350 | 0.021 | 180 | 0.050 |
| Meni, Bheda | 0.84 | 1.6 | 1300 | 13 | 29 | 810 | 44 | 68 | 250 | 1.4 | 210 | 0.029 |
| Modhu Pabda | 0.46 | 0.90 | 91 | 7.0 | 27 | 150 | 23 | 47 | 230 | 0.073 | 190 | 0.042 |
| Mola | 5.7 [a] | 3.2 [a] | 853 [a] | 17 | 5 [a] | - | 35 [a] | 39 [a] | 152 [a] | - | - | - |
| Mola (cultured) | 19 | 4.2 | 1400 | 33 | 19 | 700 | 49 | 31 | 58 | 1.9 | 160 | 0.047 |
| Rani, Bou | 2.5 | 4.0 | 1300 | 25 | 31 | 820 | 45 | 48 | 160 | 1.5 | 170 | 0.094 |
| Shing | 2.2 | 1.1 | 60 | nd | 31 | 220 | 37 | 54 | 300 | 0.038 | 230 | 0.057 |
| Taki | 1.8 [a] | 1.5 [a] | 766 [a] | 18 | 15 [a] | - | 35 [a] | 47 [a] | 260 [a] | - | - | - |
| Tara Baim | 2.5 [a] | 1.2 [a] | 457 [a] | 13 | 15 [a] | - | 34 [a] | 46 [a] | 290 [a] | - | - | - |
| Tengra | 4.0 [a] | 3.1 [a] | 1093 [a] | 28 | 24 [a] | - | 36 [a] | 57 [a] | 203 [a] | - | - | - |
| Tit Punti | 3.4 [a] | 3.8 [a] | 1480 [a] | 19 | 10 [a] | - | 47 [a] | 61 [a] | 187 [a] | - | - | - |
| *Large fish species* | | | | | | | | | | | | |
| Gojar | 0.43 | 0.60 | 9.3 | 14 | 37 | 150 | 23 | 30 | 300 | 0.018 | 230 | 0.015 |
| Ilish | 1.9 | 1.2 | 220 | 37 | 40 | 300 | 27 | 44 | 280 | 0.25 | 210 | 0.12 |
| Jatka Ilish | 2.5 | 1.8 | 500 | 34 | 41 | 430 | 32 | 58 | 280 | 0.40 | 250 | 0.12 |
| Shol | 0.41 | 0.73 | 96 | nd | 42 | 210 | 27 | 42 | 350 | 0.10 | 260 | 0.017 |
| Shrimp/prawn | | | | | | | | | | | | |
| Harina Chingri | 2.7 | 1.3 | 550 | 26 | 42 | 290 | 45 | 85 | 210 | 0.57 | 190 | 0.49 |
| Najari Icha | 13 | 3.3 | 1200 | 120 | 34 | 320 | 52 | 75 | 200 | 2.8 | 190 | 1.2 |
| Inland aquaculture | | | | | | | | | | | | |
| *Indigenous major carps* | | | | | | | | | | | | |
| Catla | 0.83 | 1.1 | 210 | 18 | 27 | 260 | 28 | 74 | 310 | 0.070 | 170 | 0.029 |
| Mrigal | 2.5 [a] | 1.5 [a] | 960 [a] | 15 | 19 [a] | - | 39 [a] | 71 [a] | 266 [a] | - | - | - |
| Rui | 0.98 | 1.0 | 51 | 20 | 29 | 210 | 28 | 61 | 330 | 0.051 | 200 | 0.038 |
| *Introduced fish species* | | | | | | | | | | | | |
| Common Carp | 1.1 | 2.2 | 37 | 13 | 22 | 180 | 26 | 67 | 300 | 0.020 | 190 | 0.033 |
| Grass Carp | 0.46 | 0.91 | 54 | nd | 31 | 190 | 27 | 73 | 300 | 0.018 | 170 | 0.034 |
| Silver Carp | 4.4 [a] | 1.4 [a] | 903 [a] | nd | 12 [a] | - | 34 [a] | 96 [a] | 225 [a] | - | - | - |
| Thai Pangas | 0.69 | 0.65 | 8.6 | nd | 19 | 150 | 21 | 47 | 250 | 0.010 | 220 | 0.023 |
| Majhari Thai Pangas | 2.7 | 1.1 | 59 | 17 | 11 | 160 | 21 | 81 | 260 | 0.092 | 170 | 0.086 |
| Thai Sharpunti | 1.6 | 1.8 | 270 | 38 | 22 | 280 | 29 | 72 | 240 | 0.073 | 250 | 0.036 |
| Tilapia | 1.1 | 1.2 | 95 | 11 | 26 | 190 | 26 | 81 | 280 | 0.052 | 240 | 0.031 |
| Majhari Tilapia | 1.6 | 1.4 | 120 | nd | 52 | 220 | 26 | 52 | 320 | 0.13 | 270 | 0.041 |
| Marine capture | | | | | | | | | | | | |
| Foli Chanda | 0.34 | 0.66 | 31 | 9.4 | 78 | 110 | 21 | 55 | 160 | 0.024 | 190 | nd |
| Kata Phasa | 1.6 | 3.1 | 1500 | 10 | 56 | 840 | 55 | 92 | 130 | 0.38 | 220 | 0.023 |
| Lal Poa | 1.7 | 2.1 | 1900 | 41 | 110 | 1000 | 54 | 110 | 150 | 0.60 | 230 | 0.042 |
| Maita | 0.49 | 0.70 | 34 | 14 | 57 | 200 | 31 | 49 | 290 | 0.051 | 250 | 0.040 |
| Murbaila | 1.7 | 0.79 | 150 | 19 | 51 | 230 | 29 | 90 | 330 | 0.012 | 250 | 0.033 |
| Parse | 1.3 | 0.84 | 66 | 6.9 | 20 | 160 | 23 | 53 | 270 | 0.036 | 220 | 0.032 |
| Tailla | 0.60 | 0.90 | 37 | 26 | 46 | 200 | 30 | 74 | 330 | 0.010 | 300 | 0.051 |
| Tular Dandi | 2.1 | 0.89 | 230 | 20 | 52 | 250 | 30 | 100 | 240 | 0.14 | 260 | 0.036 |

[a] Data previously published by Roos (2001)[15].
- No data available.
nd, Not detected. Limit of detection for iodine: 0.01 µg/kg (equivalent to 0.001 µg/100 g).
n = 1 pooled sample.

### 3.2.1 Iron

Iron content varied considerably with a range from 0.34-19 mg/100 g and a mean value of 2.6 mg/100 g. Three species of fish and one species of prawn were identified that would meet ≥25% of the RNI for PLW and infants: Chapila, Darkina, Mola and Najari Icha (Table 5). These results show a greater range in iron content compared to a values reported in the global FAO/INFOODS database on fish and shellfish (excluding molluscs) (FAO/INFOODS, 2013). Of interest is that iron content of cultured Mola (19 mg/100 g) is much higher than previously reported values for capture Mola (5.7mg/100 g)[16]. This may be partly attributable to sampling variability, methodological differences in analysis of iron content, or may reflect real differences in the accumulation of iron in this species based on differing environmental conditions. The true nature and magnitude of these differences should be further investigated. Overall, the data presented here indicate that several species (all from inland capture fisheries) may contribute significantly to dietary iron intakes in Bangladesh which is of high bioavailability as an animal-source food (FAO and WHO, 2004). This may have important policy implications given the public health significance of iron deficiency in Bangladesh, with prevalence recently estimated at 10.7% in preschool aged children and 7.1% in adult women (ICDDRB et al., 2013), and the well documented negative effects of deficiency on physical and cognitive development, pregnancy outcomes, morbidity and mortality.

### 3.2.2 Zinc

Zinc concentration varied considerably from 0.6-4.7 mg/100 g with a mean content of 1.9 mg/100 g. These results are within the range of fish and seafood reported elsewhere (FAO/INFOODS, 2013). Four species were identified that would meet ≥25% of the RNI for PLW; Chela, Darkina, cultured Mola and Rani, and two species: Chela and cultured Mola,

[15] This work was also later published as a peer-reviewed journal article (Roos et al., 2003b).
[16] Note that the sampling methods from these two studies differ slightly; in the present study, the mean content is based on duplicate analysis from a single pooled sample of ~2000 g; whereas, in the earlier study, the mean content is based on single analysis of three replicate samples of ~100-200 g each. The larger sample size of the present study reduces the standard error of the mean, but the use of replicate samples in the earlier study improves representativeness.

which would meet ≥25% of the RNI for infants, from a standard portion (Table 5). A further seven species of fish and one species of prawn (all of which are capture species) would meet 20-25% of RNIs for PLW (Dhela, Ekthute, Kachki, Kata Phasa, Mola, Najari Icha, Tengra, and Tit Punti) and a further six species of fish and one species of prawn would meet 20-25% of RNIs for infants (Darkina, Dhela, Ekthute, Mola, Najari Icha, Rani and Tit Punti). In light of recent estimates of a national prevalence of zinc deficiency in 57.3% of women and 44.6% of pre-school aged children in Bangladesh (ICDDRB et al., 2013), several SIS and prawn species could contribute significantly to dietary zinc intake, also taking into consideration that zinc in animal-source foods is highly bioavailable (FAO and WHO, 2004).

### 3.2.3 Calcium

Calcium content ranged considerably from 8.6-1900 mg/100 g with a mean content of 600 mg/100 g. These results are within the range of fish and seafood reported elsewhere (FAO/INFOODS, 2013). As would be expected, calcium content was much higher in species in which bones are commonly consumed and included in the edible parts. Fourteen species were identified that would meet ≥50% of the RNI for PLW, and 18 species that would meet ≥50% of the RNI for infants (Table 5). Calcium deficiency nationally has not been evaluated, however, it has been implicated in the development of rickets, estimated to affect 550,000 children in 2008 (Craviari et al., 2008; Fischer et al., 1999; ICDDRB, 2009), and in a study in two rural subdistricts of Bangladesh, it was estimated no women or young children had diets adequate in calcium, attributable to low food intake and low dietary diversity (Arsenault et al., 2013). In developed countries, dairy products tend to be the primary source of dietary calcium; however, this is not the case in Bangladesh where frequency of dairy consumption is very low (Belton et al., 2014), (JPGSPH and HKI, 2012). The data presented here further support the conclusion that in Bangladesh, SIS eaten whole, with bones are a significant source of highly bioavailable dietary calcium (Larsen et al., 2000; Roos et al., 2007a; Roos et al., 2007b).

### 3.2.4 Iodine

Iodine was below detectable limits in eight of the 55 species, and ranged up to 120 µg/100 g, with a mean of 22 µg/100 g. Only one species of prawn (Najari Icha) would contribute to ≥25% of the RNI, and one species of fish (Darkina) would contribute ≥20% of the RNI, for PLW and infants (Table 5). The iodine content of foods tends to be largely dependent on environmental conditions. Marine fish and seafood tend to be rich dietary sources with a mean composition of 83 µg/100 g in marine fish reported elsewhere (FAO/WHO, 2004);

however, this was not particularly evident in the marine species analysed here, with a range of only 6.9-41 µg/100 g. This is the first study in which the iodine content of fish, shrimp and prawn in Bangladesh was analysed. The composition of iodine in inland capture species reported here was within the range of fish and seafood reported elsewhere (FAO/INFOODS, 2013), but most species are unlikely to be a significant source of dietary iodine.

#### 3.2.5 Selenium, phosphorus, magnesium, sodium, potassium, manganese, sulphur, copper and chromium

The contents of these minerals were analysed for data completeness but they are not associated with significant public health concerns currently, and therefore, their nutritional significance is not discussed here. Selenium content of foods varies significantly according to surrounding environmental conditions. The selenium content of species analysed here showed a wide range from 5-110 µg/100 g, consistent with data reported elsewhere (FAO/INFOODS, 2013). Phosphorus content ranged from 110-1000 mg/100 g, with higher composition in fish species with bones included in edible parts, also consistent with values reported elsewhere (FAO/INFOODS, 2013). The ranges of magnesium (21-57 mg/100 g), sodium (26-110 mg/100 g) and potassium (58-350 mg/100 g) content were broadly consistent with ranges for other fish and seafood reported elsewhere (FAO/INFOODS, 2013). Manganese content ranged from 0.010-2.8 mg/100 g and is higher than results reported elsewhere (FAO/INFOODS, 2013), which may be related to water pollution (Törnqvist et al., 2011). Sulphur content ranged from 160-300 mg/100 g and is higher than results reported in the FAO/INFOODS global database, although consistent with results reported elsewhere in the literature (Vlieg et al., 1991). Copper content ranged from 0-1.2 mg/100 g with highest values found in shrimp and prawn, far exceeding that in fish species, with 0.49 and 1.2 mg/100 g found in Harina Chingri and Najari Icha, respectively; although largely consistent with results reported for fish and seafood elsewhere (FAO/INFOODS, 2013). Chromium was undetectable in almost all species, with the exception of cultured Mola and Najari Icha which had very low concentrations of 0.027 and 0.022 mg/100 g, respectively, also consistent with data reported elsewhere (FAO/INFOODS, 2013).

Table 5: Potential contribution of fish, shrimp and prawn species in a standard portion[a], to average daily RNI[bc] (%) for PLW[d] and infants (7-23 months)[17].

| | Iron (mg) | | Zinc (mg) | | Calcium (mg) | | Iodine (µg) | | Vitamin A (µg RAE)[e] | | Vitamin B12 (µg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PLW | Infant | PLW | Infant | PLW | Infant | PLW | Infant | PLW | Infant | PLW | Infant |
| Average daily RNI | 15 | 7 | 7.9 | 4.1 | 1040 | 467 | 200 | 90 | 829 | 400 | 2.7 | 0.8 |
| Inland capture | | | | | | | | | | | | |
| *Small indigenous fish species (SIS)* | | | | | | | | | | | | |
| Baim | 6 | 7 | 7 | 7 | 22 | 24 | 3 | 4 | 2 | 2 | 32 | 54 |
| Bele, Bailla | 8 | 8 | 13 | 13 | 38 | 42 | 6 | 7 | 1 | 1 | 39 | 66 |
| Boro Kholisha | 14 | 15 | 15 | 14 | 82 | 91 | 5 | 6 | 3 | 3 | 103 | 173 |
| Chanda | 7 | 8 | 16 | 16 | 55 | 62 | 6 | 7 | 20 | 21 | 119 | 200 |
| Chapila[f] | 25 | 27 | 13 | 13 | 51 | 57 | 3 | 4 | 4 | 5 | 129 | 218 |
| Chela[f] | 3 | 3 | 30 | 29 | 48 | 54 | 5 | 5 | 8 | 8 | 104 | 176 |
| Darkina[f] | 40 | 43 | 25 | 24 | 43 | 48 | 20 | 22 | 40 | 41 | 231 | 391 |
| Dhela[f] | 6 | 6 | 23 | 23 | 58 | 64 | 2 | 3 | 55 | 57 | 87 | 147 |
| Ekthute | 5 | 5 | 22 | 22 | 63 | 70 | 3 | 3 | 6 | 6 | 56 | 94 |
| Foli | 6 | 6 | 10 | 10 | 11 | 12 | 0 | 0 | - | - | 37 | 63 |
| Golsha | 6 | 6 | 8 | 8 | 6 | 6 | 3 | 4 | - | - | - | - |
| Guchi | 9 | 10 | 8 | 8 | 24 | 26 | 5 | 5 | 5 | 5 | 46 | 77 |
| Gutum | 11 | 12 | 16 | 15 | 46 | 51 | 4 | 4 | 5 | 5 | 162 | 273 |
| Jat Punti | 7 | 8 | 18 | 18 | 50 | 56 | 5 | 5 | 3 | 3 | 74 | 125 |
| Kachki | 9 | 10 | 20 | 19 | 23 | 25 | 2 | 2 | 5 | 5 | 66 | 111 |
| Kajuli, Bashpata | 3 | 3 | 8 | 7 | 5 | 6 | 2 | 2 | 1 | 1 | 76 | 128 |
| Kakila | 2 | 2 | 12 | 11 | 29 | 33 | 9 | 10 | 6 | 6 | 54 | 90 |
| Koi | 3 | 3 | 4 | 4 | 4 | 5 | 0 | 0 | 18 | 18 | 44 | 74 |
| Kuli, Bhut Bailla | 3 | 3 | 13 | 12 | 47 | 52 | 8 | 8 | 2 | 2 | 26 | 44 |
| Magur | 4 | 4 | 5 | 4 | 3 | 3 | 5 | 6 | 1 | 2 | 89 | 151 |
| Meni, Bheda | 3 | 3 | 10 | 10 | 63 | 70 | 3 | 3 | 4 | 4 | 17 | 28 |
| Modhu Pabda | 2 | 2 | 6 | 5 | 4 | 5 | 2 | 2 | - | - | - | - |
| Mola[f] | 19 | 20 | 20 | 20 | 41 | 46 | 4 | 5 | 151 | 156 | 148 | 249 |
| Mola (cultured)[f] | 63 | 68 | 26 | 25 | 67 | 75 | 8 | 9 | 134 | 139 | 109 | 184 |
| Rani, Bou[f] | 8 | 9 | 25 | 24 | 63 | 70 | 6 | 7 | 1 | 2 | 119 | 200 |
| Shing | 7 | 8 | 7 | 7 | 3 | 3 | 0 | 0 | 2 | 2 | 236 | 398 |
| Taki | 6 | 6 | 9 | 9 | 37 | 41 | 4 | 5 | 8 | 9 | 29 | 48 |
| Tara Baim | 8 | 9 | 8 | 7 | 22 | 24 | 3 | 3 | 5 | 5 | 96 | 162 |
| Tengra | 13 | 14 | 20 | 19 | 53 | 59 | 7 | 8 | 1 | 1 | 65 | 109 |
| Tit Punti | 11 | 12 | 24 | 23 | 71 | 79 | 5 | 5 | 1 | 1 | 125 | 210 |
| *Large fish species* | | | | | | | | | | | | |
| Gojar | 1 | 2 | 4 | 4 | 0 | 0 | 3 | 4 | - | - | 10 | 17 |
| Ilish | 6 | 7 | 7 | 7 | 11 | 12 | 9 | 10 | 1 | 1 | 43 | 72 |
| Jatka Ilish | 8 | 9 | 11 | 11 | 24 | 27 | 8 | 9 | 1 | 1 | 37 | 63 |
| Shol | 1 | 1 | 5 | 4 | 5 | 5 | 0 | 0 | - | - | 22 | 38 |
| Shrimp/prawn | | | | | | | | | | | | |
| Harina Chingri | 9 | 9 | 8 | 8 | 26 | 29 | 6 | 7 | - | - | 26 | 44 |
| Najari Icha[f] | 42 | 45 | 21 | 20 | 58 | 64 | 30 | 33 | 0 | 0 | 0 | 0 |
| Inland aquaculture | | | | | | | | | | | | |
| *Indigenous major carps* | | | | | | | | | | | | |
| Catla | 3 | 3 | 7 | 7 | 10 | 11 | 4 | 5 | 1 | 1 | 24 | 41 |
| Mrigal | 8 | 9 | 9 | 9 | 46 | 51 | 4 | 4 | 1 | 1 | 103 | 174 |
| Rui | 3 | 4 | 6 | 6 | 2 | 3 | 5 | 6 | 1 | 1 | 93 | 158 |
| *Introduced fish species* | | | | | | | | | | | | |

[17] The edible parts of each species are listed in Table 1.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Common Carp | 4 | 4 | 14 | 13 | 2 | 2 | 3 | 3 | - | - | - | - |
| Grass Carp | 2 | 2 | 6 | 6 | 3 | 3 | 0 | 0 | - | - | - | - |
| Silver Carp | 15 | 16 | 9 | 9 | 43 | 48 | 0 | 0 | - | - | 10 | 17 |
| Thai Pangas | 2 | 2 | 4 | 4 | 0 | 0 | 0 | 0 | 2 | 2 | 28 | 47 |
| Majhari Thai Pangas | 9 | 9 | 7 | 6 | 3 | 3 | 4 | 5 | 1 | 1 | 259 | 438 |
| Thai Sharpunti | 5 | 6 | 11 | 11 | 13 | 14 | 10 | 11 | 1 | 1 | 41 | 69 |
| Tilapia | 4 | 4 | 7 | 7 | 5 | 5 | 3 | 3 | 1 | 1 | 13 | 22 |
| Majhari Tilapia | 5 | 6 | 9 | 9 | 6 | 6 | 0 | 0 | 1 | 1 | 46 | 78 |
| Marine capture | | | | | | | | | | | | |
| Foli Chanda | 1 | 1 | 4 | 4 | 1 | 2 | 2 | 3 | - | - | 28 | 47 |
| Kata Phasa | 5 | 6 | 20 | 19 | 72 | 80 | 3 | 3 | - | - | 24 | 41 |
| Lal Poa | 6 | 6 | 13 | 13 | 91 | 102 | 10 | 11 | - | - | 37 | 63 |
| Maita | 2 | 2 | 4 | 4 | 2 | 2 | 4 | 4 | - | - | 30 | 50 |
| Murbaila | 6 | 6 | 5 | 5 | 7 | 8 | 5 | 5 | - | - | 9 | 16 |
| Parse | 4 | 5 | 5 | 5 | 3 | 4 | 2 | 2 | - | - | 0 | 0 |
| Tailla | 2 | 2 | 6 | 5 | 2 | 2 | 7 | 7 | - | - | 16 | 27 |
| Tular Dandi | 7 | 8 | 6 | 5 | 11 | 12 | 5 | 5 | 1 | 1 | 31 | 53 |

[a] Standard portion is assumed to be 50 g/ day for PLW and 25 g/ day for infants.
[b] RNI, recommended nutrient intake.
[c] See section 2.5 for explanation of calculation of average daily RNI.
[d] PLW, pregnant and lactating women.
[e] µg RAE, retinol activity equivalent.
- Nutrient composition not analysed, therefore unknown contribution to RNI.
[f] Shaded species are those that could potentially contribute to ≥25% of daily RNIs for PLW and/or infants for 3 or more nutrients of public health significance, if provided in a 50 g or 25 g serve, respectively.

## 3.3 Vitamin composition

The vitamin A, B12, D, E and folate composition of fish and shrimp species is shown in Table 6.

### 3.3.1 Vitamin A

In addition to vitamin A content of 20 species originally presented by Roos (2001), data on a further 28 species (and cultured Mola) are presented in Table 6. Total vitamin A was undetected in 11 species and ranged up to 2503 µg RAE/100 g. As expected, cultured Mola fish had significant concentrations of retinol and dehydroretinol as had been identified previously in capture Mola (Roos, 2001). Three species (all SIS): Mola, Dhela and Darkina were identified that could potentially contribute ≥25% of RNI for PLW and infants in a standard portion. The data presented here support previous studies in Bangladesh which have identified that some SIS such as Mola have potential to play a significant role in food-based strategies to address vitamin A deficiency (Roos et al., 2007a).

### 3.3.2 Vitamin B12

The vitamin B12 content in fish species ranged from 0.50-14 µg/100 g (n=49). The highest concentration, 14 µg/100 g, was found in Majhari Thai Pangas (juvenile Thai Pangas), however, this was not maintained in the adult Thai Pangas with a concentration of only 1.5 µg/100 g. Very limited data on vitamin B12 in fish and seafood are available for comparison in the literature. In the Australian food composition database, vitamin B12 content of fish and seafood ranges from 0.2-15.2 µg/100 g which is consistent with results reported here (FSANZ, 2010). For PLW and infants, 13 and 21 species respectively, were identified that would potentially contribute ≥100% of the daily RNI in a standard portion. Care should be taken however, when comparing results of vitamin B12 in species analysed by different laboratories due to differences in analytical methods. This is the first analysis of vitamin B12 composition of fish species in Bangladesh, and is of particular public health significance given the recent estimate of a national prevalence of vitamin B12 deficiency in 22% of adult women and the clear negative implications of deficiency on cognitive development and function (de Benoist, 2008). As dietary sources of vitamin B12 are exclusively animal-source foods, of which, in Bangladesh, fish is the most significant, increased consumption of fish is likely to be an appropriate food-based strategy to prevent and fight vitamin B12 deficiency.

### 3.3.3 Vitamin D

Vitamin D3 was undetected in five species and ranged up to 34 µg/100 g (n=49). Very limited data on vitamin D in fish and seafood are available for comparison in the literature. The range reported here is greater than the range of Vitamin D3 in Australian fish and seafood at 0-20 µg/100 g (FSANZ, 2010), and similar to the range of vitamin D3 reported for selected fish and seafood in the United States at 0-33 µg/100 g (Byrdwell et al., 2013).Considering that the RNI of total vitamin D is 5 µg/ day for PLW and infants, it is likely that several species could contribute significantly to dietary vitamin D intakes. Although the same analytical methods were used, comparisons between species of low vitamin D3 content (<0.1 µg/100 g) analysed in different laboratories should be made with caution due to differences in the LOQ in analysis by the two laboratories. For example, 14 species were identified with concentrations of vitamin D3 by analysis at *DTU* which would not have returned detectable concentrations by analysis at *AsureQuality* (LOQ of 0.05 µg/100 g at *DTU* compared to 0.5µg/100 g at *AsureQuality*). Of the species analysed for vitamin D2 (n=20) only five species were found to have detectable concentrations ranging from 0.39-2.9 µg/100 g. Vitamin D2 is however, generally only considered to be found in plant-source foods, specifically yeasts and fungi. There is evidence, however, that it is found in microalgae and zooplankton, and if this forms part of the diet of fish, may account for its presence (Rao and Raghuramulu, 1996). No species were found to have detectable concentrations of 25-hydroxyvitamin D3 (n= 29). This is the first time that vitamin D content in fish in Bangladesh has been evaluated. The data presented here indicate that some species may contribute significantly to dietary vitamin D intakes in Bangladesh and it is recommended that further analysis of both vitamin D2 and D3, using standard analytical methods be conducted.

### 3.3.4 Vitamin E

Vitamin E in the form of α-tocopherol, δ-tocopherol and γ-tocopherol was analysed in 20 species at *AsureQuality*. The form of vitamin E with highest biological activity, α-tocopherol, was analysed in an additional 25 species at *DTU* (Table 6). Across all 45 species, α-tocopherol was undetected in four species and ranged up to 1.9 mg/100 g. Very limited data on α-tocopherol in fish and seafood are available for comparison in the literature. In the Australian food composition database, α-tocopherol content of fish and seafood ranges from 0.1-4.2 µg/100 g which is broadly consistent with results reported here (FSANZ, 2010). It is worth pointing out, however, that although the same method of analysis was used by the two laboratories, differences in the LOQ mean that samples tested at *AsureQuality* were less likely to return detectable concentrations of α-tocopherol compared to those tested at *DTU* (LOQ of 0.07 and 0.02 mg/100 g at *AsureQuality* and *DTU,* respectively). No species analysed for other vitamin E components were found to have detectable concentrations of δ-tocopherol and only two species were found to have detectable concentrations of γ-tocopherol which were Tara Baim and Shing with 0.01 and 0.04 IU/100 g, respectively (0.007 and 0.03 mg/100 g, respectively). This is the first time the vitamin E content of fish species in Bangladesh has been analysed. Considering that the daily RNI for infants ranges from 2.7-5.0 mg α-tocopherol equivalents/day, (no recommendation for PLW), the data presented here indicate that some fish are a potentially important source of vitamin E, particularly in the form of α-tocopherol and it is therefore recommended that further analysis, using standard methods be conducted.

### 3.3.5 Folate

Folate content was analysed in 49 species and is shown in Table 6. Folate content was below detectable limits in 17 species and ranged up to 18 µg/100 g, consistent with results reported elsewhere (FSANZ, 2010). Comparisons between species of low folate content (<8 µg/100 g) analysed in different laboratories should be made with caution due to differences in analytical methods and LOQs (LOQ of 8 and 0.2 µg/100 g at *AsureQuality* and *DTU,* respectively). For example, 20 species were identified by analysis at *DTU* with concentrations of folate that would not have returned detectable concentrations had they been analysed at *AsureQuality*. This is the first time folate has been analysed in fish species in Bangladesh. Considering that the RNI for PLW ranges from 500-600 µg dietary folate equivalents (DFE)/day and for infants, 80-150 µg DFE/day, the results indicate that all species analysed would generally be considered low dietary sources of folate, and therefore unlikely to contribute significantly to dietary folate intake in Bangladesh.

Table 6: Vitamin A, B12, D, E and folate composition in fish and shrimp species[18].

| | Nutrient content per 100 g raw edible parts | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Vitamin A | | | | | |
| | Vitamin B12 | Vitamin D3 | Vitamin D2 | Vitamin E (α-tocopherol) | Folate | β carotene | 13-cis retinol | 13-cis dehydroretinol | all-trans retinol | all trans dehydroretinol | Total Vitamin A |
| | µg | µg | µg | mg | µg | µg | µg | µg | µg | µg | µg RAE[c] |
| **Inland capture** | | | | | | | | | | | |
| *Small indigenous fish species (SIS)* | | | | | | | | | | | |
| Baim | 1.72 | 1.30 | 0.76 | nd | nd | 5 [a] | 1 [a] | 5 [a] | 1 [a] | 51 [a] | 27 |
| Bele, Bailla[b] | 2.1 | 1.6 | - | 0.17 | 6.7 | - | nd | nd | 18 | nd | 18 |
| Boro Kholisha | 5.55 | 3.13 | 2.1 | 0.12 | nd | 11 [a] | 5 [a] | 5 [a] | 34 [a] | 14 [a] | 46 |
| Chanda | 6.42 | 11.9 | nd | 0.18 | nd | 43 [a] | 14 [a] | 51 [a] | 128 [a] | 433 [a] | 336 |
| Chapila | 6.99 | 4.92 | nd | nd | nd | nd [a] | 1 [a] | 21 [a] | 9 [a] | 136 [a] | 73 |
| Chela | 5.64 | 4.00 | nd | 0.11 | nd | 21 [a] | 25 [a] | 9 [a] | 90 [a] | 45 [a] | 132 |
| Darkina | 12.5 | 6.31 | nd | 0.84 | nd | 100 [a] | 63 [a] | 48 [a] | 433 [a] | 381 [a] | 660 |
| Dhela[b] | 4.7 | 0.14 | - | 0.24 | 6.6 | - | 15 | 68 | 28 | 2130 | 918 |
| Ekthute[b] | 3.0 | 2.4 | - | 0.65 | 11 | - | 18 | nd | 84 | nd | 98 |
| Foli[b] | 2.0 | 0.70 | - | 0.64 | 18 | - | nd | nd | nd | nd | nd |
| Guchi | 2.47 | 2.29 | nd | 0.11 | nd | 110 [a] | 1 [a] | 14 [a] | 9 [a] | 133 [a] | 78 |
| Gutum | 8.75 | nd | nd | 0.19 | nd | 25 [a] | 1 [a] | 9 [a] | 17 [a] | 131 [a] | 76 |
| Jat Punti | 4.01 | 1.29 | nd | 0.15 | nd | 13 [a] | 4 [a] | 9 [a] | 27 [a] | 49 [a] | 54 |
| Kachki | 3.55 | 1.5 | nd | 0.09 | nd | 15 [a] | 2 [a] | 30 [a] | 14 [a] | 122 [a] | 78 |
| Kajuli, Bashpata[b] | 4.1 | 0.091 | - | 0.28 | 2.9 | - | nd | nd | 37 | nd | 37 |
| Kakila | 2.89 | 1.4 | 0.66 | 0.40 | 9.2 | 56 [a] | 9 [a] | 12 [a] | 54 [a] | 53 [a] | 91 |
| Koi | 2.38 | 1.19 | nd | nd | 11.4 | 74 [a] | 61 [a] | 30 [a] | 163 [a] | 171 [a] | 295 |
| Kuli, Bhut Bailla[b] | 1.4 | 22 | - | 0.55 | 3.7 | - | nd | nd | 37 | nd | 37 |
| Magur | 4.83 | nd | nd | 0.13 | 9.4 | 64 [a] | 4 [a] | 8 [a] | 7 [a] | 15 [a] | 25 |
| Meni, Bheda[b] | 0.90 | 0.78 | - | 0.36 | 3.5 | - | nd | nd | 36 | 61 | 60 |
| Mola | 7.98 | 2.03 | 2.9 | 0.27 | nd | nd [a] | nd [a] | 460 [a] | 323 [a] | 4990 [a] | 2503 |
| Mola (cultured)[b] | 5.9 | 3.0 | - | 0.91 | 4.3 | - | 44 | 42 | 340 | 4590 | 2226 |
| Rani, Bou[b] | 6.4 | 0.12 | - | 0.63 | 3.2 | - | nd | nd | nd | 60 | 24 |
| Shing | 12.8 | nd | nd | 0.34 | nd | 45 [a] | 5 [a] | 11 [a] | 11 [a] | 22 [a] | 32 |
| Taki | 1.60 | nd | nd | 0.14 | nd | 22 [a] | 9 [a] | 13 [a] | 84 [a] | 104 [a] | 139 |
| Tara Baim | 5.20 | nd | nd | 0.17 | nd | 135 [a] | 2 [a] | 15 [a] | 16 [a] | 120 [a] | 83 |
| Tengra[b] | 3.5 | 0.19 | - | 0.23 | 10 | - | nd | nd | nd | 29 | 12 |
| Tit Punti | 6.74 | 0.995 | nd | 0.16 | nd | 25 [a] | 4 [a] | 5 [a] | 11 [a] | 8 [a] | 21 |
| *Large fish species* | | | | | | | | | | | |
| Gojar[b] | 0.55 | 0.42 | - | 0.28 | 2.0 | - | nd | nd | nd | nd | nd |
| Ilish[b] | 2.3 | 18 | - | 1.7 | 1.5 | - | nd | nd | nd | 49 | 20 |
| Jatka Ilish[b] | 2.0 | 9.0 | - | 1.9 | 3.2 | - | nd | nd | nd | 36 | 14 |
| Shol[b] | 1.2 | 0.18 | - | 0.52 | 2.4 | - | nd | nd | nd | nd | nd |
| Shrimp/prawn | | | | | | | | | | | |
| Harina Chingri[b] | 1.4 | 0.055 | - | 1.6 | 14 | - | nd | nd | nd | nd | nd |
| **Inland aquaculture** | | | | | | | | | | | |
| *Indigenous major carps* | | | | | | | | | | | |

[18] The edible parts of each species are listed in Table 1.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Catla[b] | 1.3 | 0.28 | - | 0.23 | 4.4 | - | nd | nd | 22 | nd | 22 |
| Mrigal | 5.57 | 0.616 | 0.39 | nd | nd | nd [a] | 2 [a] | 2 [a] | 9 [b] | 9 [a] | 15 |
| Rui | 5.05 | 1.17 | nd | 0.12 | nd | 6 [a] | 2 [a] | 1 [a] | 9 [b] | 4 [a] | 13 |
| *Introduced fish species* | | | | | | | | | | | |
| Silver Carp[b] | 0.55 | 0.24 | - | 0.49 | 7.7 | - | nd | nd | nd | nd | nd |
| Thai Pangas[b] | 1.5 | 0.13 | - | 0.32 | 9.0 | - | nd | nd | nd | 78 | 31 |
| Majhari Thai Pangas [b] | 14 | 0.12 | - | 0.10 | 15 | - | nd | nd | nd | 31 | 12 |
| Thai Sharpunti[b] | 2.2 | 23 | - | 0.32 | 2.2 | - | nd | nd | 12 | nd | 12 |
| Tilapia[b] | 0.70 | 6.3 | - | 0.40 | 7.6 | - | nd | nd | 10 | nd | 10 |
| Majhari Tilapia[b] | 2.5 | 34 | - | 1.5 | 8.0 | - | nd | nd | 10 | 27 | 21 |
| Marine capture | | | | | | | | | | | |
| Foli Chanda[b] | 1.5 | 0.097 | - | 0.19 | 4.8 | - | nd | nd | nd | nd | nd |
| Kata Phasa[b] | 1.3 | 3.8 | - | 0.37 | 8.6 | - | nd | nd | nd | nd | nd |
| Lal Poa[b] | 2.0 | 1.3 | - | 0.38 | 7.7 | - | nd | nd | nd | nd | nd |
| Maita[b] | 1.6 | 1.7 | - | 0.50 | 2.5 | - | nd | nd | nd | nd | nd |
| Murbaila[b] | 0.50 | 0.20 | - | 0.09 | 2.2 | - | nd | nd | nd | nd | nd |
| Tailla[b] | 0.85 | 13 | - | 0.44 | 3.1 | - | nd | nd | nd | nd | nd |
| Tular Dandi[b] | 1.7 | 0.28 | - | 0.26 | 8.7 | - | nd | nd | 20 | nd | 20 |

[a] Data on vitamin A components previously published by Roos (2001).
[b] Data on all vitamin components analysed at *DTU*, Denmark.
[c] µg RAE, retinol activity equivalent.
- No data available.
nd, Not detected. Limit of detection: vitamin A components, 10 µg/100 g; vitamin D2, 0.1 µg/100 g; vitamin D3, 0.1 µg/100 g; vitamin E, 0.11 IU/100 g (equivalent to 0.074 mg/100 g using conversion factor vitamin $E_{(tocopherol)}$ (mg/100 g) = vitamin $E_{(tocopherol)}$ (IU/100 g) x 0.67 (FAO/INFOODS, 2012)).
n = 1 pooled sample.

## 3.4 Fatty acid composition

All samples with a total fat content of >6 g/100 g were analysed further for composition of 38 fatty acids and the results are shown in Table 7 (in addition to juvenile Thai Pangas which had a total fat content of 1.4 g/100 g but was analysed for the purpose of comparison with its adult counterpart). Although it is recognised that fish species with fat content <6 g/100 g may well be good sources of fatty acids, due to resource constraints in this study, species with higher total fat content were prioritised for analyses. Total PUFA, monounsaturated fatty acid (MUFA) and saturated fatty acid (SFA) contents ranged from 0.5-3.6 g/100 g, 0.4-7.7 g/100 g and 0.5-8.9 g/100 g, respectively. Ilish was the most significant source of PUFA and SFA, whereas Thai Pangas was the most significant source of MUFA. The total n-3 PUFA content ranged from 211-2034 mg/100 g, with the most significant sources being Ilish and Parse. Total n-6 PUFA content ranged from 178-2157 mg/100 g, with the most significant sources being Thai Pangas and Jat Punti. The ratio of n-6:n-3 PUFA was highest in Thai Pangas, which is also the only farmed and omnivorous fish analysed here (except for its juvenile counterpart). This may reflect differences in the diet and or environmental conditions of farmed versus capture fish among other factors (Li et al., 2011), although this would require further investigation. A more balanced n-6:n-3 PUFA ratio is more desirable in prevention of cardiovascular and other chronic diseases (Simopoulos, 2008), however this evidence relates to higher disease risk with low n-3 intake, rather than high n-6 intake or a high n-6:n-3 PUFA ratio and as such, no dietary recommendation for such a ratio exists (FAO, 2010). The percentage contribution to daily average nutrient requirement of docosahexaenoic acid (DHA) for PLW and infants (7-23 months) from a standard portion of fish is shown in Figure 2, and clearly demonstrates that all species, except adult and juvenile Thai Pangas would contribute ≥20% of daily requirements of DHA for both PLW and infants. This is of particular interest given the growing body of literature on the role of fatty acids in growth and development during the first 1,000 days, and specifically, the role of DHA in normal retinal and brain development (FAO, 2010). The data presented here indicate that important fish species in Bangladesh, particularly indigenous species are a good dietary source of fatty acids and should be considered in food-based approaches to optimise growth and development during the first 1,000 days. It is also recommended that the fatty acid composition of further species be analysed.

Table 7: Fatty acid composition of fish species[19,20].

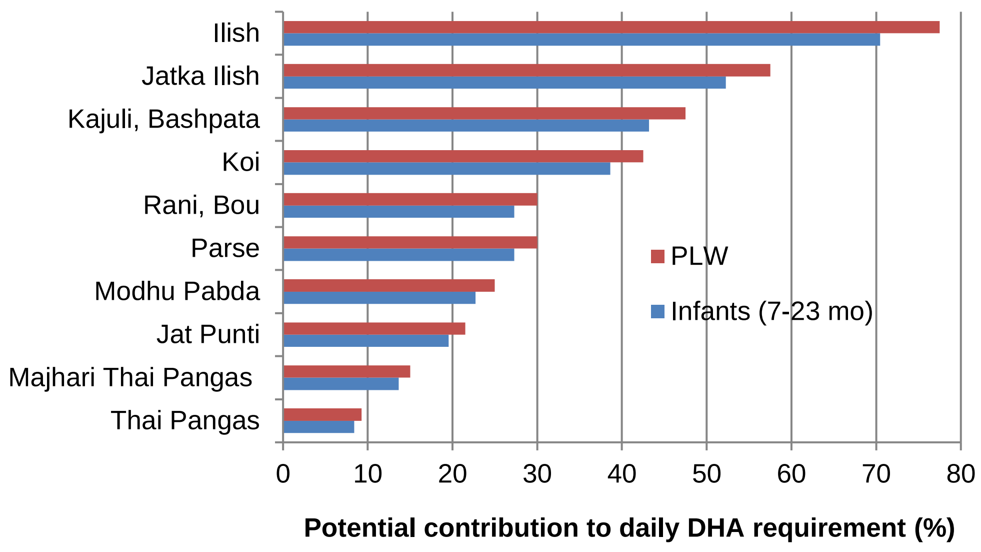
| | | Nutrient content per 100 g raw edible parts | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nutrient[a] | Unit | Ilish | Jatka Ilish | Jat Punti | Kajuli, Bashpata | Koi | Modhu Pabda | Parse | Rani, Bou | Thai Pangas | Majhari Thai Pangas |
| Total fat (mean)[21] | g | 18.3 | 7.7 | 7.2 | 12.6 | 12.8 | 9.5 | 14.3 | 10.6 | 17.7 | 1.4 |
| Total SFA | g | 8.9 | 3.8 | 2.2 | 5.4 | 4.8 | 3.6 | 7.4 | 4 | 7.5 | 0.5 |
| Total MUFA | g | 6.9 | 2.5 | 2.4 | 5.2 | 5.7 | 4.2 | 4.5 | 4 | 7.7 | 0.4 |
| Total PUFA | g | 3.6 | 1.6 | 2.5 | 2.1 | 1.9 | 1.7 | 2.7 | 2.7 | 2.6 | 0.5 |
| C12:0 | mg | 13 | 32 | 30 | 65 | 11 | 20 | 12 | 180 | nd | nd |
| C13:0 | mg | nd | nd | nd | nd | nd | 10 | nd | 35 | nd | nd |
| C14:0 | mg | 1550 | 710 | 100 | 580 | 270 | 150 | 630 | 430 | 620 | 52 |
| C15:0 | mg | 64 | 36 | 56 | 100 | 36 | 98 | 310 | 160 | 29 | nd |
| C16:0 | mg | 5780 | 2310 | 1290 | 3270 | 3270 | 2270 | 5530 | 2690 | 5180 | 310 |
| C17:0 | mg | 36 | 28 | 88 | 180 | 55 | 120 | 160 | 230 | 31 | 22 |
| C18:0 | mg | 1320 | 620 | 570 | 1120 | 1050 | 750 | 610 | 100 | 1560 | 130 |
| C20:0 | mg | 25 | 16 | 28 | 41 | 39 | 43 | 26 | 36 | 35 | nd |
| C22:0 | mg | 19 | 18 | 16 | 17 | 11 | 27 | 18 | 19 | 19 | nd |
| C24:0 | mg | 20 | 22 | 19 | 42 | 28 | 41 | 21 | 42 | nd | nd |
| C14:1 | mg | 11 | nd | 28 | 100 | 14 | 98 | 63 | 71 | 11 | 18 |
| C15:1 | mg | nd | nd | 15 | 38 | nd | 39 | 21 | 38 | nd | nd |
| C16:1 | mg | 2110 | 820 | 190 | 580 | 390 | 490 | 1930 | 760 | 160 | 51 |
| C17:1 | mg | 10 | nd | 22 | 72 | 27 | 62 | 150 | 92 | 16 | nd |
| C18:1n-6 | mg | nd | nd | nd | nd | 16 | 13 | 53 | 12 | nd | nd |
| C18:1n-7 | mg | 700 | 280 | 130 | 310 | 230 | 270 | 470 | 370 | 210 | 48 |
| C18:1n-9 | mg | 3730 | 1240 | 1790 | 3680 | 4890 | 2850 | 1490 | 2040 | 7010 | 180 |

[19] The edible parts of each species are listed in Table 1.
[20] Fatty acid content as % of total fatty acids is presented in Appendix 1 of thesis.
[21] Total fat was analysed separately so exhibits slight variation from total fatty acids.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C20:1n-9 | mg | 250 | 65 | 32 | 52 | 120 | 83 | 30 | 61 | 210 | nd |
| C20:1n-11,13 | mg | nd | nd | 34 | 15 | 11 | 41 | 22 | 120 | 14 | nd |
| C22:1n-9 | mg | 24 | nd | nd | nd | 47 | nd | nd | nd | 23 | nd |
| C22:1n-11,13 | mg | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| C24:1 | mg | 25 | 15 | nd | nd | 10 | nd | 12 | nd | nd | nd |
| | | | | | | | | | | | |
| C18:2n-6 (LA) | mg | 120 | 88 | 1710 | 410 | 1100 | 760 | 220 | 440 | 1820 | 77 |
| C18:3n-6 | mg | 47 | 16 | 43 | 33 | 80 | 25 | 91 | 31 | 42 | nd |
| C20:2n-6 | mg | nd | nd | nd | 25 | nd | 71 | nd | nd | 77 | nd |
| C20:3n-6 | mg | 57 | 21 | 46 | 46 | 65 | 55 | 27 | 61 | 110 | 15 |
| C20:4n-6 | mg | 170 | 110 | 140 | 260 | 57 | 200 | 165 | 230 | 70 | 57 |
| C22:4n-6 | mg | 34 | 20 | 35 | 53 | 22 | 32 | 34 | 56 | 38 | 29 |
| C22:5n-6 | mg | 58 | 21 | nd | nd | nd | nd | 13 | nd | nd | nd |
| Total n-6 PUFA | mg | 486 | 276 | 1974 | 827 | 1324 | 1143 | 550 | 818 | 2157 | 178 |
| | | | | | | | | | | | |
| C18:3n-3 (ALA) | mg | 24 | 27 | 150 | 430 | 81 | 140 | 370 | 300 | 140 | 69 |
| C18:4n-3 | mg | 110 | 50 | 19 | nd | 18 | nd | 300 | 16 | nd | nd |
| C20:3n-3 | mg | nd | nd | nd | 25 | nd | 28 | 26 | 55 | 13 | nd |
| C20:4n-3 | mg | 120 | 44 | 10 | 81 | 19 | 13 | 99 | 48 | 11 | 20 |
| C20:5n-3 (EPA) | mg | 1200 | 430 | 40 | 160 | 30 | 68 | 400 | 96 | 13 | 38 |
| C21:5n-3 | mg | nd | nd | nd | nd | nd | nd | nd | nd | 11 | nd |
| C22:5n-3 | mg | 270 | 94 | 24 | 120 | 59 | 53 | 120 | 84 | 19 | 24 |
| C22:6n-3 (DHA) | mg | 310 | 230 | 86 | 190 | 170 | 100 | 120 | 120 | 37 | 60 |
| Total n-3 PUFA | mg | 2034 | 875 | 329 | 1006 | 377 | 402 | 1435 | 719 | 244 | 211 |
| n-6: n-3 PUFA | - | 0.2:1 | 0.3:1 | 6:1 | 0.8:1 | 3.5:1 | 2.8:1 | 0.4:1 | 1.1:1 | 8.8:1 | 0.8:1 |

[a] SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; LA, Linoleic acid; ALA, α-Linolenic acid; EPA, Eicosapentaenoic acid; DHA, Docosahexaenoic acid.
nd, Not detected. Limit of detection for all fatty acids: 6 mg/100 g.
n = 1 pooled sample.

Figure 2: Potential contribution to daily nutrient requirement[a] of docosahexaenoic acid (DHA) from a standard serve[b] of fish for PLW[c] and infants (7-23 months).




[a] Daily average nutrient requirement of DHA for PLW is 200mg/day and the adequate intake for infants is 10-12 mg/kg/day (FAO, 2010). For infants an average figure of 110 mg/day is used. This was calculated by taking the midpoint within the maximum range of adequate intakes throughout the age period (10 mg/kg/day for a 7 month old of 7.6kg and 12 mg/kg/day for a 23 month old of 12.0 kg) where weight is estimated at the 50th percentile according to WHO growth standards (WHO, 2006).
[b] Standard serve of fish for PLW is 50 g/day and for infants is 25 g/day.
[c] PLW, pregnant and lactating women.

## 3.5 Species size, edible parts and biodiversity

When making comparisons between species on their overall nutritional value, it is important to consider the size of the fish, and implications for what is typically considered 'edible' parts. SIS are typically consumed whole with head, bones and in some cases, viscera, in stark contrast to large species, where edible parts typically include body tissue only. The nutritional consequences of this can be seen when anatomical components of fish are analysed separately. For example, in Mola, the eyes and viscera have an extremely high concentration of vitamin A compared to the body tissue (Roos et al., 2002). Although separate anatomical parts have not been analysed here, this trend can be seen when considering the edible parts of SIS compared to that of large indigenous and aquaculture species (Table 1), and potential contributions to RNIs (Table 5). When considering iron, zinc, calcium, vitamin A and vitamin B12 requirements, there are seven species that would contribute to ≥25% of RNI for PLW and six species that would contribute to ≥25% of RNI for infants, for three or more micronutrients simultaneously, when consumed in a 50 g or 25 g portion, respectively. These species are all SIS (except for Najara Icha which is a prawn) and edible parts include head and bones. This underlines the importance of considering typical consumption patterns, often related to size of the individual fish, shrimp or prawn, in design of programs that aim to influence production and or consumption of fish. One promising example of this, now gaining momentum, is the inclusion of nutrient-rich Mola in pond polyculture systems with carps, which is being promoted throughout rural Bangladesh (Thilsted and Wahab, 2014b, c).

Table 5 also calls attention to the variation in potential nutrient contributions of different species. For example, some species contribute significantly to iron and calcium RNIs and less so to vitamin A, whereas, others contribute more to zinc and vitamin A RNIs and less so to iron RNIs. No single species is of resounding superior nutritional value than any other single species, across all nutrients, which emphasises the importance of biodiversity in fish consumption for meeting population nutrient needs.

### 3.6 Limitations

Nutrient composition of foods, including fish, is known to vary seasonally, depending on the stage of the life cycle, food availability, and changes in the wider environment. It was however, outside the scope of this study to attempt to sample to account for these variations. Furthermore, a relatively small size of pooled samples was used, and in the case of analysis of fatty acids, the use of single replicates. In the local context and considering resource constraints, it was also not possible to obtain larger more representative sample sizes. Another limitation of this study is the use of different methods for analysis of vitamin B12 and folate between species analysed by different laboratories, although the methods are generally considered similar (Indyk and Woollard, 2013; Indyke et al., 2002).Therefore, whilst it is recognised that these are limitations of the study, given the lack of existing data on nutrient composition of fish species in Bangladesh, the results are still of significant value, providing time and location specific estimates for comparison with future analyses.

## 4 Conclusions

Several species have been identified that would contribute significantly to the RNIs of multiple nutrients of public health significance. When considering the role of fish in food and nutrition security, research, funding and interventions in recent decades, have largely focused on development of aquaculture, particularly of large carps and introduced species, with an assumed benefit for nutrition-related outcomes, although this linkage is dubious. The data presented here show that from a nutritional perspective, species from inland capture fisheries, particularly SIS, hold potential to provide a much greater contribution to micronutrient intakes of vulnerable groups in the population, compared to common aquaculture species. This is likely, in-part, due to the way in which small fish are consumed;

that is, whole with head and bones. Further still, given the large range in nutrient composition of different species reported here, diversity in fish consumption, particularly of SIS, is likely to promote a more all-inclusive nutrient intake. This supports the compelling argument that to effectively target malnutrition, resources should be directed towards ensuring a more balanced approach of both sustainable capture fisheries management and aquaculture, including the development of innovative aquaculture technologies which include nutrient-rich species, in particular SIS. This paper significantly expands the current knowledge on the nutritional value of the large diversity of fish species in Bangladesh, and demonstrates that many species, particularly SIS and those from inland capture fisheries have the *potential* to contribute significantly to RNIs for a variety of nutrients. In future studies, it would be useful to determine the *real* contribution of different species to nutrient intakes of vulnerable groups based on consumption, to better inform programs targeting improved access, availability and consumption of nutritious foods.

## Acknowledgements

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# 5. Using local nutrient-rich foods to improve nutrition

## 5.1. Forward to manuscript

Low food intake and low diversity of foods are the primary reasons for a high prevalence of inadequate micronutrient intakes among women and young children in Bangladesh (Arsenault, 2013). Fish is a nutrient-rich, locally available and culturally preferred food source which is well placed to address this gap. This chapter specifically addresses RQ 2: How could local nutrient-rich foods including fish, be utilised to improve the nutritional quality of diets, particularly among vulnerable groups? This study investigated the potential of selected nutrient-rich fish species (based on the analysis presented in Chapter 4) to be incorporated in modified versions of traditional recipes to increase micronutrient intakes of vulnerable groups.

Two nutrient-rich fish-based products were developed; a chutney for pregnant and lactating women, and a rice-based complementary food for infants and young children. Both products could make substantial contributions to recommended nutrient intakes if consumed in the recommended portion sizes. The simple processing methods used and the focus on local ingredients also hold potential for such products to have wider benefits for communities involved in production.

## 5.2. Formal citation and published manuscript

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# Inclusion of small indigenous fish improves nutritional quality during the first 1,000 days

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**Running head:** Fish-based food products for the 1,000 days

## Abstract

*Background:* Within food-based approaches to improve nutrition during the first 1,000 days of life, improved formulations of food products and the use of animal-source foods such as fish, are two widely cited strategies; however, there are few examples where the two strategies are combined. Furthermore, although small indigenous fish are highly nutritious and available to the poor in many regions of the world, their importance is often overlooked.

*Objective:* To document development of two nutritious fish-based food products in Bangladesh; a chutney for pregnant and lactating women and a complementary food for infants and young children (6-23 months), including potential contributions to recommended or desirable nutrient intakes in the first 1,000 days, processing methods and nutrient composition.

*Methods:* Local nutrient-rich ingredients and simple processing methods based on traditional knowledge (for the chutney), and a literature review (for the complementary food), were selected and trial batches produced. Products were analysed for nutrient composition using standard analytical procedures and results compared to recommended or desirable nutrient intakes for women and children.

*Results:* Both products could contribute significantly to micronutrient intakes of pregnant and lactating women (24% of iron and 35% of calcium recommended intakes) and macro- and micronutrient intake of infants and young children (≥65% of vitamin A, ≥61% of zinc and 41% of iron desirable intakes) when consumed in the proposed serving size.

*Conclusion:* Inclusion of small indigenous fish as an underutilised animal-source food in combination with other local nutrient-rich ingredients in food products represents a promising food-based strategy to improve nutrition, with many additional potential benefits for communities involved in production, and therefore warrants further investigation.

## Keywords

Small indigenous fish species, fish-based food products, animal-source food, complementary food, 1,000 days, local nutrient-rich ingredients, pregnant and lactating women, infants and young children.

## Introduction

Globally, 842 million people are undernourished, and more than 2 billion people are deficient in micronutrients. [1,2] A significant portion of this burden is found in Bangladesh where 24% of women (ever married, aged 15-49 years) have a body mass index below the healthy range (18.5-25 kg/m$^2$), 42% suffer from anaemia, 51% of children under 5 years are anaemic and 41% of children are stunted. [3] Key contributing factors to undernutrition in low-income countries, including Bangladesh, are low dietary diversity in the diets of women and low nutrient-density of traditional complementary foods (CFs) for infants and young children. [4-6] There is global consensus that the first 1,000 days of a child's life, from conception through to age two years, including the transition from exclusive breastfeeding to the introduction of CFs with continued breastfeeding at 6 months of age, provide a 'critical window of opportunity' to promote optimal growth and development of infants and young children, and to prevent growth faltering, micronutrient deficiencies and childhood illness. Current food-based efforts to improve the nutrient intake of women and children during the 1,000 days include the use of fortified foods and supplements such as micronutrient powders; nutrition education targeting dietary diversity and improved complementary feeding practices; and biofortification of staple foods such as rice; however, these have had mixed results with issues around access, acceptability, uptake, sustainability, and bioavailability of nutrients. [7-9] Despite broad efforts to improve dietary diversity in Bangladesh, 59% of women and 58% of children under 2 years consume inadequately diverse diets.[10] In recognition of the limitations of solely home-based approaches to dietary diversification strategies, the WHO/UNICEF Global Strategy for Infant and Young Child Feeding makes the following recommendation:

*"…low-cost complementary foods, prepared with locally available ingredients using suitable small-scale production technologies in community settings, can help to meet the nutritional needs of older infants and young children. Industrially processed complementary foods also provide an option for some mothers who have the means to buy them and the knowledge and facilities to prepare and feed them safely."* [11]

Several plant-based processed CFs have been developed in Bangladesh, however, all have required fortification with vitamins and minerals to achieve desired nutrient densities. [12,13] Concurrently, within home-based approaches to dietary diversification, there is increasing emphasis on the role of animal-source foods, because of their nutrient density, high bioavailability of minerals and vitamins, and their enhancing effect on the bioavailability of non-haem iron and zinc from other foods in the diet. [14-16] Despite their nutritional value however, there are few examples in the literature of a combined approach using animal-source foods (with the exception of milk) in processed food products targeted at the first 1,000 days. There are even fewer examples of the use of fish in food products, despite widespread recognition of their nutritional value (particularly of small indigenous fish), acceptability and popularity in the diets of many in low-income countries with rich fisheries resources. Fish offer a unique opportunity to contribute to optimal nutrition during the first 1,000 days of life, due to their content of both fatty acids [17] and micronutrients such as iron, zinc, calcium, vitamin A and vitamin B12 [18],which are often considered 'problem nutrients', particularly in low-income countries. Two new fish-based food products targeting improved nutrition in the first 1,000 days that focus on using local, culturally acceptable, nutrient-rich ingredients are presented here. These are: 1) for pregnant and lactating women (PLW), a fish chutney with dried small fish, oil, onion and spices to be served as an accompaniment to daily meals, and 2) for infants and young children, a pre-prepared dry flour product of dried small fish, orange sweet potato (OSP), rice, and oil, to be mixed with boiled water and served as a porridge.

The aims of this paper are to document the rationale for product development, recipe formulation, proposed processing methods, nutrient composition, and to estimate the potential contribution of each product to recommended nutrient intakes (RNIs) for PLW and desirable nutrient intakes from CFs for infants and young children, when consumed in the proposed serving sizes. In addition, the potential role of these products in food-based approaches for the prevention and treatment of undernutrition, further optimisation strategies, potential production and distribution models, global applicability and the next steps for future development are also discussed.

## Guiding principles for product development

The literature on recommended ingredients, nutrient composition and processing methods for CFs in low-income countries is prolific; however, guidance on food products for PLW is far less advanced. In selection of ingredients and processing methods for both products proposed here, the following characteristics were used as guiding principles: high content of micronutrients (particularly iron, zinc, calcium, vitamin A, vitamin B12 and essential fats which are of public health concern in Bangladesh [17,19,20]); high energy density (particularly for the CF); inclusion of animal-source food; low content of anti-nutrients such as phytates and polyphenols; cultural acceptability including taste and texture; ease of preparation to reduce women's time burden; affordability and availability; and hygienic safety. [14] Simple processing methods with limited equipment were also prioritised in order to develop products with potential for local community-based production requiring minimal capital investment. Guidelines within relevant Codex Alimentarius Commission standards [21,22], the WHO/UNICEF review of complementary feeding in low-income countries [23] and updates to this review [24] were also considered for the CF; however to the authors' knowledge, no such equivalent guidelines for food products specifically for PLW are available.

## Selection of ingredients

### Small indigenous fish species

Small indigenous fish species (SIS) were selected as the primary ingredient for both food products for several reasons. Firstly, fish is by far the most widely available and frequently consumed animal-source food in Bangladesh, and is therefore the obvious choice for cultural acceptability and availability. [25] Secondly, the nutritional benefits of fish are three-fold: a) SIS, consumed whole with head and bones are nutrient-rich, providing animal protein, essential fats, iron, zinc, calcium, vitamin A, vitamin B12 and other nutrients , b) these nutrients are highly bioavailable and c) due to the 'meat' factor, inclusion of fish enhances bioavailability of nutrients from other ingredients. [14] Thirdly, drying of fish is a common practice in many areas of Bangladesh, and is a suitable preservation method for use in food products, particularly as it serves to extend shelf-life, thereby reducing the effects of seasonality of fish supply. Dried fish also provides a concentrated source of micronutrients (nutrient density), is well-liked and commonly consumed across all income groups in Bangladesh. [25] Lastly, although dried fish is consumed more frequently than any other category of fish, the quantity consumed, particularly by vulnerable groups, including women and young children is low. For example, although fish are generally considered by mothers and caregivers as a healthy food and good for growth, fish are often not introduced to infants and young children due to negative perceptions about the suitability of its texture, especially for infants aged 6-8 months. [26] Furthermore, rural Bangladeshi mothers in Northern Bangladesh have been shown to have very low fish intake (12.8 g/day). [27] These examples indicate that there is significant opportunity to increase fish intake in these target groups through consumption of fish-based food products of suitable taste and texture.

### Fish chutney

The fish chutney is based on a traditional 'achar' or pickle recipe which is commonly served with rice and vegetables, and resembles various savoury condiments served in many cuisines globally. Jat Puti fish (*Puntius sophore*), a SIS, was selected for inclusion in this recipe as it is a rich source of iron, calcium, zinc, vitamin B12 and essential fatty acids[18,28], and is widely available from capture fisheries. Garlic, onion, chilli and salt were included for taste and acceptability, and also for their preserving properties, extending the product shelf-life. Soybean oil was selected for inclusion because it is a core ingredient in condiments of this nature, is widely available in Bangladesh, has a desirable fatty acid profile and contributes to overall energy content of the product. [29,30]

### Fish-based complementary food

The CF is based on the traditional rice-based porridge used in Bangladesh, with added ingredients to enhance the nutritional quality. Darkina fish (*Esomus danricus*), a SIS, was selected, particularly for it's very high iron content and also, calcium and zinc content. [28] OSP was selected for inclusion because it is a rich source of pro-vitamin A carotenoids and has a sweet flavour and pleasing colour which improves product acceptability. The benefits of OSP to address vitamin A deficiency have been recognised globally and efforts to establish large-scale production of β-carotene rich varieties of OSP in Bangladesh are expanding through the work of the International Potato Center and Bangladesh Agricultural Research Institute, indicating that it will become increasingly available. [31] Soybean oil was selected for inclusion because it has a desirable fatty acid profile in terms of omega-3 and omega-6 content, it contributes significantly to energy density of the product and is widely available. [29,30]

# Methods

## Processing methods

For the fish chutney, Bangladeshi women familiar with preparing 'achar' or pickled condiments were consulted on the various processing methods. For the CF, a literature review was conducted, using a combination of "fish", "complementary food", "weaning", "local" and "processing" as search terms in PubMed database. Reference lists in pertinent papers were also searched, and relevant processing methods described were used as a guide. [32-37] The processing methods for both products were then tried and tested, under the guidance of a food technologist, in a home kitchen for the fish chutney and at a local laboratory for the CF and was guided by what would likely be acceptable in the community (for example, it was thought that only a small quantity of dried fish in the CF would be culturally acceptable). Final processing methods selected for product development are presented in the results section. The fish chutney was produced using a gas cooktop and hand-held stone grinder. The CF was produced using a custom built fan forced electric oven, industrial pin mill machine (*Hitech,* model number HWP), sifting screener machine (*Jiangyin Kaiyue Machinery Manufacturing Co. Ltd,* model number ZS) and an industrial single screw extruder (*Jinan Dayi Extrusion Machinery Co. Ltd.*).

### Sampling

A trial batch of each food product was produced for analysis of nutrient composition. The fish chutney was produced in a home kitchen (batch size approximately 3 kg), then packaged in sealed plastic containers of 240 g each (8 individual serves of 30 g each). The CF was produced by Mark Foods factory (batch size approximately 30 kg) in Dhaka, Bangladesh, then packaged in individual serve sachets of 30 g each. The trial batch size of the CF was larger than the fish chutney due to a minimum quantity required for extrusion. Two containers of chutney (16 individual serves) and 16 individual sachets of CF were randomly selected from the trial batch for laboratory analysis.

### Analysis of nutrient composition

Nutrient composition of the two fish-based products was analysed at *AsureQuality Limited* Laboratory, New Zealand. Prior to analysis, individual samples were combined and homogenised before being sub-sampled. Energy, protein, fat, vitamin B12 and folate, were analysed using standard methods as per the Association of Official Analytical Chemists (AOAC). Iron, zinc and calcium were analysed by inductively coupled plasma optical emission spectrometry (ICP-OES). [38] Iodine was analysed by inductively coupled plasma mass spectrometry (ICP-MS). [38] Fatty acid composition was analysed by gas liquid chromatography (GLC). [39] Analysis was conducted for 45 fatty acid components, but only selected fatty acids of interest are presented in the results. β-carotene was measured by alkaline saponification, extraction, chromatography and spectrometry. [40] A conversion factor of 1 µg retinol activity equivalent (RAE) = 12 µg β-carotene was used to present the composition in µg RAE. [41] All samples were analysed in duplicate and are presented here as the mean.

### Potential contribution to recommended or desirable nutrient intakes

RNIs vary considerably throughout the trimesters of pregnancy and stages of lactation. Here, an average RNI throughout pregnancy and the first 12 months of lactation was calculated for each nutrient of interest. [42-45] RNIs for infants and young children also vary considerably from birth to two years of age, and are dependent on breast milk intake. The quantity of nutrients that should be provided by CFs (derived from desirable nutrient densities of CFs) to meet daily growth and development needs can be estimated as the total daily RNIs less the nutrients provided through breast milk, in this case, assuming average breast milk consumption and average milk composition. [24] Note however, that there is considerable variation in desirable nutrient densities for CFs depending on whether US dietary reference intakes or the WHO/FAO RNIs are used, and as such, these should not be considered as reference values. [24] Recommendations for lipid intake from CFs, in order to achieve a total lipid intake of between 30-45 % of total energy, are 0-34%, 5-38% and 17-42% of energy from CF for infants and young children, aged 6-8, 9-11 and 12-23 months, respectively. Here, the mid-point of each range was used and then converted to grams of lipid from CF per day (assuming 37 kJ energy per gram lipid). [46] The RNIs for fatty acids are provided as a percentage of total energy (not energy required from CFs), as in the current study, the average fatty acid composition of breast milk (data on which would allow quantification of the remaining amount required from CFs) has not been investigated.

# Results

## Recipe formulation and processing methods

The proposed compositions of the two fish-based food products are shown in Table 1 and the preliminary processing methods are outlined below.

### Fish chutney

Dried fish are soaked in water for approximately 30 minutes to be softened then roughly ground, using a hand-held stone grinder. Garlic is peeled and chopped, then ground into a paste, using a few drops of water. Onions are peeled and chopped, then fried in soybean oil on medium heat until translucent. Ground fish and garlic are then added to the onion and fried for approximately 5 minutes. Salt, chilli and a little water are added and fried for approximately 20 minutes, until the water has evaporated.

### Fish-based complementary food

Darkina fish are washed in clean water and oven-dried at $60^0$ C for approximately 24 hours, until a moisture level of 10-12% is reached. Dried fish are then ground into a powder and sieved to ensure uniform particle size. OSP is peeled, trimmed and washed to remove all dirt, then sliced into chips approximately 2 mm in width and blanched at $85^0$ C for 5 minutes to enhance colour retention. The chips are then oven-dried at $60^0$ C for approximately 24 hours, until a moisture level of 10-12% is reached. Dried chips are ground into flour. Rice is parboiled, milled and polished before being ground into flour. Dried fish powder, OSP flour, rice flour and soybean oil are mixed in the specified proportions and sifted to ensure a uniform particle size of < 420 µm, then extruded which allows pre-cooking of the product and improves food safety. The extruded product is then sieved again as above.

Table 1: Composition of fish-based chutney and fish-based complementary food.

| Ingredients | Composition by weight (%) | Composition per 30 g serve (g) |
|---|---|---|
| Fish chutney | | |
| Dried Jat puti fish | 37 | 11.1 (44.4 g raw)[a] |
| Onion, raw | 37 | 11.1 |
| Soybean oil | 15 | 4.5 |
| Garlic, raw | 7 | 2.1 |
| Dried red chilli powder | 4 | 1.2 |
| Iodized salt | <1 | <0.3 |
| Complementary food | | |
| Dried Darkina fish | 15 | 4.5 (18 g raw)[a] |
| Orange sweet potato flour | 30 | 9 |
| Rice flour | 45 | 13.5 |
| Soybean oil | 10 | 3 |

[a]Raw weight of fish is approximately four times the dried weight.

## Proposed serving size and acceptability

### Fish chutney

The proposed serving size for PLW is 30 g (approximately one heaped tablespoon) of chutney per day, which is equivalent to 44 g of raw fish, and is recommended to be served as an accompaniment to main meals such as boiled rice with vegetable curry. This serving size was selected to mirror typical quantities of other similar condiments such as 'achar' consumed by women and was considered to contain ample nutrients. The fish chutney was tested for acceptability among PLW and non-pregnant, non-lactating women in terms of taste, texture, aroma, appearance and overall impression, and was found to be well-liked[22(footnote)].

[22] Detailed acceptability testing of the proposed products is part of on-going research of WorldFish as mentioned in the discussion of this manuscript (see reference 58).

### Fish-based complementary food

The daily proposed serving size of the CF for infants, aged 6-11 months is a single portion of 30 g dry product, and for young children, aged 12-23 months, two portions of 30 g dry product (total of 60 g dry product per day), which is equivalent to approximately 18 g and 36 g of raw fish, respectively. These serving sizes were selected to be consistent with recommended quantities of CFs and to provide nutrients consistent with CODEX guidelines.[22,47] These serving sizes are specifically designed as a supplement to the local diet and to be given in addition to family foods, with continued breastfeeding. In the home, the pre-mixed product is to be mixed with boiled water and served as a porridge. The CF was taste tested among mother and infant dyads, and was found to be well-accepted, although some participants disliked the odour[23(footnote)]. In further production trials, the odour was found to be greatly reduced by omitting the extrusion step in processing and cooking the dry product in the home by boiling with water.

## Nutrient composition and potential contribution to RNIs

### Fish chutney

The nutrient composition of the fish chutney and the potential contribution to RNIs for PLW are shown in Table 2. Results show that the chutney, consumed in the proposed serve size, contributes significantly to micronutrient RNIs, most notably, 35% for calcium, and 24% for iron. The total fat content (10.3 g/100 g) was somewhat lower than might be expected, given that soybean oil composed 15% by weight of the ingredients, and the dried fish should have been a further source of fat. The total protein content (13.6 g/100 g) was also somewhat lower than what might be expected, given the high proportion of dried fish in the chutney (37% by weight). With respect to the fatty acid profile, the chutney had a moderate content of α-linolenic acid (ALA, 430 mg/ 100 g), low content of docosahexaenoic acid (DHA), no detected quantity of eicosapentaenoic acid (EPA), and a very high content of linoleic acid (LA, 4,770 mg /100 g).

[23] Detailed acceptability testing of the proposed products is part of on-going research of WorldFish as mentioned in the discussion of this manuscript (see reference 58).

### Fish-based complementary food

The nutrient composition of the fish-based CF and the potential contribution to desirable intakes for infants and young children are shown in Table 3. The CF, consumed in the proposed serve sizes, provided 41-63% of energy, 118-179% of protein and 68-114% of fat requirements required from CFs, dependent on age of the child (assuming average breast milk intake). In terms of micronutrient content, the proposed serve sizes exceeded 100% of desirable calcium intakes for all age groups; and vitamin A, iron and zinc intakes for children 12-23 months. A tolerable upper intake level (the highest average daily intake level that is likely to pose no risk of adverse health outcomes) for calcium for infants aged 7-11 months has not been established, however, the proposed serving for infants 12-23 months is well within acceptable limits (2500 mg/day 41), assuming average breast milk intake. Proposed serving sizes for vitamin A (600 µg RAE), iron (40 mg) and zinc (7 mg) are also well within tolerable upper intake levels, assuming average breast milk intake. [41]

Table 2: Nutrient composition of fish chutney and potential contribution of a daily serve to recommended nutrient intakes.

| Nutrient | Unit | Composition per 100 g | Composition per 30 g serve | Daily RNI[a] | Contribution to RNI from 30 g serve (%) |
|---|---|---|---|---|---|
| Macronutrients | | | | | |
| Energy | kJ | 784 | 235 | 9094[b] | 3 |
| Protein | g | 13.6 | 4.1 | 51.9[c] | 8 |
| Fat | g | 10.3 | 3.1 | 68[d] | 5 |
| Micronutrients | | | | | |
| Iron | mg | 12 | 3.6 | 15[e] | 24 |
| Zinc | mg | 3.1 | 0.9 | 7.9[f] | 12 |
| Calcium | mg | 1200 | 360 | 1040 | 35 |
| Iodine | µg | 140 | 42 | 200 | 21 |
| Vitamin B12 | µg | 0.944 | 0.283 | 2.7 | 10 |
| Fatty acids[d] | | | | | |
| Total PUFA[g] | g | 5.8 | 1.7 | 22[h] | 8 |
| Total MUFA | g | 2.6 | 1 | | |
| Total SFA | g | 2.1 | 0.6 | | |
| C18:2n-6 (LA) | mg | 4770 | 1431 | 6144 | 23 |
| C20:4n-6 (AA) | mg | 20 | 6 | | |
| C18:3n-3 (ALA) | mg | 420 | 126 | | |
| C20:5n-3 (EPA) | mg | Nd | nd | | |
| C22:6n-3 (DHA) | mg | 17 | 5 | 200 | 3 |
| Total n-6 PUFA | mg | 4819 | 1446 | | |
| Total n-3 PUFA | mg | 437 | 131 | 3072 | 4 |

[a] RNI, recommended nutrient intake.
[b] Baseline energy requirements plus average energy requirements during pregnancy and the first 6 months of lactation, assuming a mean bodyweight of 45 kg (pre-pregnancy), a physical activity factor of 1.6 and age 18-29.9 years [43], energy requirements > 6 months of lactation are highly variable depending on milk production, so were excluded.
[c] Based on 0.83 g/kg/day, assuming mean bodyweight of 45 kg (pre-pregnancy) plus 14.5 g/day throughout pregnancy and the first 12 months of lactation. [45]
[d] [44]
[e] Assuming 10% dietary bioavailability. [42]
[f] Assuming moderate dietary bioavailability. [42]

[g] PUFA, polyunsaturated fatty acid; MUFA, monounsaturated fatty acid; SFA, saturated fatty acid.
[h] Taken at the midpoint (9%) of the recommended range of PUFA as a percentage of total energy intake. [44]

For infants, aged 6-11 months, the recommended serving size would meet 65-77% of desirable vitamin A intake, 61-63% of desirable zinc intake, and 41% of desirable iron intake. Of note is that for infants, aged 12-23 months, the contribution to vitamin A substantially increases from 65% at 9-11 months to 334% at 12-23 months. This is due to the considerable drop in the RNI for vitamin A during this period, attributable to the different methods of estimating RNIs for these age groups which are constrained by the available evidence. [24] Table 3 also shows that the fish-based CF contributed substantially to fatty acid requirements, particularly the long chain omega-3 fatty acids, ALA (46-78%) and DHA (27-47%). This formulation is consistent with Codex Alimentarius Commission guidelines for macro nutrient composition of formulated CFs for older infants and young children (energy density of ≥ 17kJ/g, protein content of 6-15% energy, fat content of ≥ 20% energy). [22]

Table 3: Nutrient composition of fish-based complementary food and potential contribution of daily serve size to desirable nutrient intakes.

| Nutrient | Unit | Composition per 100 g | Composition per 30 g serve | Daily desirable intakes[a] from CF[b,c] | | | % contribution to RNIs from 1 serve | | % contribution to RNIs from 2 serves |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 6-8 mo | 9-11 mo | 12-23 mo | 6-8 mo | 9-11 mo | 12-23 mo |
| Macronutrients | | | | | | | | | |
| Energy | kJ | 1770 | 531 | 845 | 1284 | 2293 | 63 | 41 | 56 |
| Protein | g | 12.1 | 3.6 | 2.0 | 3.1 | 4.9 | 179 | 118 | 175 |
| Fat | g | 12.9 | 3.9 | 3.88 | 5.73 | 7.75 | 100 | 68 | 114 |
| Micronutrients | | | | | | | | | |
| Iron | g | 15 | 4.5 | 11[d] | 11[d] | 7[d] | 41 | 41 | 108 |
| Zinc | mg | 4.5 | 1.4 | 2.2[e] | 2.1[e] | 2.2[e] | 61 | 63 | 123 |
| Calcium | mg | 900 | 270 | 81 | 98 | 345 | 334 | 275 | 208 |
| Vitamin A | µg RAE | 418 | 125 | 164 | 193 | 27 | 77 | 65 | 322 |
| Fatty acids[f] | | | | | | | | | |
| Total PUFA[g] | g | 5.4 | 1.6 | 10.4 | 11.6 | 15.2 | 15 | 14 | 23 |
| Total MUFA | g | 4.8 | 1.4 | | | | | | |
| Total SFA | g | 2.8 | 0.8 | | | | | | |
| C18:2n-6 (LA) | mg | 3800 | 1140 | 2605 | 2909 | 3791 | 44 | 39 | 66 |
| C20:4n-6 (AA) | mg | 62 | 18 | | | | | | |
| C18:3n-3 (ALA) | mg | 600 | 180 | 347 | 388 | 505 | 52 | 46 | 78 |
| C20:5n-3 (EPA) | mg | 39 | 12 | | | | | | |
| C22:6n-3 (DHA) | mg | 95 | 29 | 87 | 106 | 132 | 33 | 27 | 47 |
| Total n-6 PUFA | mg | 3969 | 1191 | | | | | | |
| Total n-3 PUFA | mg | 838 | 251 | | | | | | |

[a] Adjusted from desirable nutrient densities. [24]
[b] CF, complementary food.
[c] Derived from average desired nutrient densities of CFs (based on US dietary reference intakes)[24(footnote)], and using the above total energy requirements from CFs. [24]
[d] Assuming 10% dietary bioavailability. [42]
[e] Assuming moderate dietary bioavailability. [42]
[f] Daily RNIs for fatty acids are for total daily RNIs (so include contributions from breast milk as well as CFs).
[g] PUFA, polyunsaturated fatty acid; MUFA, monounsaturated fatty acid; SFA, saturated fatty acid.

[24] Note that these standards are internationally relevant as they reflect an "update to the 1998 WHO/UNICEF report on complementary feeding" (reference 24).

## Discussion

The results show that SIS and other local nutrient-rich ingredients and simple processing methods can be used to formulate highly nutritious and acceptable food products, particularly suitable for the first 1,000 days of life. The fish chutney contributes significantly to micronutrient RNIs for PLW but less so to macronutrient RNIs. However, this is consistent with the concept of the chutney being served as an accompaniment to main meals (likely to provide significant amounts of energy and protein). The chutney has very high iron content and makes a significant contribution to the daily RNI (24%) from one serve. This is particularly important in Bangladesh, given the high prevalence of anaemia among women (42%), and the finding that 83% of breastfeeding rural women had an inadequate dietary intake of iron. [3,4] The chutney also contributes significantly to essential fatty acids requirements, although there is scope to optimise this further. Of note is that breast milk is the main source of PUFA in the diets of breastfed children, the content of which is largely dependent on the mother's diet. [17] The PUFA content of breast milk in Bangladesh has been shown to be low, linked to low dietary intake of PUFA-rich foods, so improvement in this aspect of the diet of PLW is likely to be of significant importance to the development of the child. A single serve of this fish-based chutney would more than triple the equivalent raw fish intake, compared to that of rural mothers in Northern Bangladesh. [27] Dietary diversity among women in Bangladesh is poor, with 59% of women consuming inadequately diverse diets (<5 food groups daily). Assuming that the single limiting food group for many of these women is animal-flesh foods, theoretically, consumption of this fish chutney by the 29% of women who are consuming only four food groups daily, could reduce dietary inadequacy to a national prevalence of <30%. [10]

The results also show that the fish-based CF contributes significantly to both macro- and micronutrient desirable intakes for infants and young children. The iron and zinc content is particularly impressive, given the tendency of CFs in low-income countries to be deficient in these nutrients. [15] In particular, contributions to iron and zinc RNIs are in stark contrast to a study in Bangladesh which used linear programming to model diets and found that nutrient requirements for infants and young children could not be realistically met without fortification. [48] The study was limited in that it was based on nutrient composition from international databases, so is not reflective of the unique nutrient composition of local foods, some of which, such as SIS, are particularly rich in several micronutrients of importance. This is a significant finding and indicates that dried small fish may indeed be a key food for achieving micronutrient adequacy for infants and young children in Bangladesh.

Furthermore, the potential nutritional contribution of this CF may be even greater than the laboratory analyses indicate. Firstly, due to the 'meat factor' - the biochemical mechanisms of which are still unclear, inclusion of fish in this CF would enhance the absorption of non-haem iron from other ingredients in the food. [14] Secondly, the daily RNIs for fatty acids presented in Table 3 refer to total daily RNIs, including contributions from breast milk, because, to the authors' knowledge, recommendations for composition of fatty acids in CFs have not been defined. This means that the values shown are perhaps less impressive than the potential contribution of this CF to requirements from CFs (excluding contributions from breast milk). The composition of fatty acids is of particular interest in relation to the essential role of fatty acids in cognitive development in infants and young children. [17] Thirdly, the contribution to desirable vitamin A intakes may also be higher than results indicate, as results only reflect the contribution to vitamin A from β-carotene (as this was the only vitamin A component analysed). The CF is likely to contain other components of vitamin A, given the known composition of dehydroretinol in Darkina fish and Jat puti fish [49], and the composition of other pro-vitamin A carotenoids in OSP. [50]

As mentioned above in relation to women, dietary diversity among infants and young children in Bangladesh is also poor, with 58% consuming an inadequately diverse diet (<4 food groups daily). Again, assuming that the single limiting food group for many of these infants and young children is animal-flesh foods, theoretically, consumption of this CF by the approximately 25% of children who are consuming only three food groups daily, could reduce the national prevalence of dietary inadequacy to <33%. [10]

## Strategies to further improve nutritional value of the fish-based products

Although the products presented in this paper have the potential to make significant contributions to RNIs and desirable intakes, depending on the quality of the overall diet of women and children, nutrient gaps may still remain. There is scope to further optimise nutritional value of the food products and more closely match RNIs or desirable intakes, for example, through alteration of serving size, inclusion of biofortified raw materials or substitution of ingredients. For example, several research groups are working towards development and release of biofortified high-zinc rice varieties and higher β-carotene OSP varieties in Bangladesh, which could be substituted in the fish-based CF to increase nutrient contributions. [51] Substitution of ingredients could also improve the fatty acid profile. For example, the fatty acid composition of the fish chutney as presented here is less desirable in relation to low and zero content of DHA and EPA, respectively, and the high content of

LA, given that diets high in LA can inhibit synthesis of DHA, and that LA inhibits incorporation of long chain PUFA into tissue. [52] The high content of LA in the chutney is likely due to inclusion of soybean oil, so the option for using an alternative oil with a lower LA content that is also accessible and culturally acceptable, such as mustard oil, should be investigated. [29] Inclusion of other nutrient-rich SIS or a combination of SIS with more desirable fatty acid profiles may also be an option, depending on availability. The WHO developed software – Optifood – based on linear programming, could be a useful tool for optimising the nutritional value of the food products, using local nutrient composition data, within certain context-specific constraints. [37]

Furthermore, the effect of different processing methods on nutrient composition of the final products should also be considered. For example, the fish chutney recipe proposed here uses dried fish obtained from the market (which is sun-dried). Other work has shown that sun drying destroys the vitamin A content in a particular SIS [53], although it is unknown if other methods such as oven-drying would have the same effect. This may have implications for suitability of production in small-scale versus industrial settings.

## Production models and potential distribution channels

One key feature in development of these products was selection of local ingredients and simple processing methods in order to ensure products were suitable for small-scale, or local community-based production which would maximise employment opportunities and local benefits to the economy. There are numerous examples globally of women's groups and local enterprises successfully establishing production of similar products. [54-57] Small-scale farmers could be contracted to produce all raw plant-based ingredients (as all are grown locally), and fisher-folk could be contracted to supply small fish from sustainable capture fisheries. Another promising source of raw fish for production is the polyculture of SIS with carps in homestead pond aquaculture – a food production system developed and promoted by WorldFish and others. [49] Rural women's groups, using a community business model could be engaged in initial processing of ingredients, for example, solar drying of SIS and OSP, and (with modifications to processing methods) even the entire production process of the two fish-based products. This is currently being piloted in a project implemented by WorldFish. [58]There are many potential channels for distribution of these fish-based products, the scale of which may dictate the production model. For example, if production is community-based, focusing on small-scale producers or women's groups for processing and distribution, this model would lend itself to local commercial sales including traditional sales outlets and alternative sales models such as the CARE rural sales programme which employs local women who earn a commission and sell products door-to-door. [59] On a larger scale, and potentially requiring a shift to industrial processing (which can still maintain local benefits through supply of raw ingredients), distribution channels could include national food programmes and emergency response food rations such as those of the World Food Programme, USAID Food for Peace and USDA Food for Progress programmes. The ready-made garment industry in Bangladesh which employs millions of young women, and in some cases provides child care services can also be an appropriate and targeted avenue for distribution of these products. [60] Ingredients and proposed serving sizes could be modified as necessary and used in school feeding programmes or as a therapeutic food in clinical and community health services for rehabilitation of children with moderate and severe acute malnutrition.

## Global relevance

The specific ingredients were selected for their relevance in the context of Bangladesh, but the broader concept of the use of underutilised animal-source foods (specifically SIS) and other local, nutrient-rich ingredients in development of nutritious food products, is applicable to many regions in the world. Indeed, some work is already under way, such as the WinFood study which; in Cambodia, investigated use of two local SIS (*Esomus longimanus* and *Paralaubuca typus*) in combination with spiders, rice and other ingredients; and in Kenya, investigated use of a local SIS (*Rastrineobola argentea*) in combination with edible termites, amaranth grain and other ingredients. [35,37] The concept is also applicable to other countries in the Great Lakes region of Africa such as Uganda and Tanzania and in West Africa where consumption of small dried fish is common, especially among the poor. Lessons can be learned from the large number of industrially processed fortified CFs in developing countries in terms of large-scale production and distribution models. [61]

## Next steps

WorldFish is currently trialling production, distribution and acceptability of these two products among approximately 300 households in Bangladesh. [58] A business model to determine the feasibility of different production models and distribution channels for the fish-based products should be developed, taking into consideration, lessons learned from other international examples. [61] In future, the efficacy and effectiveness of these fish-based food products for improving nutrition in the first 1,000 days, including impacts on cognitive development should be tested and the feasibility for expansion to other regions facing similar challenges should be investigated. The concept presented here also represents a significant opportunity for collaboration between the Consultative Group on International Agricultural Research (CGIAR) centres and others, in linking nutrition with agriculture, fisheries and aquaculture as a comprehensive and cross-disciplinary strategy to address food and nutrition insecurity, particularly in the first 1,000 days.

## Conclusion

The results shown here demonstrate that use of local, underutilised animal-source foods (specifically SIS) with other nutrient-rich ingredients and simple processing methods can be used to formulate highly nutritious and acceptable food products which can be particularly useful for targeting improved nutrient intake during the first 1,000 days of life. There is scope to improve the nutritional value of these products further by substituting ingredients, and in the case of the CF, use of biofortified ingredients such as high-zinc rice and high β-carotene OSP. The simple processing methods and use of local ingredients ensure that these products are suitable for local production with significant local economic and social benefits for communities. The products may also be suitable for industrial processing (which can still maintain local benefits through supply of raw ingredients) and scaled distribution through various channels including national food distribution programmes, commercial sales, school feeding programmes, and modification for use in treatment of moderate and severe acute malnutrition. The concept of these local fish-based nutritious food products is applicable to many other countries in Asia and Africa where consumption of small fish is common and context-specific opportunities for expansion of this concept should be investigated.

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## Authorship

Jessica Bogard contributed to conceptualising the research project, conducting practical research aspects, collation and interpretation of results and is responsible for writing of the manuscript. Anne-Louise Hother contributed to practical aspects of the research and significant review of draft manuscripts. Manika Saha contributed significantly to conceptualisation and practical aspects of the research project. Sanjoy Bose and Humayan Kabir contributed to development and refinement of food processing methods and production of the fish-based CF. Geoffrey Marks contributed significantly to review of draft manuscripts. Shakuntala Haraksingh Thilsted contributed significantly to formulating the research concept, establishing partnerships and review of draft manuscripts.

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# 6. Contribution of fish to diets, particularly in the first 1,000 days of life

## 6.1. Forward to manuscript

Understanding the contribution of a particular food or food group to nutritional quality of diets, in addition to data on the nutrient composition of that food, requires knowledge of the dietary patterns of the target group of interest. In Chapter 4, new data on the nutrient composition of common fish species was presented. The following chapter draws on this data, and secondary analysis of nationally representative quantitative food consumption data to address RQ3: What does fish currently contribute to diets in terms of nutrient intakes, particularly among vulnerable groups?

Key findings are that fish is by far the most important ASF in diets in Bangladesh across all population groups. There are however, large differences in consumption across wealth, age and gender groups, and geographic areas. Non-farmed species (those sourced from capture fisheries) make a larger contribution to iron, zinc, calcium, vitamin A and vitamin B12 intakes, compared to farmed species.

## 6.2. Formal citation and published manuscript

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# Non-farmed fish contribute to greater micronutrient intakes than farmed fish: results from an intra-household survey in rural Bangladesh

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Fish consumption and nutrient contribution

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**Conflict of Interest:**

None.

**Authorship:**

Conceptualisation of research questions, study design: JRB, GCM, SHT

Statistical methods: JRB, AM, GCM

Data analyses: JRB, AM

Preparation of manuscript: JRB, GCM, SHT

## Abstract

**Objective:** Fish is the most important animal-source food (ASF) in Bangladesh, produced from capture fisheries (non-farmed) and aquaculture (farmed) sub-sectors. Large differences in micronutrient content of fish species from these sub-sectors exist. The importance of fish in diets of vulnerable groups compared to other ASFs; contribution from non-farmed and farmed species to nutrient intakes; and differences in fish consumption among age, gender, wealth groups, and geographic regions were analysed, using quantitative intra-household fish consumption data, focusing on the first 1,000 days of life.

**Design:** 2-stage stratified sample.

**Setting:** Nationally representative of rural Bangladesh.

**Subjects:** 5,503 households; 24,198 individuals.

**Results:** Fish consumption in poor households is almost half that of wealthiest households; and lower in females than males, in all groups, except the wealthiest, and those aged ≥15 years ($P<0.01$). In infants of complementary feeding age, 56% did not consume ASFs on the day of the survey, despite 78% of mothers knowing this was recommended. Non-farmed fish make a larger contribution to iron, zinc, calcium, vitamin A and vitamin B12 intakes than farmed fish ($P<0.0001$).

**Conclusions:** Policies and programmes aimed to increase fish consumption as a means to improve nutrition in rural Bangladesh should focus on women and young children, and on the poorest households. Aquaculture plays an important role in increasing availability and affordability of fish, however, non-farmed fish species are better placed to contribute to greater micronutrient intakes. This presents an opportunity for aquaculture to contribute to improved nutrition, utilising diverse production technologies, and fish species, including small fish.

## Keywords

Fish, capture fisheries, aquaculture, animal-source foods, micronutrients, first 1,000 days, intra-household food consumption

## Introduction

Fisheries in Bangladesh is a diverse and growing food sector, with scores of species commonly consumed from capture fisheries, and large growth in availability of few local and imported species from aquaculture – the fastest growing food production sector globally [(1)]. Bangladesh ranks fifth in fish production from aquaculture, globally, and the main species farmed are carp, pangasius and tilapia [(2; 3)]. Fish is by far the most important animal-source food (ASF) in diets in Bangladesh [(3)], and is inextricably linked to the culture and livelihoods of the Bangladeshi people. Fish is also widely acknowledged as a nutrient-rich food with high content and bioavailability of micronutrients [(4; 5)], and as playing an essential role in diets of vulnerable groups. However, despite its diversity and nutritional importance, our knowledge of consumption of this food group is limited to household level food acquisition data or few surveys of small sample size, carried out in very specific geographic locations [(6)]. Furthermore, whilst capture fisheries and aquaculture as production systems are distinct from each other, in terms of management and governance, and the foods from these systems (non-farmed and farmed fish) have distinct nutritional profiles [(4)], consumption patterns of these foods are rarely differentiated. Lack of recognition of the complementary roles for capture fisheries and aquaculture to play in contributing to sustainable healthy diets represents an untapped opportunity [(7)].

The ubiquity of malnutrition in all its forms, despite decades of global research, investment and policy-making, in addressing its immediate determinants, has seen gathering momentum for research which takes a more nuanced approach to understanding dietary quality [(8)]. Furthermore, targeting vulnerable groups has been recognised as an essential strategy, particularly women and children during the first 1,000 days of life (from conception through to two years of age) and women throughout their reproductive years, for prevention of adverse outcomes including poor cognition and stunted growth [(9)]. A recent nationally representative survey of rural Bangladesh offers a unique opportunity to apply such approaches to our understanding of diets. In contrast to typical household surveys, this survey includes detailed quantitative 24-hour recall data on foods consumed by all household members, including pregnant and lactating women, and infants less than two years of age. Of particular interest, is consumption of nutrient-rich foods which can provide informative data for designing food-based policies, programmes and interventions to improve diets. Given the importance of fish in diets compared to other ASFs, the detailed data on consumption of more than 60 species of fish in this survey are the focus of analysis. Of note is that recent research found large variations in the nutrient composition of small indigenous fish species (SIS), from non-farmed sources, compared to commonly farmed large fish species (with SIS having a richer concentration of several important micronutrients) [(4)]. For this reason, our analysis compares and contrasts consumption according to the two categories: non-farmed and farmed fish.

The aims of this paper are to describe the importance of fish in diets of vulnerable groups in comparison to other ASFs, and the contribution of species from non-farmed and farmed sources to nutrient intakes. We present quantitative food consumption data from a representative intra-household level survey of rural Bangladesh, focusing on the first 1,000 days of life (including pregnant women, lactating women, and children less than two years of age). We describe differences in fish consumption among age groups, females and males, wealth groups, and geographic regions. Our analysis reveals the relative importance of the two fisheries sub-sectors; capture fisheries and aquaculture to vulnerable groups, and can inform the research agenda for fisheries management, with the goal of optimising the nutritional, economic and environmental outcomes of the sector. In doing so we make an important contribution to the policy debate about how capture fisheries and aquaculture sub-sectors can best contribute to sustainable healthy diets [(7)].

## Methods

Food consumption data from the Bangladesh Integrated Household Survey (BIHS) are analysed to describe fish consumption patterns, disaggregated by age and gender (in comparison to other ASFs), wealth groups and geographic region [(10)]. This cross-sectional survey was conducted by the International Food Policy Research Institute (IFPRI), from October 2011 to March 2012, using a two-stage stratified sample design and was statistically representative of rural Bangladesh (77% of the country's population) [(11)]. The survey covered 5,503 households, comprising 24,198 individuals. Fish consumption from non-farmed and farmed sources was also compared across wealth groups and geographic regions. Households were categorised within wealth groups, based on per capita expenditures according to analysis of food and non-food expenditure. Group one represents the poorest 20% and group five the wealthiest 20% of surveyed households. In combination with data on nutrient composition of fish species, we then use regression analyses to estimate nutrient intakes from fish from non-farmed and farmed sources.

## Dietary intake

The survey was comprehensive, covering many aspects of livelihoods and health status. Here, we used the modules on household food consumption (including quantitative data on raw ingredients used to prepare composite meals) and intra-household food consumption (including quantitative data on portions of cooked composite meals consumed by individuals within the household). We also use data from the modules on nutrition knowledge and awareness of mothers, and trial and adoption of sentinel practices. Data for both household and intra-household food consumption were collected from the person primarily responsible for meal preparation, using a 24-recall method [10]. The intra-household dataset provided only the cooked weight of composite foods (menu items) consumed by the individual (e.g. fish and vegetable curry), and therefore, calculation of the equivalent amount of raw ingredients by each individual (to estimate nutrient intakes using food composition data) required the following calculation:

$$\text{Weight of raw ingredient} = \text{Weight of raw ingredient}_{\text{(household)}} \times \text{Cooked weight of composite food}_{\text{(individual)}}$$

Quantities of dried foods (such as dried fish) were converted to raw weight equivalents, using conversion factors based on moisture content of foods (dried fish, factor of 3.5; fermented fish, factor of 2.2; dried meat, factor of 8.75 [12] (moisture content of fermented fish, 36 g moisture per 100 g, from unpublished WorldFish data).

## Procurement of fish

Knowledge of the ways in which fish is procured is useful in understanding interactions of different population groups with the market, own-production of food, fishing activities and other ways of procuring fish. Data on the source of food procured at household level were collected from the person primarily responsible for food preparation (usually an adult female), using a seven day recall. Sources of fish were recorded as: purchased, own production (for example, in homestead ponds), collected, caught or fished, gifted, given as wages, loaned, begged or as sacrificial meat. In data presented here ‘caught or fished’ and ‘collected’ were grouped together as these represent closely related activities. Fish sourced from a loan, begging or as sacrificial meat were grouped together as ‘other’ as they were reported in very low frequency. Only households which had procured fish in last seven days were included in this part of the analysis (n=5,181).

## Source of fish production

Analysing the contributions of fish to nutrition according to production sub-sector (non-farmed or farmed) is pertinent for two reasons: 1) governance of the two sub-sectors are distinct and unique, 2) nutrient composition of species from these sub-sectors are distinct [(4)]. The 63 categories of fish recorded in the survey were grouped according to their primary production sub-sector (Supplementary Table 1). Two local species: magur (*Clarias batrachus*) and shing (*Heteropneustes fossilis*) are commonly produced in both sub-sectors and so their contributions to fish consumption and nutrient intakes (see following section) were distributed evenly across both. All results for non-farmed fish consumption include dried fish (converted to fresh weight equivalent), and in some cases, dried fish consumption is additionally presented as its own category.

## Nutrient intakes from fish

To estimate the nutrient intakes from fish, the raw weight of individual ingredients consumed by individuals was first adjusted by an average edible part conversion factor for small and large fish [(13)], to account for parts such as large fish bones that are not consumed (Supplementary Table 1). The adjusted individual portion was then multiplied by the nutrient composition of that species, based on published literature [(4; 12; 14)]. Some survey categories represented several species. In these cases, a simple weighted average nutrient composition was applied (Supplementary Table 1). In the case of lack of data on nutrient composition of a species, expert opinion was sought on the most similar species (based on taxonomy) for which data are available (Dr. M. A. R. Hossain, Bangladesh Agricultural University, personal communication, 2015).

## Statistical analysis

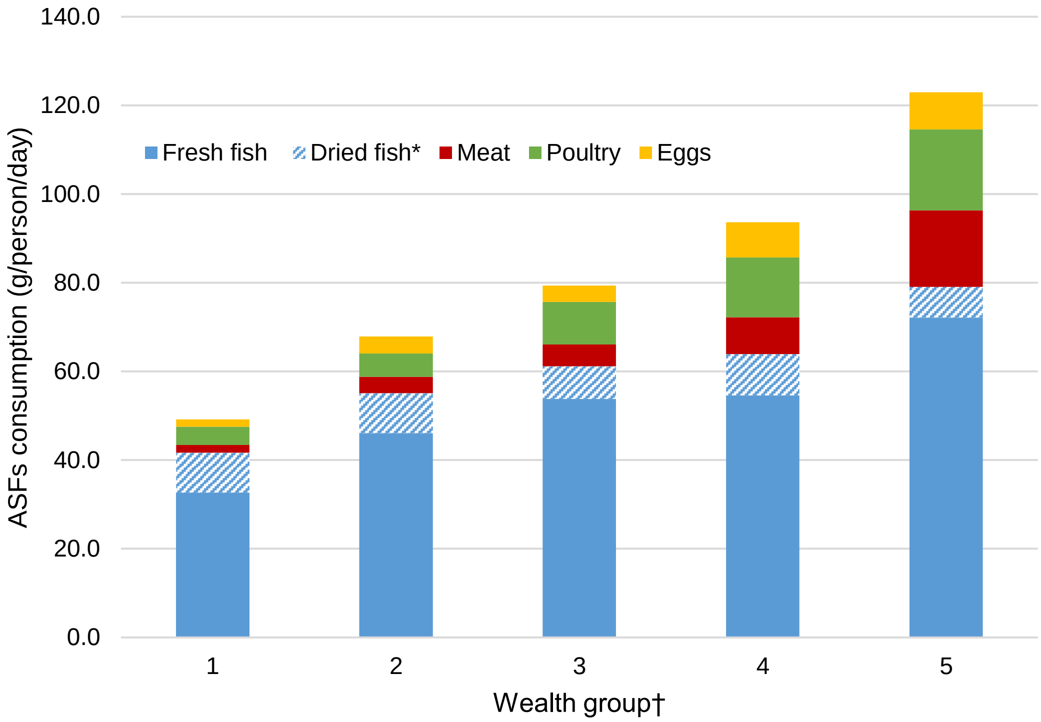
Data analysis was conducted using STATA version 13.1. Individuals were excluded if they were currently residing away from the homestead, considered not a valid household member or they were a child being exclusively breastfed and therefore not consuming other foods (n=24,198 individuals included). Regression analysis was used to estimate mean fish consumption, whilst controlling for age (including a quadratic term), sex, wealth group, and geographic region ($P<0.05$). In comparing nutrient intakes from fish from non-farmed and farmed categories, persons who did not consume any fish, and persons who consumed fish from both categories on the one day surveyed were excluded (n=14,525 individuals included). In regression analysis, nutrient intakes from fish were the primary outcome variables (energy, protein, fat, iron, zinc, calcium, vitamin A and vitamin B12) as predicted by category of fish (non-farmed or farmed), within the above specified model (P<0.05). All outcome variables were positively skewed in distribution. Repeat analysis on log-transformed variables revealed the same significance in results, except for protein (see results section). Due to a number of zero values for zinc, vitamin B12 and vitamin A intake from fish (for species with nutrient composition not analysed, or analysed as having no detectable quantity of these nutrients), log transformation did not produce a Normal distribution for those variables. In these cases, a sensitivity analysis was conducted using quantile regression which predicts the median rather than the mean and is therefore not influenced by skewness of the data. Energy intake was not adjusted for, as is commonly done in epidemiological studies [(15)], because in this case energy intake from fish is considered an effect mediator rather than a confounder, given we modelled nutrient intakes as an outcome rather than as a predictor of disease risk. Sampling weights provided by IFPRI derived from 2011 census data were applied in all results presented in this paper.

## Results

### Animal-source foods consumption

Fish has by the far the highest average consumption (g/person/day) compared to other ASFs (excluding milk which was not analysed here) across all wealth groups in rural Bangladesh (see Figure 1), with a mean national fish consumption of 60 g/person/day (standard error, SE ±1) compared to 7 g meat (± 1), 10 g poultry (± 1), and 5 g eggs (± <1) per person per day. Dried fish (adjusted to fresh weight equivalent) represents a considerable portion of total fish consumed, at 8 g/person/day, with no significant differences across wealth groups (P>0.05). Figure 1 shows that as a proportion of total ASFs, fish is relatively more important for the poorest, constituting 85% of mean total ASFs consumption in the poorest group, compared to 64% of mean total ASFs consumption in the wealthiest group.

Figure 1: Mean consumption of animal-source foods (g/person/day) by wealth group in rural Bangladesh (adjusted for age, sex, geographic region).




ASF, animal-source food.
*Dried fish includes fermented and dried fish, adjusted to fresh weight equivalent.
†Wealth group one represents the poorest 20% of households and wealth group five represents the least poor 20% of households.

### The first 1,000 days

Consumption of ASFs by pregnant women, lactating women, and children less than two years, follows a similar trend to national averages; with fish having by far the highest average consumption compared to other ASFs (see Table 1). Consumption of total fish by pregnant or lactating women was slightly higher than non-pregnant or non-lactating women of childbearing age. Mean fish consumption by lactating women in this analysis is much higher than that reported by Yakes et al (12.3 g/person/day) - the only other known quantitative data on fish consumption among lactating women in Bangladesh [(16)]. Consumption of meat, poultry and eggs by lactating women was also much higher than that reported by Yakes (3.6 g meat and poultry/woman/day, 4.7 g eggs/woman/day). However, this was a very small study (n=259 women), carried out in only two locations in Northern Bangladesh and so is not directly comparable.

Understanding aspects of nutrition knowledge, attitudes and practices of caregivers is necessary for interpreting food consumption patterns within the first 1,000 days of life.

Regarding nutrition knowledge, when caregivers of children less than two years of age (n=979) were asked “what foods does a young child need in order to grow and develop their brain”, fish was the highest ranking primary response, reported by 29% of women, followed by eggs, at 19%. Regarding awareness, trial and adoption of feeding practices, when asked if they had heard about the practice of feeding ASFs (such as fish, meat, liver or eggs) at least once a day to children older than six months, 78% reported yes and 63% reported that they had put this knowledge into practice. This is more optimistic when compared with actual consumption data, showing 44% of children of complementary feeding age actually consumed ASFs on the previous day (of which, 76% consumed fish and the mean intake was 22 g fish/child/day, SE 1.6). For those who reported that they had not put this knowledge into practice, the most common reason (45%) was that the child was not old enough, followed by financial limitations (39%).

Table 1: Mean consumption of animal-source foods (g/person/day) among children under 2 years, pregnant women, lactating women and women of childbearing age in rural Bangladesh (adjusted for age, sex, wealth group, geographic region).

| Group | n | Total fish* | | Dried fish† | | Meat | | Poultry | | Eggs | | Fish as % of all ASFs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | SE | Mean | SE | Mean | SE | Mean | SE | Mean | SE | |
| Children < 2 years | 726 | 7 | 1 | 1 | <1 | 1 | <1 | 1 | <1 | 6 | 1 | 47 |
| Pregnant women | 262 | 69 | 5 | 10 | 2 | 10 | 4 | 13 | 4 | 4 | 1 | 73 |
| Lactating women | 1200 | 73 | 3 | 9 | 1 | 8 | 2 | 12 | 3 | 4 | 1 | 75 |
| Women of CBA‡ | 5057 | 64 | 2 | 9 | 1 | 7 | 1 | 10 | 1 | 5 | <1 | 74 |

ASFs, animal-source foods. SE, standard error. CBA, childbearing age.
*Total fish includes fresh, dried and fermented fish converted to fresh weight equivalent.
†Dried fish includes dried and fermented fish converted to fresh weight equivalent.
‡ Women aged 15-49 years, excluding pregnant or lactating women.

## Gender, age and wealth differences in fish consumption

Fish consumption is significantly lower for females than males from the age group 15 years and older (see Table 2). The largest discrepancies between females and males were within the 50 years and over age group, with females consuming 12 g/day less than males on average (P<0.001). There were no significant differences in fish consumption between females and males for infants, children and adolescents <15 years old. A similar pattern was found when examining gender differences in dried fish consumption (see Table 2). These findings are in contrast to previous studies, which although not of similar methods or sample size, have indicated that female children consume less ASFs, including fish, compared to male children [17; 18].

When examining gender differences by wealth group, we found that total fish consumption by females is consistently and significantly lower than by males, for all wealth groups, except the wealthiest (Table 2). When examining dried fish, consumption by females was significantly lower than males for wealth groups one and three ($P<0.05$). Of note is that there were no significant differences in mean consumption of dried fish (g/person/day) across wealth groups ($P>0.05$). However, dried fish as a proportion of total fish was more important for the poorer wealth groups, representing 21% of total fish consumption (fresh weight equivalent) compared to 9%, in the wealthiest group. This trend is consistent with that observed by Belton and colleagues based on household data [(3)]. The importance of dried fish for the poor, has been described elsewhere, based on surveys of varying sample sizes and methods; however, this is the first time it has been described at intra-household level.

## Procurement of fish

For the first time, data on procurement of fish consumed in rural Bangladesh is reported. The large majority of households (80%) procured fish from a single source, most commonly, through purchasing (71% of households), followed by fishing related activities (3% of households) and own production (3% of households). Only 20% of households relied on procuring fish from a combination of two or more sources. Purchased fish accounted for 79-81% of total fish consumed by wealth group, with the only significant difference between wealth groups three and five (Table 3, $P<0.05$). Reliance on fish from own production accounted for an average of 4-13% of total fish consumption, with significant differences across wealth groups and geographic regions ($P<0.05$). By examining own production of fish versus fishing activities, we see that the poor rely more heavily on fishing activities (8% of total fish consumed compared to 4% from own production), whereas the rich rely much more heavily on own production (13% of total compared to 4% from fishing activities). The poor procured 8% of total fish consumed as ‘gifted’ fish, which was significantly higher than the proportion of gifted fish consumed by all other wealth groups ($P<0.05$). When examining geographical differences in fish procurement, Khulna had the lowest reliance on purchased fish (73% of total procurement), and the highest reliance on fish from own production. Rajshahi and Sylhet were the only regions in which the proportion of fish procured from fishing activities was higher than the proportion procured from own production. Fish procured from wages or other methods were <1% of total fish consumed and are not shown here.

Table 2: Mean total fish and dried fish consumption (g/person/day) by age and wealth group in total and by gender in rural Bangladesh (adjusted for age, sex, wealth group and geographic region).

| | Total fish* | | | | | | | | | Dried fish† | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | | By gender | | | | | | | | | | | |
| | | | n | | Female | | Male | | P-value | Female | | Male | | P-value |
| | Mean | SE | Female | Male | Mean | SE | Mean | SE | | Mean | SE | Mean | SE | |
| **Age group (years)** | | | | | | | | | | | | | | |
| < 2 | 7 | 1 | 368 | 358 | 6 | 1 | 7 | 1 | 0.61 | 1 | 1 | 2 | <1 | 0.15 |
| 2-5 | 31 | 1 | 1143 | 1165 | 31 | 2 | 31 | 2 | 0.88 | 3 | 1 | 4 | 1 | 0.10 |
| 6-14 | 52 | 2 | 2730 | 2713 | 50 | 2 | 53 | 2 | 0.06 | 7 | 1 | 8 | 1 | 0.41 |
| 15-49 | 71 | 2 | 6483 | 5295 | 67 | 2 | 75 | 2 | <0.001 | 9 | 1 | 11 | 1 | 0.002 |
| ≥50 | 67 | 2 | 1852 | 1961 | 61 | 2 | 73 | 2 | <0.001 | 8 | 1 | 10 | 1 | 0.02 |
| **Wealth Group‡** | | | | | | | | | | | | | | |
| 1 | 42 | 1 | 2620 | 2318 | 35 | 2 | 41 | 2 | <0.001 | 8 | 1 | 10 | 1 | 0.01 |
| 2 | 55 | 1 | 2551 | 2283 | 51 | 2 | 58 | 3 | <0.001 | 8 | 1 | 9 | 1 | 0.06 |
| 3 | 61[a] | 1 | 2447 | 2301 | 58 | 3 | 65 | 3 | <0.001 | 7 | 1 | 8 | 1 | 0.03 |
| 4 | 64[a] | 1 | 2489 | 2330 | 66 | 3 | 71 | 4 | 0.002 | 10 | 2 | 12 | 2 | 0.11 |
| 5 | 79 | 1 | 2469 | 2260 | 78 | 3 | 83 | 4 | 0.07 | 7 | 1 | 7 | 1 | 0.84 |
| Total | 60 | 1 | 12576 | 11492 | 57 | 1 | 63 | 2 | 0.001 | 8 | 1 | 9 | 1 | <0.001 |

SE, standard error.
*Total fish includes fresh, dried and fermented fish converted to fresh weight equivalent.
†Dried fish includes dried and fermented fish converted to fresh weight equivalent.
‡Wealth group one represents the poorest 20% of households and wealth group five represents the wealthiest 20% of households.
[a] Mean values within this column are all significantly different from each other (P<0.05), except wealth group 3 and 4.

Table 3: Proportion of fish consumption by procurement source (as % of total fish consumed) in rural Bangladesh.

| | Purchased* | | Own production* | | Fished/collected* | | Gifted* | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SE | Mean | SE | Mean | SE | Mean | SE |
| By wealth group† | | | | | | | | |
| 1 | $79^{a,b}$ | 2 | 4 | 1 | $8^{a}$ | 1 | 8 | 1 |
| 2 | $81^{a,b}$ | 1 | $5^{a}$ | 1 | $8^{a,b}$ | 1 | $5^{a}$ | 1 |
| 3 | $81^{a}$ | 1 | $6^{a}$ | 1 | $6^{b}$ | 1 | $5^{a}$ | 1 |
| 4 | $81^{a,b}$ | 1 | 8 | 1 | $7^{a,b}$ | 1 | $4^{a}$ | 1 |
| 5 | $79^{b}$ | 2 | 13 | 1 | 4 | 1 | $4^{a}$ | 1 |
| Total | 81 | 1 | 7 | 1 | 7 | 1 | 5 | <1 |
| By geographic division‡ | | | | | | | | |
| Barisal | $81^{a,b}$ | 3 | $8^{a,b}$ | 2 | $7^{a,b}$ | 2 | $4^{a}$ | 1 |
| Chittagong | $86^{a}$ | 2 | $5^{a}$ | 1 | $3^{b}$ | <1 | $6^{a}$ | 1 |
| Dhaka | $80^{b,c}$ | 2 | $7^{a}$ | 1 | $6^{a,c}$ | 1 | $6^{a}$ | 1 |
| Khulna | $73^{b,d}$ | 4 | $13^{b}$ | 2 | $7^{a}$ | 1 | $6^{a}$ | 1 |
| Rajshahi | $81^{a,c,d}$ | 3 | $5^{a}$ | 1 | $7^{a,b}$ | 2 | $6^{a}$ | 1 |
| Rangpur | $83^{a,c}$ | 3 | $8^{a,b}$ | 2 | $4^{b,c}$ | 1 | $5^{a}$ | 1 |
| Sylhet | $80^{a,c,d}$ | 3 | $4^{a}$ | 1 | $11^{a}$ | 2 | $4^{a}$ | 1 |
| Total | 81 | 1 | 7 | 1 | 7 | 1 | 5 | <1 |

SE, standard error.
$^{a,b,c,d}$ Mean values within a column with unlike superscript letters were significantly different (P<0.05), sections on wealth group and geographic division considered separately.
* All fish categories include dried and fermented fish converted to fresh weight equivalent.
†Wealth group one represents the poorest 20% of households and wealth group five represents the wealthiest 20% of households. Means adjusted for geographic division).
‡ Means adjusted for wealth groups.

## Consumption of non-farmed and farmed fish

When fish consumption is disaggregated according to production source (non-farmed or farmed), non-farmed fish constitutes the majority of consumption, with a national average of 33 g/person/day compared to 27 g/person/day from farmed fish (Table 4). This is dissimilar to previously reported results [(3)]. However, consumption of farmed fish species was likely to be overrepresented in that analysis, as it was based on a survey covering four districts with a higher than average level of pond ownership and where participation in aquaculture related development projects was common. Mean consumption of non-farmed fish ranged from 27-37 g/person/day across wealth groups, with consumption by the poorest wealth group significantly lower than all other groups (P<0.05). In contrast, mean consumption of farmed fish significantly increased with each higher wealth groups (with the only non-significant difference between wealth groups three and four, P>0.05). In other words, consumption of non-farmed fish is relatively stable across wealth groups, but as wealth increases, consumption of fish from farmed sources increases. Figure 2 demonstrates that non-farmed fish (as a proportion of total fish consumption) is relatively more important in the diets of the poor, constituting 64% of total fish consumption in the poorest wealth group compared to

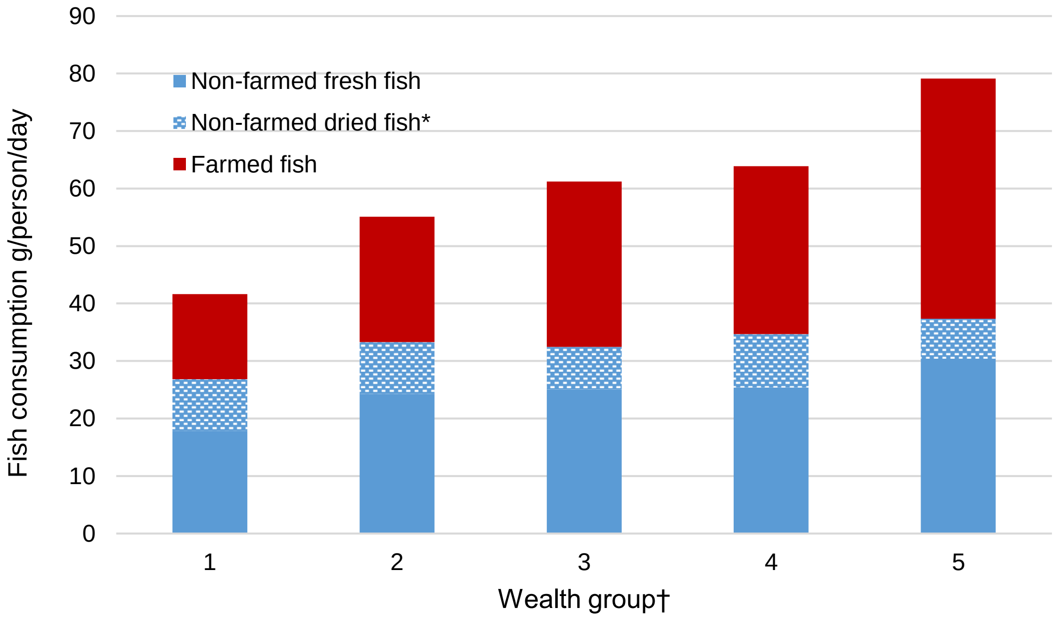
47% in the wealthiest group. This is consistent with the general trend reported by Belton et al (2014).

Table 4: Mean fish consumption from non-farmed, farmed and dried fish (g/person/day) by geographic division in rural Bangladesh (adjusted for age, sex and wealth group).

| Division | Non-farmed fish* | | Farmed Fish | | Dried fish† | |
|---|---|---|---|---|---|---|
| | Mean | SE | Mean | SE | Mean | SE |
| Barisal | 36[a] | 3 | 21[a] | 2 | 4[a,b] | 1 |
| Chittagong | 37[a] | 4 | 27[b] | 2 | 14[c,d,e] | 2 |
| Dhaka | 40[a] | 2 | 34[c] | 2 | 14[c,e] | 2 |
| Khulna | 26[b] | 3 | 35[c,d] | 3 | <1 | <1 |
| Rajshahi | 17[b] | 3 | 28[b,d] | 2 | 2[a] | 1 |
| Rangpur | 24[b] | 3 | 18[a] | 2 | 9[b,d,e] | 3 |
| Sylhet | 50 | 3 | 29[b,c] | 3 | 15[c] | 2 |
| Total | 33 | 1 | 27 | 1 | 8 | 1 |

SE, standard error.
[a,b,c,d,e] Mean values within a column with unlike superscript letters were significantly different ($P<0.05$).
* Non-farmed fish includes fresh, dried and fermented fish converted to fresh weight equivalent.
† Dried fish includes dried and fermented fish converted to fresh weight equivalent.

Figure 2: Mean fish consumption from non-farmed and farmed fish (g/person/day) by wealth group in rural Bangladesh (adjusted for age, sex, geographic region).




*Dried fish includes dried and fermented fish converted to fresh weight equivalent. The sum of non-farmed fresh fish and non-farmed dried fish equals total non-farmed fish consumption.
†Wealth group one represents the poorest 20% of households and wealth group five represents the wealthiest 20% of households.

## Geographic differences in fish consumption

Consumption of total fish and the proportions from non-farmed and farmed sources vary by geographic region (Table 4). There are large variations in the total amount of fish consumed, with mean consumption in Sylhet (79 g/person/day) almost double that in Rangpur (42 g/person/day).

Consumption of non-farmed fish was significantly lower in Rajshahi, Rangpur and Khulna (17-26 g/person/day) compared to that in all other regions (36-50 g/person/day). Mean consumption of farmed fish by district was also highly variable (18-35 g/person/day), with consumption in Rangpur and Barisal significantly lower than all other regions ($P<0.05$). The proportion of non-farmed versus farmed fish also varies; non-farmed fish made up the majority of total fish consumed in all districts, except in Rajshahi and Khulna. These differences are likely due to varied availability and affordability of fish in different areas. Sylhet, for example is a region with extensive inland wetlands, and is therefore likely to have greater availability of non-farmed species. Khulna is a region with higher than average pond ownership, and also with commercial aquaculture farms, which most likely increase local fish availability. Dried fish consumption also varies considerably by geographic region, with mean consumption of 15 g/person/day (fresh weight equivalent) in Sylhet compared to <1 g/person/day in Khulna. In Chittagong, dried fish made up 22% of total fish consumed, compared to 4% in Rajshahi. This reflects a combination of geographical differences in both availability of fish which are considered suitable for drying/fermenting, and the cultural preferences that have hence evolved for such fish products.

## Nutrient intakes from fish

Analysing nutrient intakes from fish consumption, according to fisheries sub-sectors is important as there are large differences in nutritional quality of non-farmed and farmed fish species. Fish from non-farmed sources constitutes a large variety of species from both inland and marine sources, many of which are SIS. These SIS when consumed whole, with head and bones offer a particularly rich source of micronutrients such as iron, zinc, calcium, vitamin A and vitamin B12. This is in contrast to farmed species which are dominated by relatively few, large fish species, generally with lower micronutrient content [(4)]. This trend can be seen when comparing the mean nutrient intake from fish (among those who consumed fish) from non-farmed and farmed categories, adjusted for age, sex, wealth group, and geographic region (Table 5).

Table 5: Mean nutrient intakes (per person per day, among those who consumed fish) from non-farmed and farmed fish in rural Bangladesh (adjusted for age, sex, wealth group, geographic region).

| Nutrient | Non-farmed fish* | | Farmed fish | | P-value | Daily RNI† |
|---|---|---|---|---|---|---|
| | Mean | SE | Mean | SE | | |
| Energy (kJ) | 284 | 8 | 336 | 9 | <0.0001 | 10,800 |
| Protein (g) | 11.3 | 0.3 | 11.5 | 0.3 | P=0.38‡ | 47 |
| Fat (g) | 2.5 | 0.1 | 3.9 | 0.2 | <0.0001 | 80 |
| Iron (mg) | 2.90 | 0.11 | 1.04 | 0.06 | <0.0001 | 29.4 |
| Zinc (mg) § | 1.70 | 0.05 | 0.68 | 0.02 | <0.0001 | 9 |
| Calcium (mg) | 521 | 15 | 169 | 12 | <0.0001 | 1000 |
| Vitamin A (µg) § | 113 | 8 | 12 | 3 | <0.0001 | 500 |
| Vitamin B12 (µg) § | 1.77 | 0.08 | 1.44 | 0.08 | <0.0001 | 2.4 |

SE, standard error; RNI, recommended nutrient intake.
* Non-farmed fish includes fresh, dried and fermented fish converted to fresh weight equivalent.
† Based on a female of reproductive age, with moderate physical activity level and weight of 57 kg. Fat requirements range from 25-35% of total energy intake, which here is presented at the mid-point of the range (1 g fat=37 kJ).
‡When repeated using log transformed outcome variable, predicted mean differences in protein intake became statistically significant (P<0.0001).
§Using quantile regression, predicted mean zinc intake was 1.18 mg and 0.60 mg from non-farmed and farmed sources, respectively (P<0.0001); predicted mean vitamin B12 intake was 0.87 µg and 0.72 µg from non-farmed and farmed sources, respectively (P<0.0001); predicted mean vitamin A intake was 11 µg RAE and 6 µg RAE from non-farmed and farmed sources, respectively (P<0.0001).

Non-farmed fish make a larger contribution to nutrient intakes for all micro-nutrients considered, than farmed fish (P<0.0001). There is no statistically significant difference between protein intakes from the two sub-sectors, and energy and fat intakes are both statistically significantly lower from non-farmed compared to farmed fish. Results are even starker, when we consider the typical portion sizes of fish consumed from each sub-sector. Those who consumed farmed fish had approximately 18 g more fish than those who consumed non-farmed fish. So, even though the quantities of non-farmed fish consumed were smaller, the micronutrient contribution was greater than from farmed fish.

Statistically significant differences between nutrient intakes from the two sub-sectors were identified for all nutrients (except protein), but are these differences nutritionally important? In terms of energy, mean intake of farmed fish contributed 46 kJ more, per person per day; however, given an active adult female's typical estimated energy expenditure (EER) is around 10,000 kJ per day, a difference of <50 kJ is relatively un-important (a difference of <0.5% of the recommended nutrient intake (RNI) for an adult female). Similarly the difference in fat intake from the two sub-sectors as a percentage of RNI is low (2% of RNI for an adult female). In contrast, when the differences in mean intakes of micronutrients (iron, zinc, calcium, vitamin A and vitamin B12) between non-farmed and farmed fish are compared to their RNIs, these differences are much more nutritionally important (a difference of 6-35% of RNIs for an adult female). Both non-farmed and farmed fish make an equal and important contribution to protein requirements (approximately 25% of daily RNI).

Differences in predicted intake of zinc, vitamin B12 and vitamin A between non-farmed and farmed fish are less stark when using quantile regression which estimates the median intake rather than mean, but remain in the same direction and statistically significant (Table 5, $P<0.001$).

## Discussion

For the first time, using a national representative survey of rural Bangladesh, we have analysed quantitative data on ASF consumption, at the intra-household level, with focus on the first 1,000 days of life. This analysis has shown significant variations in fish consumption related to wealth group, gender, age group and geographic location, all of which have implications for policies, programmes and interventions aiming to increase fish consumption and nutrient intake. Given that national nutrition guidelines recommend fish consumption of 60 g/person/day [(19)], it is evident that targeted programmes to increase availability and affordability of fish for the people of the poorest two wealth groups nationally (whose consumption is much lower than this recommendation) should be prioritised. Fish consumption in females was significantly lower than in males, in all wealth groups, except the wealthiest, and in those aged less than 15 years. Further investigation as to the nutritional significance of these gendered differences in fish consumption, in relation to nutrient requirements is needed. For example, given that women generally have lower energy requirements compared to men, the lower consumption of fish may not be surprising; however, fish is a nutrient-rich food and its value lies more in provision of micronutrients rather than dietary energy. In this respect, particularly for women of child-bearing age who often have higher nutrient requirements than men, these gendered differences in consumption are likely to be of nutritional significance. With respect to geographic trends, mean fish consumption in some regions, particularly Rangpur and Rajshahi was much lower than the national recommendation, indicating that context-specific interventions to increase consumption are needed.

Consumption of dried fish formed a large component (9-29%) of total fish consumption, across age, gender and wealth groups as well as in the first 1,000 days of life. There were no differences in the quantity of dried fish consumed across wealth groups, although as a proportion of total fish, dried fish consumption was much more significant for the poor. Dried fish provides a concentrated source of micronutrients and potentially reduces the effects of seasonable availability of fresh fish (due to its longer shelf life) and is therefore likely an important source of nutrients for particular groups. Given nutrient-dense foods are desirable for young children (given their high nutrient needs and low stomach volume capacity) [20], dried fish may be well suited to the dietary needs of infants and young children. Further research in the dried fish value chain, including food safety aspects, seasonality of consumption and nutritional quality of dried fish is necessary.

In relation to fish consumption in the first 1,000 days of life, it was evident that the predominant reason for not feeding fish to infants from six months of age was due to the perception that they are too young, even though caregivers knew that fish is a nutritious food recommended for young children. One plausible explanation identified elsewhere is that caregivers are concerned about suitability of fish with regards to consistency (e.g. presence of bones) for young children [21]. This represents an opportunity for education and training on optimal complementary feeding practices, including modified preparation methods for fish particularly suited to infants. Innovative food preparation methods such as fish-based food products, using powdered dried fish designed specifically for this age group may be an appropriate alternative [22]. Overall, mean fish intakes among pregnant and lactating women were surprisingly slightly higher than the national average. Maternal seafood consumption throughout pregnancy has been shown to improve neurodevelopmental outcomes of infants and children [23; 24]. Breastmilk and fish have been identified as the most important dietary sources of omega-3 fatty acids for infants of complementary feeding age. Furthermore, consumption of marine foods by the mother appears to be the most important determinant of omega-3 fatty acids content of breastmilk [25]. Therefore, further investigation of the enablers and barriers to increased fish consumption, particularly for women of child-bearing age, is necessary.

Purchased fish formed the majority of total fish consumed for households across all wealth groups and locations. However, there were important differences in fish procurement among wealth groups. The poor were more reliant on fishing activities (capture fisheries) and the rich more on own production (aquaculture).

When considering the source of fish production, we have shown that non-farmed fish makes a greater contribution to micronutrient intakes compared to farmed fish, in rural Bangladesh. This is likely due to the large diversity of species within the non-farmed fish category, each with a unique nutrient profile, as well as differences in the edible portion of SIS which make up a large proportion of the non-farmed category compared to farmed large fish. SIS are commonly consumed whole, with head, bones and sometimes viscera, which contribute to the nutritional diversity of fish as consumed, compared to commonly farmed species which are typically large in size and only the flesh is consumed (26). The differences in micronutrient content between commonly farmed large species and selected common SIS are large; in many cases, more than an order of magnitude (4). Whilst there is no question that aquaculture has an important role to play in increasing fish availability and stabilising prices (27), policies and production technologies that enhance access to and consumption of SIS (compared to large, commonly farmed species) by vulnerable groups are likely to have greater impacts on nutrition (given their higher micronutrient content, on a direct substitution basis). Economic analysis was considered outside the scope of this study, however, other work has demonstrated the lower price and income elasticity of SIS compared to large fish, particularly for the poor (28). This indicates that a) SIS are considered more of a staple food (rather than a luxury) compared to large fish; and b) changes in price of large fish will bring about larger changes in consumption (either increases or decreases).

There are several initiatives in Bangladesh that show great potential to enhance consumption of SIS, but they are yet to receive adequate policy attention and be widely disseminated. For example, WorldFish and partners have developed a polyculture technology in which the micronutrient-rich SIS, mola (*Amblypharyngodon mola)* is produced in homestead ponds along with farmed large-sized species such as carp (29) [25(footnote)]. The SIS breed in the pond and are ideally suited for regular harvesting and consumption by the household, whereas the large fish, stocked as fingerlings are harvested as adults and are suited for sale. This technology has been shown to be a cost-effective approach to the reduction of micronutrient malnutrition (30). This research should be further developed to incorporate other SIS. Another example of a promising production technology is enhanced stocking of SIS in wetlands (as an alternative to the well-documented method of stocking exotic or indigenous large species), with benefits for increased productivity, sustainability, biodiversity and nutrition (31). Other authors have recognised the under-utilised but auspicious practice of rice-fish production systems, another diverse production system traditional to many Asian countries but largely forgotten during the Green Revolution focus on rice production (32).

[25] The polyculture system with carp species and SIS was originally developed by Bangladesh Agricultural University in the late 1990s (Roos et al., 2007), and has been further developed and promoted by WorldFish and partners.

The important policy and programme implications of the detailed analysis presented here demonstrates the value of intra-household level data, as well as consumption surveys in which foods are recorded at species/variety level. Investment in methods and tools for collection of high quality food consumption data should be prioritised in other countries where fish is an important ASF. High quality and detailed data will inform and maximise the potential of policies and programmes designed to improve diets and nutrition, particularly among vulnerable groups.

Limitations of the study relate largely to the survey design. This survey is nationally representative of rural Bangladesh, and therefore the results are not generalisable to the urban population. Furthermore, the survey was conducted over a period of six months. Food insecurity is known to vary seasonally and spatially, reflecting diverse production and harvest systems across the country [33]. Data collected periodically throughout the year are required to understand seasonal differences in fish consumption within geographic regions, particularly among vulnerable groups.

## Conclusion

This research confirms that policies and programmes aimed to increase fish consumption as a means to improve nutrition in rural Bangladesh should focus on women and young children, on households from the poorest wealth groups, and particularly those in Rajshahi and Rangpur. Aquaculture will continue to play an important role in increasing availability and affordability of fish; however, fish species from the non-farmed sector are better placed to contribute to greater micronutrient intakes, on a direct substitution basis. This presents an opportunity for aquaculture to contribute to improved nutrition, through development and scale up of diverse production technologies suitable for different agro-ecologies and producing diverse fish species, including SIS. There are several good examples of diverse production systems (such as homestead pond polyculture systems with SIS, rice-fish systems, and stocking of wetlands with SIS) which show potential for increasing availability of this nutritious food. Protection and promotion of sustainable capture fisheries remains imperative, and should be considered as complementary to aquaculture development. Details of the nutritional quality and safety of fish species remain a significant gap and research in this field must be given high priority. Our findings are of significance to many other regions where small fish are commonly consumed (as fresh, dried or processed in condiments), such as South East Asia, the African Great Lakes region and Latin America.

Supplementary Table 1: Survey categories of fish consumption grouped according to primary production sub-sector, and matched to nutrient composition data*.

| BIHS Survey Code | BIHS Survey Fish Category | Scientific name used for nutrient composition | Edible parts conversion factor | Nutrient composition per 100 g raw, edible parts | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Energy (kJ) | Protein (g) | Fat (g) | Iron (mg) | Zinc (mg) | Calcium (mg) | Vitamin B12 (µg) | Vitamin A (µg RAE) |
| | Non-farmed fish | | | | | | | | | | |
| 180 | Surma | *Scomberomorus guttatus*[12] | 0.830 | 431 | 20.9 | 2.0 | 0.80 | 0.78 | 35.0 | NA | NA |
| 181 | Chital | *Chitala chitala*[12] | 0.830 | 405 | 17.8 | 2.8 | 1.60 | 0.61 | 104.0 | NA | 30 |
| 182 | Boal | *Wallago attu*[12] | 0.830 | 339 | 15.4 | 2.1 | 0.80 | 0.27 | 83.0 | NA | 1 |
| 183 | Aair | *Sperata aor*[12] | 0.830 | 373 | 17.0 | 2.3 | 0.90 | 0.23 | 11.0 | NA | NA |
| 185 | Ritha | *Arius truncatus* †[14] | 0.830 | 385 | 18.7 | 1.9 | 4.20 | NA | 98.0 | NA | NA |
| 186 | Hilsa | *Tenualosa ilisha* | 0.830 | 1020 | 16.4 | 18.3 | 1.90 | 1.20 | 220.0 | 2.30 | 20 |
| 187 | Jatka | *Tenualosa ilisha (jatka)* | 0.830 | 618 | 19.0 | 7.7 | 2.50 | 1.80 | 500.0 | 2.00 | 14 |
| 193 | Shole/gozar | *Channa striatus, Channa marulius* | 0.830 | 298 | 17.9 | 0.3 | 0.42 | 0.67 | 53.0 | 0.88 | 0 |
| 194 | Taki | *Channa punctatus* | 0.867 | 306 | 18.3 | 0.6 | 1.80 | 1.50 | 766.0 | 1.60 | 139 |
| 197 | Baim | *Mastacembelus armatus* | 0.867 | 381 | 17.9 | 1.7 | 1.90 | 1.10 | 449.0 | 1.72 | 27 |
| 199 | Meni | *Nandus nandus* | 0.867 | 338 | 16.7 | 1.7 | 0.84 | 1.60 | 1300.0 | 0.90 | 60 |
| 200 | Shapla/padda/rupsha | *Dasyatis kuhlii, D. uarnak, D. zugei*[14] | 0.830 | 368 | 21.3 | 0.3 | 0.60 | NA | 18.0 | NA | 11 |
| 205 | Large dried fish | *Lates calcarifer* ‡[12] | 1.0 | 1340 | 60.2 | 8.6 | 3.00 | 0.57 | 939.0 | NA | NA |
| 211 | Gura mach | Mixed small fish § | 0.867 | 410 | 15.6 | 4.0 | 4.46 | 3.38 | 1085.0 | 6.87 | 587 |
| 212 | Panch mishali | Mixed small fish § | 0.867 | 410 | 15.6 | 4.0 | 4.46 | 3.38 | 1085.0 | 6.87 | 587 |
| 213 | Puti | *Puntius sophore / Puntius ticto* | 0.867 | 463 | 15.6 | 5.3 | 2.80 | 3.35 | 1261.0 | 5.38 | 38 |
| 214 | Tengra | *Mystus vittatus* | 0.867 | 428 | 15.1 | 4.6 | 4.00 | 3.10 | 1093.0 | 3.50 | 12 |
| 215 | Pabda | *Ompok pabda* | 0.867 | 619 | 16.2 | 9.5 | 0.46 | 0.90 | 91.0 | NA | NA |
| 216 | Moa/mola | *Amblypharyngodon mola* | 0.867 | 445 | 17.3 | 4.5 | 5.70 | 3.20 | 853.0 | 7.98 | 2503 |
| 217 | Dhela | *Osteobrama cotio cotio* | 0.867 | 387 | 14.7 | 3.8 | 1.80 | 3.70 | 1200.0 | 4.70 | 918 |
| 218 | Batashi | *Ailia coila* | 0.867 | 751 | 17.1 | 12.6 | 0.82 | 1.20 | 110.0 | 4.10 | 37 |
| 219 | Kachki | *Corica soborna* | 0.867 | 267 | 11.9 | 1.9 | 2.80 | 3.10 | 476.0 | 3.55 | 78 |
| 220 | Chanda | *Pseudambassis ranga* | 0.867 | 400 | 15.5 | 3.8 | 2.10 | 2.60 | 1153.0 | 6.42 | 336 |
| 221 | Khalisa | *Colisa fasciata* | 0.867 | 354 | 15.2 | 2.5 | 4.10 | 2.30 | 1700.0 | 5.55 | 46 |
| 222 | Chela | *Chela cachius* | 0.867 | 349 | 15.2 | 2.4 | 0.84 | 4.70 | 1000.0 | 5.64 | 132 |
| 223 | Chapila | *Gudusia chapra* | 0.867 | 385 | 15.5 | 3.8 | 7.60 | 2.10 | 1063.0 | 6.99 | 73 |
| 224 | Kajari | *Ailia coila* | 0.867 | 751 | 17.1 | 12.6 | 0.82 | 1.20 | 110.0 | 4.10 | 37 |
| 225 | Tatkeni | *Crossocheilus latiusa* †[12] | 0.867 | 405 | 15.3 | 3.9 | 2.20 | 1.09 | 195.0 | NA | NA |
| 226 | Bata | *Labeo bata*[12] | 0.867 | 446 | 15.9 | 4.7 | 1.20 | 0.94 | 493.0 | NA | NA |
| 227 | Ghutum | *Lepidocephalichthys guntea* | 0.867 | 431 | 17.2 | 3.9 | 3.30 | 2.50 | 950.0 | 8.75 | 76 |
| 228 | Bele | *Glossogobius giuris* | 0.867 | 292 | 16.6 | 0.4 | 2.30 | 2.10 | 790.0 | 2.10 | 18 |
| 229 | Chewa | *Glossogobius giuris* | 0.867 | 292 | 16.6 | 0.4 | 2.30 | 2.10 | 790.0 | 2.10 | 18 |
| 230 | Poa | *Protonibea diacanthus*[12] | 0.867 | 422 | 18.6 | 2.9 | 0.40 | 0.65 | 32.0 | NA | 17 |
| 231 | Foli | *Notopterus notopterus* | 0.867 | 384 | 20.5 | 0.6 | 1.70 | 1.60 | 230.0 | 2.00 | 0 |
| 232 | Bacha | *Eutrpiichthys vacha*[12] | 0.867 | 512 | 16.1 | 6.4 | 0.70 | NA | 520.0 | NA | NA |
| 233 | Baicha | *Colisa fasciata* † | 0.867 | 354 | 15.2 | 2.5 | 4.10 | 2.30 | 1700.0 | 5.55 | 46 |
| 234 | Kaikla | *Xenontedon cancila* | 0.867 | 329 | 17.1 | 1.2 | 0.65 | 1.90 | 610.0 | 2.89 | 91 |
| 235 | Darkini | *Esomus danricus* | 0.867 | 384 | 15.5 | 3.2 | 12.00 | 4.00 | 891.0 | 12.50 | 660 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 236 | Palshe | *Liza parsia* | 0.867 | 813 | 16.1 | 14.3 | 1.30 | 0.84 | 66.0 | NA | NA |
| 239 | Kakra | *Scylla serrata*[14] | 0.830 | 411 | 17.9 | 2.9 | 2.60 | NA | 183.0 | NA | 218 |
| 240 | Small prawn | *Macrobrachium malcolmsonii* | 0.867 | 364 | 15.7 | 2.2 | 13.00 | 3.30 | 1200.0 | NA | NA |
| 241 | Dried small shrimp/prawn | *Penaeus sp. Palaemon spp* ‡[14] | 1.0 | 1322 | 69.1 | 4.0 | 5.30 | 3.20 | 770.0 | NA | 40 |
| 242 | Dried small fish | *Puntius sophore, Setipinna phasa* ‡ ¶ [12] | 1.0 | 1610 | 62.0 | 14.7 | 25.00 | 12.00 | 2540.0 | NA | 8 |
| 243 | Fermented fish | *Puntius sophore, Setipinna phasa* ‖¶ | 1.0 | 1049 | 37.6 | 10.1 | 20.98 | 4.22 | 432.0 | NA | NA |
| 908 | Other big fish | Average of survey codes 176-193[12; 14] | 0.830 | 473 | 17.48 | 4.7 | 1.34 | 1.05 | 166.0 | 2.00 | 32 |
| 909 | Other small fish | Mixed small fish § | 0.867 | 410 | 15.6 | 4.0 | 4.46 | 3.38 | 1085.0 | 6.87 | 587 |
| | Farmed fish | | | | | | | | | | |
| 176 | Rui | *Labeo rohita* | 0.830 | 422 | 18.2 | 3.0 | 0.98 | 1.00 | 51.0 | 5.05 | 13 |
| 177 | Katla | *Catla catla* | 0.830 | 267 | 14.9 | 0.7 | 0.83 | 1.10 | 210.0 | 1.30 | 22 |
| 178 | Mrigel | *Cirrhinus mrigala* | 0.830 | 363 | 18.9 | 1.1 | 2.50 | 1.50 | 960.0 | 5.57 | 15 |
| 179 | Kalibaus | *Labeo calbasu* [12] | 0.830 | 400 | 17.0 | 3.0 | 1.10 | 0.36 | 13.0 | NA | NA |
| 184 | Pangash | *Pangasianodon hypophthalmus* | 0.830 | 925 | 16.0 | 17.7 | 0.69 | 0.65 | 9.0 | 1.50 | 31 |
| 188 | Grass carp | *Ctenopharyngodon idella* | 0.830 | 341 | 15.2 | 1.1 | 0.46 | 0.91 | 54.0 | NA | NA |
| 189 | Mirror carp | *Cyprinus carpio* | 0.830 | 381 | 16.4 | 2.9 | 1.10 | 2.20 | 37.0 | NA | 2 |
| 190 | Silver carp | *Hypophthalmichthys molitrix* | 0.830 | 435 | 17.2 | 4.1 | 4.40 | 1.40 | 903.0 | 0.55 | 0 |
| 191 | Telapia | *Oreochromis niloticus* | 0.830 | 390 | 19.5 | 2.0 | 1.10 | 1.20 | 95.0 | 0.70 | 10 |
| 192 | Swarputi | *Barbonymus gonionotus* | 0.830 | 729 | 17.4 | 11.7 | 0.60 | 0.74 | 227.0 | NA | NA |
| 198 | Koi | *Anabas testudineus* | 0.867 | 737 | 15.5 | 12.8 | 0.87 | 0.60 | 85.0 | 2.38 | 295 |
| 201 | Bagda chingree | *Penaeus monodon*[12] | 0.830 | 388 | 16.5 | 2.9 | 0.60 | 1.73 | 17.0 | NA | NA |
| 202 | Golda chingree | *Macrobrachium rosenbergii*[12] | 0.830 | 431 | 20.9 | 2.0 | 0.70 | 1.25 | 18.0 | NA | 2 |
| 204 | Poona fish | *Oreochromis niloticus* | 0.876 | 412 | 19.0 | 2.6 | 0.69 | 0.65 | 9.0 | 2.50 | 21 |
| 238 | Karfu fish | *Cyprinus carpio* | 0.830 | 381 | 16.4 | 2.9 | 1.10 | 2.20 | 37.0 | NA | NA |
| | Fish both non-farmed and farmed | | | | | | | | | | |
| 195 | Magur | *Clarias batrachus* | 0.867 | 326 | 16.5 | 1.3 | 1.20 | 0.74 | 59.0 | 4.83 | 25 |
| 196 | Singi | *Heteropneustes fossilis* | 0.867 | 374 | 19.1 | 1.9 | 2.20 | 1.10 | 60.0 | 12.80 | 32 |

BIHS, Bangladesh Integrated Household Survey; RAE, retinol activity equivalent; NA, Data not available.

*Nutrient composition data are sourced from Bogard et al (2015)[4], except where specified otherwise by citation in ‘Scientific name used for nutrient composition’ column.

† No composition data was available for exact species, so composition data from a similar fish from the same family was used.

‡ Conversion factor of 3.5 used to estimate fresh weight equivalent.

§ Average of Pseudambassis ranga, Gudusia chapra, Chela cachius, Esomus danricus, Osteobrama cotio cotio, Puntius sophore, Puntius ticto, Amblypharyngodon mola.

‖ Conversion factor of 2.2 used to estimate fresh weight equivalent.

¶Nutrient composition sourced from WorldFish unpublished data

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# 7. The impact of aquaculture development on nutrition

## 7.1. Forward to manuscript

In Bangladesh over recent years the aquaculture industry has grown rapidly, whilst at the same time, production from capture fisheries has stagnated. This trend is mirrored globally with continuing pressure on marine fisheries which has been more than compensated for by growth in aquaculture. The impacts of this transition on nutritional quality of diets, in terms of diversity of species available for consumption and nutrient intakes, are yet to be explored. In Bangladesh, given the higher nutritional quality of species from capture fisheries compared to commonly farmed species (described in Chapter 4 and 6) it is possible that increases in fish consumption may have had detrimental impacts on micronutrient intakes. This chapter directly addresses RQ 4: How has the transition in aquatic food systems impacted nutrient intakes from fish, particularly among vulnerable groups? This chapter presents an analysis of nationally representative apparent food consumption data at three time points from 1991-2010 reflecting the period in which aquaculture has flourished, again drawing on nutrient composition of species (presented in Chapter 4) to show changes in both consumption, and nutrient intakes from fish.

Key findings are that consumption of fish from capture fisheries has declined, though this has been more than compensated for (in terms of quantity) by increases in consumption of species from aquaculture, resulting in an overall increase in national fish consumption by 30%. However, despite this increase, intakes of iron and calcium from fish have significantly decreased, and intakes of calcium, vitamin A and vitamin B12 have remained unchanged. This reflects a decline in nutritional quality of fish available for consumption over time.

## 7.2. Citation and published manuscript

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# Higher fish but lower micronutrient intakes: Temporal changes in fish consumption from capture fisheries and aquaculture in Bangladesh

**Short title:** Higher fish but lower micronutrient intakes over time

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## Abstract

Malnutrition is one of the biggest challenges of the 21st century, with one in three people in the world malnourished, combined with poor diets being the leading cause of the global burden of disease. Fish is an under-recognised and undervalued source of micronutrients, which could play a more significant role in addressing this global challenge. With rising pressures on capture fisheries, demand is increasingly being met from aquaculture. However, aquaculture systems are designed to maximise productivity, with little consideration for nutritional quality of fish produced. A global shift away from diverse capture species towards consumption of few farmed species, has implications for diet quality that are yet to be fully explored. Bangladesh provides a useful case study of this transition, as fish is the most important animal-source food in diets, and is increasingly supplied from aquaculture. We conducted a temporal analysis of fish consumption and nutrient intakes from fish in Bangladesh, using nationally representative household expenditure surveys from 1991, 2000 and 2010 (n=25,425 households), combined with detailed species-level nutrient composition data. Fish consumption increased by 30% from 1991-2010. Consumption of non-farmed species declined by 33% over this period, compensated (in terms of quantity) by large increases in consumption of farmed species. Despite increased total fish consumption, there were significant decreases in iron and calcium intakes from fish ($P<0.01$); and no significant change in intakes of zinc, vitamin A and vitamin B12 from fish, reflecting lower overall nutritional quality of fish available for consumption over time[26]. Our results challenge the conventional narrative that increases in food supply lead to improvements in diet and nutrition. As aquaculture becomes an increasingly important food source, it must embrace a nutrition-sensitive approach, moving beyond maximising productivity to also consider nutritional quality. Doing so will optimise the complementary role that aquaculture and capture fisheries play in improving nutrition and health.


[26] These results are based on mean nutrient intakes from nationally representative data, suggesting that on average, there was lower overall nutritional quality over time. These results are supported by the nutrient profiles of species consumed.

## Introduction

Malnutrition and poor diet are the leading causes of the global burden of disease, with nearly 800 million people suffering from hunger and two billion people suffering from micronutrient deficiencies [1]. Undernutrition alone accounts for 45% of all child deaths, and prevents millions from reaching their developmental potential, with profound social and economic impacts [2]. The immensity and urgency of this global challenge is reflected in the Unites Nations Sustainable Development Goals (SDGs), with goal two specifically aiming to end all forms of malnutrition [1].

Bangladesh experiences amongst the worst malnutrition rates in the world. The most recent estimates show that 36% of children under 5 years are stunted, 33% of children under 5 are underweight, 19% of adult women are undernourished [3], and millions live with various micronutrient deficiencies [4]. It is estimated that this costs Bangladesh USD 1 billion each year in economic productivity forgone [5].

Fish is an essential component of diets around the world, providing more than 3 billion people with around 20% of their animal-source protein [6], and an even greater contribution in many developing countries [7]. In Bangladesh, fish is by far the most important nutrient-rich food in the diet, across all population groups; urban and rural, rich and poor, female and male, young and old [8, 9]. However, the contribution of fish to food and nutrition security is often overlooked [6, 10] and even when acknowledged, is typically only defined in terms of animal protein [11]. However, fish is a rich source of multiple nutrients: essential fats, vitamins and minerals of high bioavailability, which all play critical roles in human health, growth and development, cognition and disease prevention [12-15]. Another rarely recognised nutritional characteristic of fish is that micronutrient content varies widely by species. Common farmed species are generally of lower nutritional quality compared to non-farmed species harvested from capture fisheries, as shown by analyses from Bangladesh [16].

Global fish supply is undergoing a profound transition. World supply of fish doubled from an average of 9.9 kg/capita/year during the 1960s to 20.1 kg/capita/year, in 2014, and aquaculture now provides more than half of the global supply of fish available for human consumption [11]. On the other hand, global capture fisheries production peaked in the 1990s and has plateaued since [11]. Other estimates show production peaked at a much higher level and has since been in more rapid decline [17]. As a result, it is projected that future global fish demand growth will be met entirely from aquaculture [18].

This global transition is mirrored at the national level in Bangladesh where per capita fish supply increased from 7.6 kg/capita/year in 1990 to 19.2 kg/capita/year in 2013 [19]. Over this same period, the share of aquaculture in Bangladesh’s fish supply increased from 23% to 55% and the quantity of farmed fish produced grew 810%, from 0.2 million tonnes to 1.96 million tonnes [20, 21]. Bangladesh is now the world’s sixth largest producer of aquaculture products [11].

The scale of this transition has given rise to concerns over the implications for nutrient supply and associated nutrition outcomes [22, 23], but its effects have never been examined empirically. Given how many people depend on fish as a food source and are also at risk of malnutrition, this is an important omission in the literature. This leads us to pose the question, how has the transition from capture fisheries to aquaculture affected micronutrient intakes in Bangladesh?

To answer this, we combine detailed fish consumption data from nationally representative household income and expenditure surveys (HIES) over a 20 year time series from 1991 to 2010, with comprehensive species-specific nutrient composition data for fish. We hypothesize that, either: 1) gains in farmed fish intakes should have raised micronutrient intakes from fish in Bangladesh, or; 2) the inferior nutritional quality of farmed fish has been insufficient to offset declines in nutrient intakes from capture fisheries. Both possibilities have important policy and health implications for Bangladesh and other developing countries where fish makes an important contribution to diets.

The rest of the paper is set out as follows: Firstly, we describe trends in apparent fish consumption patterns from 1991 to 2010. We also present the proportion of surveyed households consuming other animal-source foods (ASFs) in each survey year to give context as to the relative importance of fish in the diet. We then estimate changes in nutrient intakes from fish over time. The key micronutrients of interest are: iron and zinc, both considered ‘problem nutrients’ in developing countries [24]; calcium, as fish is known to be an important dietary source in Bangladesh [25]; and vitamin A and vitamin B12; as deficiency of both these micronutrients is widespread in Bangladesh [4]. We also examine results within extreme poor, moderate poor and non-poor households, and rural and urban areas to further understand the importance of nutrient intake from fish among different socioeconomic groups. We conclude by showing how these results contribute to understanding of the links between capture fisheries, aquaculture and nutrition, particularly for vulnerable groups, and advance recommendations for mitigating the impacts of this transition on human nutrition and health in Bangladesh and the developing world.

# Methods

## Household surveys

Nationally representative household food consumption data from the Household Expenditure Survey 1991, and HIES 2000 and 2010 in Bangladesh were used to estimate apparent fish consumption [26-28]. The three independent cross-sectional survey sample designs were based on a two-stage stratified sampling technique; primary sampling units were selected with probability proportional to size in the first stage, and households were selected by systematic random or circular sampling in the second stage [29-31]. General characteristics of surveyed households are described in Table 1. These are consistent with broader demographic trends in Bangladesh, including increasing urbanisation, decreased poverty rates, reduced fertility rates and an aging population, along with improved access to water and sanitation, and health care [3]. Of note is the considerable reduction in the proportion of extreme poor households between 1991 (40%) and 2010 (17%).

Table 1: Characteristics of surveyed households 1991-2010.

| Characteristic | 1991 | 2000 | 2010 |
|---|---|---|---|
| Total number of HH | 5,745 | 7,440 | 12,240 |
| Rural HH, n (% of total) | 4,971 (87%) | 5,932 (80%) | 8,956 (73% ) |
| HH size, mean (SD) | 5.35 (2.54) | 5.20 (2.23) | 4.50 (1.86) |
| AMEs per HH, mean (SD) | 4.11 (2.10) | 3.98 (1.81) | 3.53 (1.53) |
| Age group (year) | | | |
| <2 (%) | 4.2 | 4.1 | 3.6 |
| 2-5 (%) | 13.4 | 10.2 | 8.4 |
| 6-14 (%) | 26.1 | 25.4 | 22.7 |
| 15-49 (%) | 45.9 | 47.9 | 50.9 |
| >50 (%) | 10.4 | 12.4 | 14.4 |
| Poverty group | | | |
| Extreme poor (%) | 40.0 | 35.9 | 16.9 |
| Moderate poor (%) | 15.0 | 13.0 | 12.6 |
| Non-poor (%) | 45.0 | 51.1 | 70.5 |

HH, household; SD, standard deviation; AME, adult male equivalent.
Means adjusted using sample weights.

Food consumption data were collected by trained interviewers using one-day recall for the 1991 survey over a period of 30 days, and using two-day recall for the 2000 and 2010 surveys to obtain food consumption over 14 consecutive days. Data collection was structured throughout the year, thereby controlling for seasonal effects.

Poverty status was defined, using the cost of basic needs method as per survey reports, with households categorised as extreme poor, moderate poor and non-poor. The food poverty line (FPL) was estimated as the cost of a basic food basket that meets the energy needs of an adult, and the non-food poverty line (NFPL) was estimated as the cost of non-food expenditure by households close to the FPL. Thresholds for each line were set for each survey year for each district and for rural and urban areas by the Bangladesh Bureau of Statistics (BBS). Extreme poor households are those with total expenditures at or below the FPL, and the moderate poor households are those with total expenditures at or below the NFPL and above the FPL.

Fish species recorded in the survey were grouped according to their dominant production sector; either capture fisheries (non-farmed) or aquaculture (farmed), for each survey year, allowing comparison of the relative contribution that each sector makes to fish consumption over time (see Detailed methods and Table A in S1 File). Results are presented per Adult Male Equivalent (AME). AME reflects the energy requirements of individual households members, based on age and sex, as a proportion of an adult male, providing a more accurate estimate of the adequacy of household food consumption compared to per capita intake [32] (see Detailed methods and Table B in S1 File). Households with unrealistic levels of fish consumption in the local context (>500 g/AME/day, for comparison, mean fish consumption was 54 g/AME/day) were excluded (n=15 in 1991, from a total of 5,745 households). Data on the quantity of each fish species consumed were then combined with species level nutrient composition data to estimate apparent nutrient intakes from fish, at each time point [16, 33]. Fish species consumption is recorded in the surveys according to common Bangla names, which may represent several distinct species. In these cases, the average nutrient composition of several applicable species was used (see Table B in S1 File). For a small number of fish species recorded in the surveys, data were not available for vitamin A content (4-6 species across the three surveys, see Table B in S1 File for details) or vitamin B12 content (7-13 species across the three surveys). A small number of households consuming only fish with these missing data were therefore excluded from analysis of those specific nutrients (vitamin A, n=171; vitamin B12, n=465) to minimise impacting the results. The proportion of households consuming some quantity of fish, eggs, poultry, meat or dairy within the survey period (compared to total households), is also reported. This data is used to reflect consumption patterns of other ASFs relative to fish, over time.

## Statistical analysis

All statistical analyses were conducted using STATA (version 12.1, StataCorp, College Station, TX, USA). Regression analyses were used to estimate mean fish consumption and mean nutrient intakes from fish, at each time point (P<0.01, using sample weights provided by BBS and adjusting for clustering of primary sampling units in survey design). All primary outcome variables (fish consumption and nutrient intakes from fish, per AME/day) were positively skewed in distribution and log transformation did not produce a Normal distribution. Non-parametric tests and equality of means were not appropriate, given the need to apply sample weights. However, a sensitivity analysis was conducted, using quantile regression which is suitable for non-parametric analyses and is also not sensitive to the presence of outliers [34]. This analysis revealed similar trends and statistical significance; any deviations to main results are explained in footnotes to results tables. Unfortunately, quantile regression in STATA is not able to adjust for both clustering in survey design and survey weights simultaneously, and so, the sensitivity analyses presented here is based on quantile regression, adjusting for survey weights only. Overall strengths and limitations of the analysis are detailed in the S1 File.

## Results

### Fish consumption

Analysis of total fish consumption nationally shows no significant change between 1991 and 2000, followed by an increase from 53.7 g/AME/day in 2000 to 68.2 g/AME/day in 2010 (Table 2). However, examining consumption with respect to poverty and location groups over this period shows disparate trends. Between 1991 and 2000, there were no significant changes in fish consumption among all poverty groups and rural households, but a significant decrease among urban households. From 2000 to 2010, fish consumption increased significantly among urban, rural and non-poor households, and increased slightly but not significantly among extreme and moderate poor households. Overall, national mean fish consumption increased by 30% between 1991 and 2010. The *relative* increase between 1991 and 2010 was greatest among extreme poor households (19%, given their much lower intakes in 1991 compared to other poverty groups); however as expected, mean fish consumption was consistently much higher among non-poor households compared to moderate and extreme poor households.

Examining fish consumption over time according to source of production (non-farmed or farmed) demonstrates contrasting trends (see Table 2). Consumption of non-farmed fish decreased significantly, both nationally (-33%) and across all poverty and location groups between 1991 and 2010, whereas consumption of farmed fish increased significantly for all poverty and location groups, from a national average intake of 2.1 g/AME/day in 1991 to

34.5 g/AME/day in 2010. Farmed fish made up a larger proportion of total fish consumption for the non-poor (5-51%) compared to the extreme poor (3-47%), consistently over time.

Table 2: Mean total, non-farmed and farmed fish consumption (g/AME/day, % of total fish) over time.

| | 1991 | | 2000 | | 2010 | | Change 1991-2010 | |
|---|---|---|---|---|---|---|---|---|
| | Mean[27] [% of total fish] | SE | Mean[27] [% of total fish] | SE | Mean[27] [% of total fish] | SE | g/AME/day | % ‡ |
| **Total fish** | | | | | | | | |
| National | 52.5 | 1.9 | 53.7§ | 1.3 | 68.2* | 1.2 | +15.7† | 30 |
| Location | | | | | | | | |
| Rural | 49.5 | 2.2 | 53.8§ | 1.5 | 63.9* | 1.3 | +14.5† | 29 |
| Urban | 72.0 | 3.1 | 53.5* | 2.5 | 80.0†† | 1.9 | +8.0† | 11 |
| Poverty group | | | | | | | | |
| Extreme poor | 33.7 | 1.8 | 37.2§ | 1.2 | 40.0§ | 1.1 | +6.3† | 19 |
| Moderate poor | 51.5 | 2.2 | 51.1 | 1.8 | 53.2§ | 1.3 | +1.7§ | 3 |
| Non-poor | 69.6 | 2.5 | 66.0 | 1.5 | 77.7* | 1.2 | +8.1† | 12 |
| **Non-farmed fish** | | | | | | | | |
| National | 50.4 [96] | 1.9 | 37.6* [70] | 1.2 | 33.8* [49] | 0.9 | -16.6† | -33 |
| Location | | | | | | | | |
| Rural | 47.4 [96] | 2.1 | 37.5* [70] | 1.4 | 30.6* [48] | 1.0 | -16.8† | -35 |
| Urban | 69.4 [96] | 3.1 | 37.8* [71] | 2.0 | 42.2§ [53] | 1.6 | -27.2† | -39 |
| Poverty status | | | | | | | | |
| Extreme poor | 32.6 [97] | 1.7 | 27.8** [75] | 1.1 | 21.3* [53] | 0.7 | -11.3† | -35 |
| Moderate poor | 49.9 [97] | 2.2 | 37.9* [74] | 1.8 | 25.7* [48] | 0.9 | -24.2† | -49 |
| Non-poor | 66.4 [95] | 2.5 | 44.4* [67] | 1.4 | 38.2* [49] | 1.0 | -28.2† | -43 |
| **Farmed fish** | | | | | | | | |
| National | 2.1 [4] | 0.2 | 16.1* [30] | 0.6 | 34.5* [51] | 0.7 | +32.4† | - |
| Location | | | | | | | | |
| Rural | 2.0 [4] | 0.3 | 16.2* [30] | 0.7 | 33.3* [52] | 0.8 | +31.3† | - |
| Urban | 2.6 [4] | 0.3 | 15.7* [29] | 1.2 | 37.7* [47] | 1.1 | +35.2† | - |
| Poverty status | | | | | | | | |
| Extreme poor | 1.1 [3] | 0.2 | 9.4* [25] | 0.5 | 18.7* [47] | 0.7 | +17.6† | - |
| Moderate poor | 1.6 [3] | 0.3 | 13.2* [26] | 0.7 | 27.5* [52] | 0.9 | +25.9† | - |
| Non-poor | 3.2 [5] | 0.4 | 21.6* [33] | 0.8 | 39.5* [51] | 0.7 | +36.4† | - |

SE, standard error; AME, adult male equivalent.
Means adjusted for clustering and sample weights. n=25,425. Significance of sensitivity analysis only noted when different from main analysis.
* Significantly different from previous survey year at P<0.01.
** Significantly different from previous survey year at P<0.05.
† 2010 mean is significantly different from 1991 mean at P<0.01.
†† 2010 mean is significantly different from 1991 mean at P<0.05.
‡ Change (%) not calculated when baseline in 1991 was less than 5 g/AME/day.
§ In sensitivity analysis, median intake was significantly different than median intake in previous year at P<0.05.

## Consumption of fish and other animal-source foods

The importance of fish compared to other ASFs in diets over time is shown in Table 3. Nearly all households in each survey year (95-99%) reported consumption of fish in the survey

[27] Mean is reported in units of g/AME/day.

recall period, compared to much more variable consumption of other ASFs; 36-87% reported egg consumption, 8-59% reported meat consumption, 9-59% reported poultry consumption and 23-68% reported dairy consumption; within the survey recall period. As expected, extreme poor and rural households were much less likely to have consumed all ASFs within the survey recall period, compared to non-poor and urban households, respectively, in each survey year. These trends are in line with data reported elsewhere, with fish being by far the most important ASF in diets of women [35].

## Nutrient intakes from fish

There were significant increases in average energy, protein and fat intake from fish, in line with increasing total fish consumption, both nationally and for all poverty groups between 1991 and 2010 (P<0.01, increase in energy intake among moderate poor households significant at P<0.05, Table 4), except for protein intake among moderate poor households in which there was no significant change. However, there was no significant change in average intakes of zinc, vitamin A and vitamin B12; and consumption of iron and calcium significantly decreased (P<0.01), despite a national increase of 30% in the total quantity of fish consumed (proportional changes shown in Fig 1).

When comparing changes among poverty groups, the moderate and non-poor experienced smaller increases in energy, protein and fat, compared to extreme poor households, which are consistent with lower proportional increases in total fish consumption among the moderate and non-poor (Table 2). Moderate and non-poor households show larger proportional decreases in zinc, calcium, vitamin A and vitamin B12 over time compared to extreme poor households. This could be a result of larger proportional decreases in consumption of non-farmed fish by these groups (Table 2). Absolute intakes of nutrients from fish by extreme-poor households are far lower than moderate and non-poor households in each survey year, which is consistent with lower intakes of total fish (Table 2).

Table 3: Proportion of total households (%) reporting consumption of selected animal-source foods in the survey period*.

| | Fish | | | Eggs | | | Meat | | | Poultry | | | Dairy products | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1991 | 2000 | 2010 | 1991 | 2000 | 2010 | 1991 | 2000 | 2010 | 1991 | 2000 | 2010 | 1991 | 2000 | 2010 |
| National | 96.8 | 98.4 | 98.7 | 49.5 | 63.8 | 73.9 | 30.1 | 39.7 | 26.4 | 18.6 | 24.3 | 43.2 | 43.6 | 53.1 | 50.8 |
| Location | | | | | | | | | | | | | | | |
| Rural | 96.5 | 98.2 | 98.4 | 48.4 | 60.9 | 69.1 | 27.2 | 34.9 | 21.1 | 18.2 | 21.6 | 37.6 | 42.1 | 50.0 | 47.5 |
| Urban | 99.2 | 99.1 | 99.3 | 56.6 | 75.4 | 86.9 | 49.3 | 58.6 | 40.8 | 21.8 | 34.6 | 58.5 | 53.2 | 65.1 | 59.9 |
| Poverty status | | | | | | | | | | | | | | | |
| Extreme poor | 94.6 | 96.9 | 96.2 | 36.0 | 49.3 | 53.6 | 17.0 | 23.5 | 8.1 | 8.6 | 10.8 | 18.4 | 26.9 | 33.4 | 23.4 |
| Moderate poor | 97.6 | 98.7 | 98.7 | 51.4 | 62.6 | 68.9 | 27.4 | 34.2 | 18.0 | 18.3 | 19.4 | 30.8 | 43.4 | 49.8 | 38.3 |
| Non-poor | 98.6 | 99.4 | 99.2 | 60.9 | 74.4 | 79.6 | 42.8 | 52.5 | 32.3 | 27.7 | 35.0 | 51.4 | 58.6 | 67.7 | 59.7 |

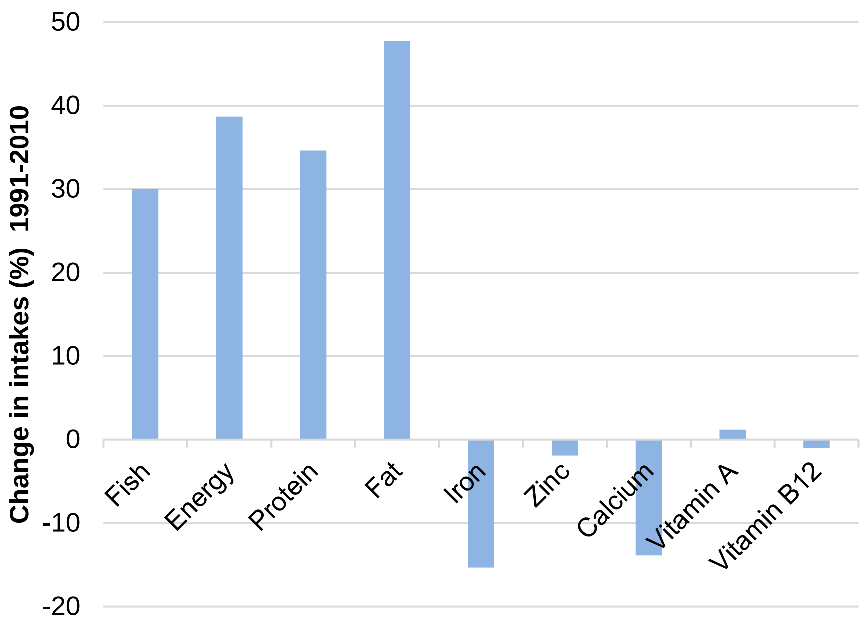
* Note that the recall period for the 1991 survey is 30 days compared to 14 days in 2000 and 2010.
n=25,425. Proportions adjusted using sample weights.

Table 4: Mean nutrient intakes (nutrient/AME/day) from fish, nationally and by poverty groups over time.

| Nutrient | 1991 | | 2000 | | 2010 | | Change between 1991-2010 | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SE | Mean | SE | Mean | SE | unit/AME/day | % |
| National | | | | | | | | |
| Energy (kJ) | 218 | 8.0 | 210‡ | 5.7 | 302* | 6.4 | +85† | +39 |
| Protein (g) | 7.2 | 0.3 | 7.7‡ | 0.2 | 9.7* | 0.2 | +2.5† | +35 |
| Fat (g) | 2.5 | 0.1 | 2.1* | 0.1 | 3.7* | 0.1 | +1.2† | +48 |
| Iron (mg) | 1.9 | 0.1 | 1.7** | 0.1 | 1.6‡ | 0.0 | -0.3† | -15 |
| Zinc (mg) | 1.0 | 0.0 | 0.9 | 0.0 | 1.0** | 0.0 | -0.0§ | -2 |
| Calcium (mg) | 324 | 12.4 | 286* | 7.5 | 279 | 5.7 | -45† | -14 |
| Vitamin A (µg RAE) | 47.3 | 3.5 | 46.9‡ | 2.3 | 47.8 | 1.7 | +0.6 | +1 |
| Vitamin B 12 (µg) | 1.3 | 0.0 | 1.1* | 0.0 | 1.3* | 0.0 | -0.0¶ | -1 |
| Extreme poor | | | | | | | | |
| Energy (kJ) | 137 | 7.2 | 142‡ | 5.1 | 169* | 5.0 | +31† | +23 |
| Protein (g) | 4.7 | 0.2 | 5.4** | 0.2 | 5.7‡ | 0.2 | +1.1† | +23 |
| Fat (g) | 1.5 | 0.1 | 1.4 | 0.1 | 2.0* | 0.1 | +0.4† | +28 |
| Iron (mg) | 1.4 | 0.1 | 1.3 | 0.0 | 1.1* | 0.0 | -0.3† | -24 |
| Zinc (mg) | 0.7 | 0.0 | 0.7 | 0.0 | 0.7 | 0.0 | -0.1 | -9 |
| Calcium (mg) | 226 | 12.3 | 210 | 7.0 | 180* | 5.2 | -46† | -20 |
| Vitamin A (µg RAE) | 36.3 | 4.6 | 35.8¶ | 2.2 | 35.3‡ | 2.1 | -1.1 | -3 |
| Vitamin B 12 (µg) | 0.8 | 0.1 | 0.7 | 0.0 | 0.7 | 0.0 | -0.1 | -12 |
| Moderate poor | | | | | | | | |
| Energy (kJ) | 210 | 8.7 | 198 | 7.7 | 234* | 6.4 | +24†† | +11 |
| Protein (g) | 7.1 | 0.3 | 7.3 | 0.3 | 7.6‡ | 0.2 | +0.5§ | +7 |
| Fat (g) | 2.3 | 0.1 | 2.0** | 0.1 | 2.9* | 0.1 | +0.5† | +22 |
| Iron (mg) | 1.9 | 0.1 | 1.8 | 0.1 | 1.3* | 0.0 | -0.6† | -32 |
| Zinc (mg) | 1.0 | 0.0 | 0.9‡ | 0.0 | 0.8* | 0.0 | -0.2† | -21 |
| Calcium (mg) | 325 | 14.7 | 291 | 11.5 | 221* | 5.9 | -104† | -32 |
| Vitamin A (µg RAE) | 47.3 | 3.7 | 48.2 | 3.5 | 37.7** | 2.0 | -9.6†† | -20 |
| Vitamin B 12 (µg) | 1.2 | 0.1 | 1.0* | 0.0 | 0.9 | 0.0 | -0.3† | -26 |
| Non-poor | | | | | | | | |
| Energy (kJ) | 293 | 10.6 | 261**# | 6.7 | 347* | 6.9 | +54† | +18 |
| Protein (g) | 9.5 | 0.3 | 9.5‡ | 0.2 | 11.1* | 0.2 | +1.5† | +16 |
| Fat (g) | 3.4 | 0.1 | 2.7* | 0.1 | 4.3* | 0.1 | +0.8† | +25 |
| Iron (mg) | 2.4 | 0.1 | 2.0* | 0.1 | 1.8** | 0.0 | -0.6† | -24 |
| Zinc (mg) | 1.3 | 0.0 | 1.1* | 0.0 | 1.1‡ | 0.0 | -0.2† | -13 |
| Calcium (mg) | 411 | 15.9 | 337* | 8.7 | 313** | 6.4 | -97.7† | -24 |
| Vitamin A (µg RAE) | 56.8 | 4.3 | 54.3 | 3.0 | 52.6 | 1.9 | -4.2 | -7 |
| Vitamin B 12 (µg) | 1.7 | 0.1 | 1.4* | 0.0 | 1.5‡ | 0.0 | -0.2† | -13 |

SE, standard error; AME, adult male equivalent.
Means adjusted for clustering and sample weights. Significance of sensitivity analysis only noted when different from main analysis.
n=25,425; for vitamin A, n= 25,254; for vitamin B12, n= 24,960.
* Significantly different from previous survey year at P<0.01.
**Significantly different from previous survey year at P<0.05.
† 2010 mean is significantly different from 1991 mean at P<0.01.
†† 2010 mean is significantly different from 1991 mean at P<0.05.
‡ In sensitivity analysis, median intake was significantly different than median intake in previous year at P<0.05.
§ In sensitivity analysis, median intake in 2010 was significantly different than median intake in 1991 at P<0.05.
¶ In sensitivity analysis, a significant change in medians was observed in the opposite direction to that detected by means at P<0.05.
# In sensitivity analysis, no significant change was detected.

Figure 1: Change (%) in fish consumption and nutrient intakes from fish from 1991 as baseline to 2010*.




*All changes except for zinc, vitamin A and vitamin B12 between 1991 and 2010 are statistically significant P<0.01.

## Discussion

Fish consumption has significantly increased from 1991 to 2010; rapid growth in aquaculture has more than compensated, in terms of quantity, for a decline in availability of fish from capture fisheries. This is broadly consistent with increased fish production figures over this period [36], and the general socio-demographic trend with households moving out of poverty, and consumption of higher market value foods (including ASFs) increasing.

However, growth in aquaculture has not sufficiently compensated for the decline in capture fisheries in terms of nutritional quality. Changes in nutrient intakes from fish would be expected to be similar to overall changes in consumption, if nutritional quality of the fish in supply was maintained over time (i.e. a national increase of approximately 30% for all nutrients between 1991 and 2000). This was observed in the increases in animal protein, fat and energy intakes from fish. However, despite an increase in quantity of fish consumed, results show decreased intakes of iron and calcium from fish; and no change in intakes of zinc, vitamin A and vitamin B12 between 1991 and 2010 (results were robust to sensitivity analysis). Based on our analysis, the only likely explanation for this finding is lower overall nutritional quality of the fish species being consumed in 2010 compared to 1991, related to a greater proportional contribution of farmed fish over time. This is supported by research that has demonstrated the higher nutritional quality of non-farmed species compared to commonly farmed species, with regards to certain micronutrients, including iron, zinc, calcium, vitamin A and vitamin B12 [8, 16].

Given the importance of fish in diets, this reduction in nutritional quality is likely to have exacerbated existing widespread micronutrient deficiencies. The most recent estimates from Bangladesh in 2011-12 show that among non-pregnant, non-lactating (NPNL) women, 57% were zinc deficient, 22% were vitamin B12 deficient, 7.1% were iron deficient, and 5.4% were vitamin A deficient [4]. If nutritional quality of the fish supply in 1991 had been maintained, and consumption was still able to grow to 2010 levels, the average NPNL woman would be consuming an additional 21% of the recommended nutrient intake (RNI) for vitamin B12 (0.5 µg/day), 17% of the RNI for calcium (165 mg/day), 4% of the RNI for zinc (0.4 mg/day), and 3% of the RNI for iron (1 mg/day) [37]. Given that NPNL women on average, meet only 25% of the daily iron RNI, and 51% of the daily zinc RNI, this reflects an important contribution.

It could be reasoned that declines in nutrient intakes from a particular food source are of little concern if they can be met from other foods in the diet. The HIES reports published elsewhere show that consumption of ASFs excluding fish increased by 13 g/capita/day from 1991-2010 [29-31], mostly from increases in poultry, potentially compensating to some extent for the reductions in certain micronutrient intakes from fish. This cannot be said for the poor – given that in 2010, more than 80% of extreme poor households had consumed no poultry in the two weeks' survey period (compared to <4% who consumed no fish). Other recent work investigating quantities of ASFs consumption in rural Bangladesh found that fish consumption was six times higher than poultry – the second most highly consumed ASF [8]. Furthermore, nutritional profiles of ASFs differ, and therefore cannot be considered nutritionally equivalent. For example, fish is often a rich source of long-chain omega 3 fatty acids (not found, or found in small quantities in other ASFs), which are particularly important for cognitive development in children [15]. Vitamin B12 is an essential nutrient required for brain and nervous system function which cannot be produced by the body and is found almost exclusively in ASFs, of which fish is often the richest source [38]. Calcium is essential for bone development as well as many metabolic processes. Milk and dairy products are often assumed to be the most important dietary sources of calcium, however several species of fish in Bangladesh have a much higher calcium content [16, 33], and with the same high calcium bioavailability as milk [39]. ASFs are also recognised as a rich source of highly bioavailable iron due to the high content of haem iron (compared to non-haem iron). The haem iron content of red meat is approximately 40% (of total iron) and can be up to 70%;

recent analysis of SIS in Bangladesh has shown haem iron content as high as 93% [40]. Given the importance of fish in diets in Bangladesh (in terms of quantity, nutritional quality and frequency of consumption), this reduction in nutritional quality in fish supply at population level is undoubtedly of concern. In the context of widespread micronutrient deficiencies, even if the negative impacts of declines in nutrient intakes from fish are partially averted in some population groups by substitution with other ASFs, from a population perspective, this still represents an opportunity forgone to improve overall diets.

These results also highlight that the dominant discourse linking fish to food security which confines the nutritional importance of fish to being a source of animal protein, is inadequate and problematic. Protein content of different fish species varies very little - usually by less than 5% (protein content of most species is around 15-20 g/100 g raw, edible parts) [16]. So increases in production and productivity, regardless of species automatically increase availability of protein (as our results show). This is important, particularly as protein from fish is of high quality. However, our results demonstrate that failure to consider fish as an irreplaceable source of micronutrients occludes the ‘bigger picture’ and can be detrimental for nutrition and health.

These results also emphasise the importance of dietary diversity, not only in terms of food groups, as it is often understood, but also diversity of foods within foods groups (e.g. consumption of a diversity of fish species given their unique nutritional profiles). This point is particularly relevant given the above-mentioned transition in aquatic food systems, away from diverse capture fisheries towards less diverse aquaculture systems. Food production systems which promote diversity should be prioritised. One such example is pond polyculture, in which several large fish species are cultured together with SIS in homestead ponds. The different species fulfil different ecological niches within the system, increasing the productivity and nutritional quality of the system as a whole; encouraging frequent harvesting and consumption of SIS by the household, and sale of large fish for income [41]. Public investments in research on the artificial reproduction of key nutrient-rich SIS and the transfer of this technology to private sector hatcheries must be central to this approach. Similar research and investments have preceded growth in production of all the main fish species farmed commercially [42, 43].

Nutrition-sensitive aquaculture must be a complement to diverse capture fisheries, not a substitute for it. Conserving and rebuilding inland, coastal and marine fish stocks through improved management are also essential. One such example is the stocking of nutrient-rich SIS in community-managed wetlands, which improves nutritional quality of production as well as overall productivity and biodiversity of the system [44]. Achieving wider recognition of the essential contributions that capture fisheries make to food and nutrition security is an important step towards ensuring that capture fisheries attains a higher level of priority in global and national policy initiatives, and that their governance is improved for long-term sustainability.

Other factors that influence the nutritional quality of fish species may provide opportunities to improve the contribution of aquaculture systems to nutrition. For example, in response to increasing pressures on marine fisheries as a source of fish meal used as feed in aquaculture systems, modifications in fish feed composition are being investigated as a means to improve the fatty acid profile of farmed fish [45, 46]. Further research within aquatic agricultural food systems, including consideration of other nutrients of public health concern, and analysis of the bioavailability of nutrients are required. WorldFish, the World Bank and social entrepreneurs have recently launched an initiative for attracting investments from major development partners and the private sector to develop and test food systems approaches for optimizing the contribution of fish to improve nutrition and health, especially in women and young children in the first 1,000 days of life.

## Conclusion

The valuable role of aquaculture in Bangladesh in securing the availability and affordability of fish is unquestionable. If growth in this sector had not occurred, declines in nutrient intakes described here would undoubtedly be much more severe, with far more serious implications for nutrition and health. However, the results presented here highlight unintended negative consequences of policy decisions and agricultural investments which are narrowly focused on maximising production and productivity. In doing so, our results challenge the dominant rhetoric that increases in food supply automatically lead to improvements in diet and nutrition. These findings are of significance to many countries experiencing rapid growth in aquaculture alongside declining quantity and diversity of species from capture fisheries. In this light, whilst the findings are specific to Bangladesh, it is possible that this decline of nutritional quality linked to a shift towards greater farmed fish consumption, is occurring on a global scale. As aquaculture becomes an increasingly important food source for many, it must embrace a nutrition-sensitive approach, by considering how changes in food supply affect nutritional quality of diets. To do so requires greater knowledge of the nutritional value of indigenous foods at species/varietal level, and the contributions these foods make in terms of nutrient intakes and dietary patterns, specific to age and sex groups, as well as to differences in rural/urban locations and geographic regions. Indicators used in the monitoring and evaluation of agricultural interventions must go beyond production and productivity, to also include nutritional quality. If the intrinsically linked issues of poverty, food insecurity and malnutrition are to be truly addressed; and for the SDGs to be achieved, agricultural policies must integrate strategies to mitigate trade-offs across multiple sectors, including (but not limited to) nutrition and health.

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# Supporting Information

## Detailed methods

### Fish consumption

The HES of 1991, and the HIESs of 2000 and 2010 record fish consumption according to 37 and 15 categories, respectively. Some categories represent a single fish species, whereas others include several. It was considered important to de-cluster the categories as accurately as possible given the wide differences in nutrient composition of different species. As far as possible, this was done using official production figures from the Department of Fisheries in order to estimate consumption of individual species [36, 47-49]. In cases of insufficient available production data, consumption was estimated to be distributed evenly among species within a category. Individual fish species were then categorised according to predominant source, either capture fisheries or aquaculture, for each survey. Fish that are commonly from both non-farmed and farmed sectors were attributed proportionately between sectors. Official production data were complemented by expert opinion from fisheries and aquaculture specialists in Bangladesh in order to estimate the contribution of fish from the different production sectors as accurately as possible (SI Table 1). The 2010 HIES collected information on foods consumed outside the home, including fish. As this information was not collected in the earlier surveys and accounted for <1% of total fish consumption, this fish category was excluded from analysis.

Supporting Information Table 1: Survey food categories, production weighting, source of production and nutrient composition of fish species.

| Survey food code | Survey food description | Scientific name of species used for nutrient composition | Weighting within survey category | Source of production | | Edible part coefficient | Nutrient composition (per 100 g raw, edible parts) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Non-farmed | Farmed | | Energy (kJ) | Protein (g) | Fat (g) | Iron (mg) | Zinc (mg) | Calcium (mg) | Vitamin A (µg RAE) | Vitamin B12 (µg) |
| 1991 | | | | | | | | | | | | | | |
| 28 | Hilsa | *Tenualosa ilisha* | 100 | 100 | | 0.83 | 1020 | 16.4 | 18.3 | 1.90 | 1.20 | 220 | 20 | 2.30 |
| 29 | Koi/Magur/Shing/Khalisha | Average* | 100 | 100 | | 0.867 | 448 | 16.6 | 4.6 | 2.09 | 1.19 | 476 | 100 | 6.39 |
| 30 | Sol | *Channa striatus* | 33.33 | 100 | | 0.83 | 310 | 18.7 | 0.3 | 0.41 | 0.73 | 96 | 0 | 1.20 |
| | Gazar | *Channa marulius* | 33.33 | 100 | | 0.83 | 286 | 17.1 | 0.3 | 0.43 | 0.60 | 9 | 0 | 0.55 |
| | Taki | *Channa punctatus* | 33.33 | 100 | | 0.867 | 306 | 18.3 | 0.6 | 1.80 | 1.50 | 766 | 139 | 1.60 |
| 31 | Puti/Sharputi | Average† | 100 | 100 | | 0.867 | 552 | 16.2 | 7.4 | 2.07 | 2.48 | 916 | 25 | 3.58 |
| 32 | Mala/Kachi/Chala/Chapila | Average‡ | 100 | 100 | | 0.867 | 362 | 15.0 | 3.2 | 4.24 | 3.28 | 848 | 697 | 6.04 |
| 33 | Chingri | *Macrobrachium malcolmsonii* | 100 | 100 | | 0.867 | 364 | 15.7 | 2.2 | 13.00 | 3.30 | 1200 | - | - |
| 34 | Dried fish | Average§ | 100 | 100 | | 0.867 | 1610 | 62.0 | 14.7 | 25.00 | 12.00 | 2540 | 8 | - |
| 35 | Tengra | *Mystus vittatus* | 50 | 100 | | 0.867 | 428 | 15.1 | 4.6 | 4.00 | 3.10 | 1093 | 12 | 3.50 |
| | Baim | *Mastacembelus armatus* | 50 | 100 | | 0.867 | 381 | 17.9 | 1.7 | 1.90 | 1.10 | 449 | 27 | 1.72 |
| 36 | Seafish | Average¶ | 100 | 100 | | 0.83 | 443 | 17.7 | 4.1 | 1.41 | 1.52 | 745 | 5 | 1.63 |
| 37 | Chital | *Chitala chitala* | 100 | 100 | | 0.83 | 405 | 17.8 | 2.8 | 1.60 | 0.61 | 104 | 30 | - |
| 38 | Rui | *Labeo rohita* | 45.17 | 30 | 70 | 0.83 | 422 | 18.2 | 3.0 | 0.98 | 1.00 | 51 | 13 | 5.05 |
| | Katal | *Catla catla* | 32.67 | 30 | 70 | 0.83 | 267 | 14.9 | 0.7 | 0.83 | 1.10 | 210 | 22 | 1.30 |
| | Mrigel | *Cirrhinus mrigala* | 22.16 | 50 | 50 | 0.83 | 363 | 18.9 | 1.1 | 2.50 | 1.50 | 960 | 15 | 5.57 |
| 39 | Aier | *Sperata aor* | 100 | 100 | | 0.867 | 373 | 17.0 | 2.3 | 0.90 | 0.23 | 11 | - | - |
| 40 | Pangas | *Pangasianodon hypophthalmus* | 100 | 100 | | 0.83 | 925 | 16.0 | 17.7 | 0.69 | 0.65 | 9 | 31 | 1.50 |
| 41 | Vetki | *Lates calcarifer* | 100 | 100 | | 0.83 | 406 | 18.6 | 2.5 | 1.00 | 0.16 | 24 | 8 | - |
| 42 | Baila | *Glossogobius giuris* | 100 | 100 | | 0.867 | 292 | 16.6 | 0.4 | 2.30 | 2.10 | 790 | 18 | 2.10 |
| 43 | Mani | *Nandus nandus* | 100 | 100 | | 0.867 | 338 | 16.7 | 1.7 | 0.84 | 1.60 | 1300 | 60 | 0.90 |
| 44 | Pabda | *Ompok pabda* | 100 | 100 | | 0.867 | 619 | 16.2 | 9.5 | 0.46 | 0.90 | 91 | - | - |
| 45 | Kakra | *Scylla serrata* | 100 | 100 | | 0.83 | 411 | 17.9 | 2.9 | 2.60 | - | 183 | 218 | - |
| 46 | Bata | *Labeo bata* | 100 | 100 | | 0.83 | 446 | 15.9 | 4.7 | 1.20 | 0.94 | 493 | - | - |
| 47 | Tapshi | *Eleutheronema tetradactylum* | 100 | 100 | | 0.83 | 425 | 20.6 | 2.2 | 0.60 | 0.90 | 37 | 0 | 0.85 |
| 48 | Farsha | *Setipinna phasa* | 100 | 100 | | 0.867 | 441 | 17.7 | 3.8 | 1.80 | 3.20 | 452 | 12 | - |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 49 | Khaira | *Gudusia chapra* | 100 | 100 | | 0.867 | 385 | 15.5 | 3.8 | 7.60 | 2.10 | 1063 | 73 | 6.99 |
| 50 | Dagra†† | *Glossogobius giuris* | 100 | 100 | | 0.867 | 292 | 16.6 | 0.4 | 2.30 | 2.10 | 790 | 18 | 2.10 |
| 51 | Chanda | *Pseudambassis ranga* | 100 | 100 | | 0.867 | 400 | 15.5 | 3.8 | 2.10 | 2.60 | 1153 | 336 | 6.42 |
| 52 | Champa | *Scomberomorus commerson* | 100 | 100 | | 0.83 | 470 | 19.8 | 3.6 | 2.00 | 0.40 | 92 | 30 | - |
| 53 | Kazeli†† | *Ailia coila* | 100 | 100 | | 0.867 | 751 | 17.1 | 12.6 | 0.82 | 1.20 | 110 | 37 | 4.10 |
| 54 | Laitta | *Channa punctatus* | 100 | 100 | | 0.867 | 306 | 18.3 | 0.6 | 1.80 | 1.50 | 766 | 139 | 1.60 |
| 55 | Lona hilsa | *Tenualosa ilisha* | 100 | 100 | | 0.83 | 1020 | 16.4 | 18.3 | 1.90 | 1.20 | 220 | 0 | 2.30 |
| 56 | Rita†† | *Mystus cavasius* | 100 | 100 | | 0.83 | 479 | 16.8 | 5.1 | 1.80 | 1.30 | 120 | - | - |
| 57 | Shuri†† | Average¶ | 100 | 100 | | 0.867 | 443 | 17.7 | 4.1 | 1.41 | 1.52 | 745 | 4 | 1.30 |
| 58 | Boyal | *Wallago attu* | 100 | 100 | | 0.83 | 339 | 15.4 | 2.1 | 0.80 | 0.27 | 83 | 1 | - |
| 59 | Kalibaus | *Labeo calbasu* | 100 | 50 | 50 | 0.83 | 400 | 17.0 | 3.0 | 1.10 | 0.36 | 13 | - | - |
| 60 | African rui | *Clarias batrachus* | 100 | | 100 | 0.867 | 326 | 16.5 | 1.3 | 1.20 | 0.74 | 59 | 25 | 4.83 |
| 61 | Silver cup | *Hypophthalmichthys molitrix* | 100 | | 100 | 0.83 | 435 | 17.2 | 4.1 | 4.40 | 1.40 | 903 | 0 | 0.55 |
| 62 | Talapia | *Oreochromis niloticus* | 100 | | 100 | 0.83 | 390 | 19.5 | 2.0 | 4.40 | 1.40 | 903 | 10 | 0.70 |
| 63 | Nilotika | *Oreochromis niloticus* | 100 | | 100 | 0.83 | 390 | 19.5 | 2.0 | 4.40 | 1.40 | 903 | 10 | 0.70 |
| 64 | Others | Average# | 100 | 100 | | 0.867 | 444 | 16.9 | 4.2 | 2.33 | 2.19 | 713 | 151 | 3.83 |
| 2000 | | | | | | | | | | | | | | |
| 41 | Hilsha | *Tenualosa ilisha* | 100 | 100 | | 0.83 | 1020 | 16.4 | 18.3 | 1.90 | 1.20 | 220 | 20 | 2.30 |
| 42 | Rui | *Labeo rohita* | 39.36 | | 100 | 0.83 | 422 | 18.2 | 3.0 | 0.98 | 1.00 | 51 | 13 | 5.05 |
| | Catla | *Catla catla* | 32.79 | | 100 | 0.83 | 267 | 14.9 | 0.7 | 0.83 | 1.10 | 210 | 22 | 1.30 |
| | Mrigel | *Cirrhinus mrigala* | 26.48 | | 100 | 0.83 | 363 | 18.9 | 1.1 | 2.50 | 1.50 | 960 | 15 | 5.57 |
| | Kal baush | *Labeo calbasu* | 1.37 | 30 | 70 | 0.83 | 400 | 17.0 | 3.0 | 1.10 | 0.36 | 13 | - | - |
| 43 | Boal | *Wallago attu* | 15.65 | 100 | | 0.83 | 339 | 15.4 | 2.1 | 0.80 | 0.27 | 83 | 1 | - |
| | Air | *Sperata aor* | 6.81 | 100 | | 0.83 | 373 | 17.0 | 2.3 | 0.90 | 0.23 | 11 | - | - |
| | Pangas | *Pangasianodon hypophthalmus* | 77.54 | 100 | | 0.83 | 925 | 16.0 | 17.7 | 0.69 | 0.65 | 8.6 | 31 | 1.50 |
| 44 | Khalisha/Magur/Shinghi | Average‖ | 100 | 100 | | 0.867 | 351 | 16.93 | 1.9 | 2.5 | 1.38 | 606 | 34 | 7.73 |
| 45 | Koi | *Anabas testudineus* | 100 | 100 | | 0.867 | 737 | 15.5 | 12.8 | 0.87 | 0.60 | 85 | 295 | 2.38 |
| 46 | Silver carp | *Hypophthalmichthys molitrix* | 84.38 | | 100 | 0.83 | 435 | 17.2 | 4.1 | 4.40 | 1.40 | 903 | 0 | 0.55 |
| | Grass carp | *Ctenopharyngodon idella* | 7.72 | | 100 | 0.83 | 341 | 15.2 | 1.1 | 0.46 | 0.91 | 54 | - | - |
| | Miror carp | *Cyprinus carpio* | 7.9 | | 100 | 0.83 | 381 | 16.4 | 2.9 | 1.10 | 2.20 | 37 | 2 | - |
| 47 | Shoal | *Channa striatus* | 33.33 | 100 | | 0.83 | 310 | 18.7 | 0.3 | 0.41 | 0.73 | 96 | 0 | 1.20 |
| | Gajar | *Channa marulius* | 33.33 | 100 | | 0.83 | 286 | 17.1 | 0.3 | 0.43 | 0.60 | 9.3 | 0 | 0.55 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Taki | *Channa punctatus* | 33.33 | 100 | | 0.867 | 306 | 18.3 | 0.6 | 1.80 | 1.50 | 766 | 139 | 1.60 |
| 48 | Puti/Big puti | Average† | 50 | 100 | | 0.867 | 552 | 16.2 | 7.4 | 2.07 | 2.48 | 916 | 25 | 3.58 |
| | Tilapia/Nilotica | *Oreochromis niloticus* | 50 | | 100 | 0.83 | 390 | 19.5 | 2.0 | 1.10 | 1.20 | 95 | 10 | 0.70 |
| 49 | Mala/Kachi/Chala/Chapila | Average‡ | 100 | 100 | | 0.867 | 362 | 15.0 | 3.2 | 4.24 | 3.28 | 848 | 697 | 6.04 |
| 51 | Shrimp | *Macrobrachium malcolmsonii* | 100 | 100 | | 0.867 | 364 | 15.7 | 2.2 | 13.00 | 3.30 | 1200 | - | - |
| 52 | Dried fish | Average§ | 100 | 100 | | 0.867 | 1610 | 62.0 | 14.7 | 25.00 | 12.00 | 2540 | 8 | - |
| 53 | Tangra/Eel fish | Average** | 100 | 100 | | 0.867 | 411 | 16.5 | 3.6 | 3.35 | 2.20 | 792 | 45 | 2.99 |
| 54 | Seafish | Average¶ | 100 | 100 | | 0.867 | 443 | 17.7 | 4.1 | 1.41 | 1.52 | 745 | 5 | 1.63 |
| 55 | Baila | *Glossogobius giuris* | 50 | 100 | | 0.867 | 292 | 16.6 | 0.4 | 2.30 | 2.10 | 790 | 18 | 2.10 |
| | Tapashi†† | *Eleutheronema tetradactylum* | 50 | 100 | | 0.83 | 425 | 20.6 | 2.2 | 0.60 | 0.90 | 37 | 0 | 0.85 |
| 56 | Others | Average# | 100 | 100 | | 0.867 | 444 | 16.9 | 4.2 | 2.33 | 2.19 | 713 | 151 | 3.83 |
| 2010 | | | | | | | | | | | | | | |
| 41 | Hilsha | *Tenualosa ilisha* | 100 | 100 | | 0.83 | 1020 | 16.4 | 18.3 | 1.90 | 1.20 | 220 | 20 | 2.30 |
| 42 | Rui | *Labeo rohita* | 40.33 | | 100 | 0.83 | 422 | 18.2 | 3.0 | 0.98 | 1.00 | 51 | 13 | 5.05 |
| | Catla | *Catla catla* | 31.41 | | 100 | 0.83 | 267 | 14.9 | 0.7 | 0.83 | 1.10 | 210 | 22 | 1.30 |
| | Mrigel | *Cirrhinus mrigala* | 22.80 | | 100 | 0.83 | 363 | 18.9 | 1.1 | 2.50 | 1.50 | 960 | 15 | 5.57 |
| | Kal baush | *Labeo calbasu* | 5.46 | | 100 | 0.83 | 400 | 17.0 | 3.0 | 1.10 | 0.36 | 13 | - | - |
| 43 | Boal | *Wallago attu* | 3.00 | 100 | | 0.83 | 339 | 15.4 | 2.1 | 0.80 | 0.27 | 83 | 1 | - |
| | Air | *Sperata aor* | 1.35 | 100 | | 0.83 | 373 | 17.0 | 2.3 | 0.90 | 0.23 | 11 | - | - |
| | Pangas | *Pangasianodon hypophthalmus* | 95.65 | | 100 | 0.83 | 925 | 16.0 | 17.7 | 0.69 | 0.65 | 8.6 | 31 | 1.50 |
| 44 | Khalisha | *Colisa fasciata* | 33.33 | 100 | | 0.867 | 354 | 15.2 | 2.5 | 4.10 | 2.30 | 1700 | 46 | 5.55 |
| | Magur | *Clarias batrachus* | 33.33 | 50 | 50 | 0.867 | 326 | 16.5 | 1.3 | 1.20 | 0.74 | 59 | 25 | 4.83 |
| | Shinghi | *Heteropneustes fossilis* | 33.33 | 50 | 50 | 0.867 | 374 | 19.1 | 1.9 | 2.20 | 1.10 | 60 | 32 | 12.80 |
| 45 | Koi | *Anabas testudineus* | 100 | | 100 | 0.867 | 737 | 15.5 | 12.8 | 0.87 | 0.60 | 85 | 295 | 2.38 |
| 46 | Silver carp | *Hypophthalmichthys molitrix* | 61.94 | | 100 | 0.83 | 435 | 17.2 | 4.1 | 4.40 | 1.40 | 903 | 0 | 0.55 |
| | Grass carp | *Ctenopharyngodon idella* | 10.19 | | 100 | 0.83 | 341 | 15.2 | 1.1 | 0.46 | 0.91 | 54 | - | - |
| | Miror carp | *Cyprinus carpio* | 27.87 | | 100 | 0.83 | 381 | 16.4 | 2.9 | 1.10 | 2.20 | 37 | 2 | - |
| 47 | Shoal | *Channa striatus* | 33.33 | 100 | | 0.83 | 310 | 18.7 | 0.3 | 0.41 | 0.73 | 96 | 0 | 1.20 |
| | Gajar | *Channa marulius* | 33.33 | 100 | | 0.83 | 286 | 17.1 | 0.3 | 0.43 | 0.60 | 9.3 | 0 | 0.55 |
| | Taki | *Channa punctatus* | 33.33 | 100 | | 0.867 | 306 | 18.3 | 0.6 | 1.80 | 1.50 | 766 | 139 | 1.60 |
| 48 | Puti/Big puti | Average† | 50 | 100 | | 0.867 | 552 | 16.2 | 7.4 | 2.07 | 2.48 | 916 | 25 | 3.58 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tilapia/Nilotica | *Oreochromis niloticus* | 50 | 100 | 100 | 0.83 | 390 | 19.5 | 2.0 | 1.10 | 1.20 | 95 | 10 | 0.70 |
| 49 | Mala/Kachi/Chala/Chapila | Average‡ | 100 | 100 | | 0.867 | 362 | 15.0 | 3.2 | 4.24 | 3.28 | 848 | 697 | 6.04 |
| 51 | Shrimp | *Macrobrachium malcolmsonii* | 100 | 100 | | 0.867 | 364 | 15.7 | 2.2 | 13.00 | 3.30 | 1200 | - | - |
| 52 | Dried fish | Average§ | 100 | 100 | | 0.867 | 1610 | 62.0 | 14.7 | 25.00 | 12.00 | 2540 | 8 | - |
| 53 | Tangra/Eel fish | Average** | 100 | 100 | | 0.867 | 411 | 16.5 | 3.6 | 3.35 | 2.20 | 792 | 45 | 2.99 |
| 54 | Seafish | Average¶ | 100 | 100 | | 0.867 | 443 | 17.7 | 4.1 | 1.41 | 1.52 | 745 | 5 | 1.63 |
| 55 | Baila | *Glossogobius giuris* | 50 | 100 | | 0.867 | 292 | 16.6 | 0.4 | 2.30 | 2.10 | 790 | 18 | 2.10 |
| | Tapashi†† | *Eleutheronema tetradactylum* | 50 | 100 | | 0.83 | 425 | 20.6 | 2.2 | 0.60 | 0.90 | 37 | 0 | 0.85 |
| 56 | Others | Average# | 100 | 100 | | 0.867 | 444 | 16.9 | 4.2 | 2.33 | 2.19 | 713 | 151 | 3.83 |

* Average of *Colisa fasciata, Heteropneustes fossilis, Clarias batrachus, Anabas testudineus*.
† Average of *Puntius ticto, Puntius sophore, Puntius sarana*.
‡ Average of *Amblypharyngodon mola, Gudusia chapra, Chela cachius, Corica soborna*.
§ Average of *Puntius sophore, Setipinna phasa*.
¶ Average of *Liza parsia, Johnius argentatus, Sillaginopsis panijus, Stolephorus tri, Pampus argenteus*.
\# Average of *Mastacembelus armatus, Esomus danricus, Osteobrama cotio cotio, Hyporhamphus limbatus, Notopterus notopterus, Mystus cavasius, Lepidocephalichthys guntea, Ailia coila, Xenontedon cancila, Eleotris fusca, Nandus nandus, Ompok pabda, Botia dario, Macrognathus aculeatus*.
‖ Average of *Colisa fasciata, Heteropneustes fossilis, Clarias batrachus*.
** Average of *Mystus vittatus, Mastacembelus pancalus*.
†† No nutrition composition data available for fish species, so data of similar species, or species from same family used.

### Use of the adult male equivalent

Food consumption from household surveys is normally reported as per capita means; total household food consumption is divided by the number of people present in the household (children and adults are treated equally). This is a limitation because it does not take into account the different physiological energy requirements of different age and gender groups [32]. An alternative method is to divide household consumption according to the number of AMEs in the household, which are estimated from energy requirements of individual household members, based on age and gender, as a proportion of the energy requirement of an adult male (SI Table 2) [32]. This method produces a more accurate estimate of the adequacy of household food consumption. The energy requirements (ERs) for different age and gender groups were estimated based on FAO/WHO methodology [50], assuming a moderate physical activity level (PAL). This calculation requires details of individual body weight which were not available from the surveys, and so alternative methods for different age groups were applied, as explained below. For children under ten years, weight data from WHO growth reference data were used [51, 52]. There are no universal growth charts for child weight over the age of nine years, so the 2007 WHO growth reference for body mass index (BMI) for age, and height for age, with adjustments for the short stature of Bangladeshis, were used. This adjustment is important because adult height cannot be assumed to be equal across different populations, unlike the universal child growth standards. The maximal heights for men and women were adjusted to heights observed in Bangladesh in the 2011 Bangladesh Demographic and Health Survey (BDHS), and the intermediate measures were smoothed by reducing the growth pattern to match the maximal height using the following formula:

$$x_{a,s} = \left( \left( h_{a,s} - h_{a120,s} \right) \times \frac{m_s}{h_{a228,s}} \right) + h_{a120,s}$$

| | |
|---|---|
| $x_{a,s} =$ | Adjusted height of an individual of a given age and sex |
| $h_{a,s} =$ | Height of an individual from the 2007 WHO growth reference curve of the given age and sex |
| $h_{a120,s} =$ | Height of an individual from the 2007 WHO growth reference curve of the given sex at age 120 months |
| $m_s =$ | Mean height of an adult individual of the given sex as observed in the population |
| $h_{a228,s} =$ | Adult height of an individual from the 2007 WHO growth reference curve of the given sex at age 228 months |

These heights were then used to impute weights, using the mean 2007 WHO growth reference BMI for age (by age in months). Using the formulae provided by the FAO manual, daily ERs for adolescents of each month of age and sex were calculated, then averaged over the year. To obtain estimates of adult weight, we used the mean BMI of adults of 19 years from the 2007 WHO growth curves (female BMI=21.427; male BMI= 22.19) and the mean adult heights observed in Bangladesh. These two measures were used to impute an optimal adult weight (female, 48.84 kg; male, 58.38 kg), and combined with a PAL of 1.85 (moderately active) to estimate ERs for adults.

The AME method can be further improved by accounting for increased energy needs of pregnant or lactating women within each household. No data were available within the surveys on pregnancy or lactation status of women, however, given that breastfeeding rates are relatively high in Bangladesh (90% of children until age two years in 2011 [53] and 81% in the first BDHS in 1993-94 [54]), it was assumed that for every household with a child two years of age or less that they would be breastfed, and so the household AME was increased to account for this. The increased energy requirement for breastfeeding was estimated at 20% of the energy cost of milk production (as milk produced is converted to food energy to meet the needs of the infant with 80% efficiency). This is highest in the first six months (2.8 MJ/day) and decreases to (1.925 MJ/day) thereafter [50], so for households with an infant less than one year old, the energy cost of lactation was averaged over the first 12 months (((2.8+1.925)/2) X 0.8 efficiency), and for households with an infant aged one year, it was estimated as 1.925 MJ/day X 0.8 efficiency.

Supporting Information Table 2: Adult male equivalent values for age and gender groups in Bangladesh.

| Age (years) | Females | Males |
|---|---|---|
| <1 | 0.20 | 0.22 |
| 1.0–1.9 | 0.29 | 0.32 |
| 2.0–2.9 | 0.36 | 0.39 |
| 3.0–3.9 | 0.40 | 0.43 |
| 4.0–4.9 | 0.44 | 0.47 |
| 5.0–5.9 | 0.47 | 0.51 |
| 6.0–6.9 | 0.51 | 0.55 |
| 7.0–7.9 | 0.55 | 0.59 |
| 8.0–8.9 | 0.59 | 0.64 |
| 9.0–9.9 | 0.64 | 0.69 |
| 10.0–10.9 | 0.67 | 0.71 |
| 11.0–11.9 | 0.72 | 0.76 |
| 12.0–12.9 | 0.75 | 0.83 |
| 13.0–13.9 | 0.78 | 0.90 |
| 14.0–14.9 | 0.80 | 0.96 |
| 15.0–15.9 | 0.81 | 1.00 |
| 16.0–16.9 | 0.82 | 1.04 |
| 17.0–17.9 | 0.82 | 1.07 |
| 18.0–18.9 | 0.83 | 1.08 |
| 19.0-29.9 | 0.78 | 1.02 |
| 30.0–59.9 | 0.80 | 1.00 |
| ≥65 | 0.71 | 0.82 |
| Lactation^ (children<1) | 0.04 | |
| Lactation^ (children 1.0–1.9) | 0.03 | |

^in addition to base requirement for age group

## Matching household roster and household consumption modules

The age and sex of household members (used to calculate AMEs) is recorded in the household roster module of the survey. However, the presence or absence of household members and guests on each day within the food consumption reference period is not recorded in the survey, posing difficulty in estimating household AMEs that accurately reflect the age and sex distribution of individuals among whom food was distributed. The survey does record the number of females and males under and over age 10 years who are present in the household on each day food consumption was measured, allowing for assumptions to be made as to the presence or absence of household members and guests. In cases where the number of people present for food consumption did not precisely match the household roster information (1991, n= 4366; 2000, n=4809; 2010, n=7284) the household AME was adjusted. Note that these discrepancies do not indicate error in data collection; rather they provide detail on the number of individuals consuming food on specific days within the reference period, which may deviate from the individuals who are considered 'household members' for other purposes. If the number of individuals in any category (females and males under and over age 10 years) in the consumption module was *more than* the number recorded in the roster, an average AME (of all individuals within that category in the survey) was added to the household AME. If the number of individuals in any category (females and males under and over age 10 years) in the consumption module was *less than* the number recorded in the roster, an average AME (of all household members within that category) was subtracted from the household AME. In cases where data on the number of people present in the household for food consumption were missing (1991, n=69; 2000, n=43; 2010, n=0), household AMEs were estimated solely on information contained in the household roster information.

## Strengths and limitations

This study has drawn on high quality nationally representative survey data using multiple times points, in combination with comprehensive food composition data at species level, in a unique analysis of changes in nutritional quality of fish consumed over time. The use of AMEs rather than per capita estimates takes into consideration changes in age and sex distributions over time, as well as a more accurate estimate of the adequacy of household food consumption in each survey year. Whilst this is an improvement on per capita estimates, the AME only considers energy requirements and does not account for different physiological requirements of micronutrients by different age and sex groups.

The potential for bias to influence results has been removed or minimised where possible, however, some aspects were unavoidable. Of note are considerable changes to survey methodology implemented in the 2000 HIES onwards (see detailed methods). Data checking at field level was conducted in 2000 and 2010, allowing opportunity for enumerators to re-visit households with extreme or missing values. This means that data from 1991 are more likely to be effected by outlying values, although the sensitivity analyses conducted in this study in the form of quantile regression mitigated this effect. Furthermore, households with unrealistic levels of fish consumption in the local context (>500 g/AME/day) were excluded (n=15), all of which were from the 1991 survey. The questionnaire was also changed in 2000, with the total number of fish categories recorded consolidated. The effect of this consolidation was largely mitigated by re-expanding the fish categories according to production figures as described in Detailed methods section and in SI Table 1; however, the number of fish categories was still less diverse than those recorded in previous years. This was also the first year that the recall period for food consumption was increased (from 24 hours to 2-days), and the number of repeated measures and reference period was decreased (from 30 measurements over a 30 day reference period to 7 measurements over a 14 day reference period). Generally, a higher number of repeated measures of food consumption and a longer reference period increase the reliability of results, however, this must be balanced against increased interviewer and interviewee burden and fatigue. As such, there is no consensus as to the level of improvement expected from seven to 30 measurements and a reference period of 30 instead of 14 days [55]. The increase in recall period in later survey years is likely to underestimate consumption (some consumption may be overlooked over a longer recall period). It should also be emphasised that food consumption recorded in HIESs reflects ‘apparent’ consumption and does not consider food wastage, plate waste and foods consumed outside the home, or consumption patterns among individuals. Other research has shown that large fish species have higher plate waste compared to SIS which are normally consumed whole [56]. Given that farmed fish (which are typically large in size) made up a greater proportion of consumption in later survey years, this may have disproportionately overestimated actual intakes. To minimise the impact of this limitation in the nutrient intake analysis, we adjusted for this by using an edible part conversion for small and large fish before estimating nutrient intakes (as nutrient composition refers to edible parts only). It is also likely that more food is being consumed outside the home in later survey years. By excluding this category, we may have underestimated actual fish consumption in 2010 (this information was not recorded in earlier surveys). Another minor limitation of the study was the absence of food composition data for vitamin B12 and vitamin A for some fish species. A small number of households consuming only fish with these missing data were therefore excluded from analysis of those specific nutrients (vitamin A, n=171; vitamin B12, n=465) to minimise impacting results. However, many households consumed a mix of species (with both known and unknown content of vitamin A or vitamin B12) and so were included in analysis of these nutrients. Assuming that these species of unknown vitamin content are a source of those vitamins, vitamin A and vitamin B12 intakes from fish are likely to have been underestimated.

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# 8. Measuring nutritional quality of agricultural production systems

## 8.1. Forward to manuscript

The analysis presented in Chapter 7 highlighted the importance of considering nutritional quality of food production systems as opposed to the status quo focus on quantity. Drawing on fish as an example, this leads to RQ 5: How could nutritional quality of fish production systems be measured and used in decision making? Chapter 8 presents an examination of available indicators which capture some aspect of nutritional quality of agricultural production sub-systems. A summary of the strengths and limitations of applicable indicators is presented. Relevant indicators are then applied to 18 selected pond aquaculture production sub-systems in Bangladesh by way of demonstrating the different aspects of nutritional quality captured by different indicators.

This analysis finds that there are a large number of indicators relevant to the latter stages of the food and nutrition system (particularly the consumption stage), and many fewer indicators relevant at the agricultural production stage. By applying available indicators to selected pond aquaculture production sub-systems, it is clear that the different indicators capture different aspects of nutritional quality, so using a combination of different indicators is important for comprehensive evaluation. However, if the goal is to identify production systems with the greatest potential to nourish the most people, and which could potentially be useful for decision making and prioritising of agricultural production sub-systems, ‘nutritional yields’, ‘potential nutrient adequacy’ and ‘Rao’s quadratic entropy’ are likely to be of significant value.

## 8.2. Submitted manuscript

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# Measuring nutritional quality of agricultural production systems: application to fish production

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## Abstract

Reorienting food systems towards improving nutrition outcomes, is vital if the global goal of ending all forms of malnutrition is to be achieved. Crucial to transitioning to nutrition-sensitive agriculture, is valuing and measuring nutritional quality of the outputs of agricultural production. We review existing indicators which capture an element of nutritional quality applicable to different stages of the food and nutrition system. Applying relevant indicators from the agricultural production stage to common aquaculture systems, we compare and contrast their strengths and limitations. ‘Nutritional yields’, ‘potential nutrient adequacy’ and ‘Rao’s quadratic entropy’ show particular promise in capturing the ability of a production system to nourish the most people and could be useful tools for prioritising and decision making.

**Keywords:** food system, food and nutrition system, indicator, nutritional quality, diversity, production

# 1 Introduction

Malnutrition, in its various forms directly affects one third of the global population, and combined with poor diets, is the leading driver of the global burden of disease (IFPRI, 2016). At the heart of this problem, are food systems which are narrowly focused on maximising yields and economic value, without due consideration for the impacts on human health. Through the Sustainable Development Goals (SDGs), the world has committed to ending all forms of malnutrition (United Nations, 2015). Reorienting food systems, across all actors and levels, towards improving nutrition outcomes (nutrition-sensitive food systems), is central to achieving this goal, as was recognised in the second International Conference on Nutrition (ICN2) Framework for Action (FAO & WHO, 2014). In line with this, The Global Panel on Agriculture and Food Systems for Nutrition has recently called for a paradigm shift in food systems thinking away from 'feeding people' to 'nourishing people', emphasising the importance of nutrition as an outcome of food systems (Global Panel on Agriculture and Food Systems for Nutrition, 2016). It is suggested here, that a vital advancement in this pursuit, lies in valuing nutritional quality of agricultural production (as the first stage of the food system) rather than yields alone. The purpose of this analysis, therefore, is to elucidate indicators which capture the ability of a production system to nourish the most people, and which could potentially be useful for decision-making in agricultural production systems.

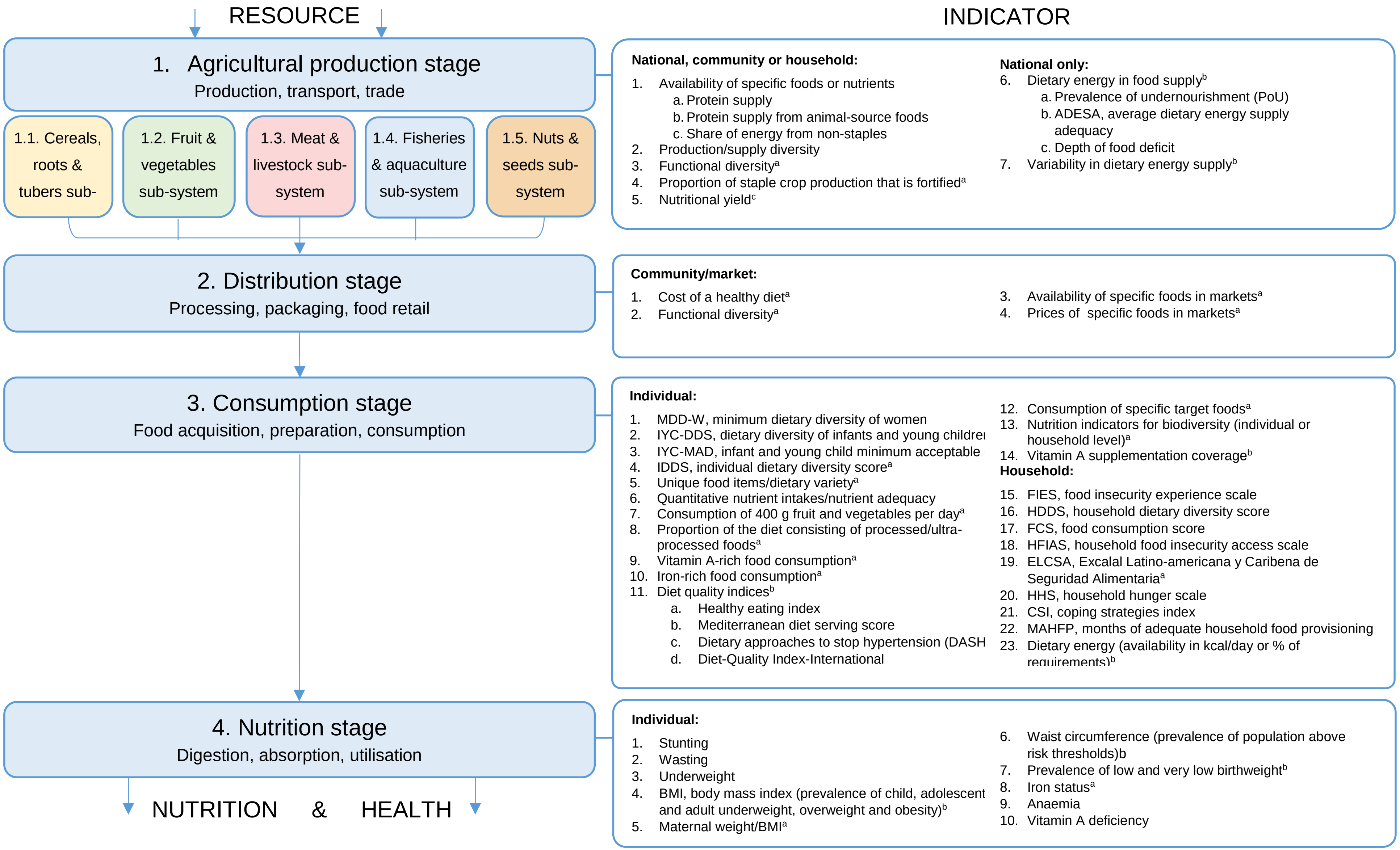
Food systems can be conceptualised as consisting of all of the inputs and activities required to produce and distribute food for human consumption. Various conceptual models of food systems include several stages, including agricultural production (consisting of a number of sub-systems), distribution, and consumption; each of which involves inputs, which undergo transformation and result in various outputs, which continue their flow throughout the system (Global Panel on Agriculture and Food Systems for Nutrition, 2016; Ingram, 2011; National Health and Medical Research Council, 2013). Several authors propose a broader concept of food systems which incorporates nutrition and health outcomes, emphasising the interdependence of agricultural production, food consumption and nutritional status (Burchi et al., 2011; Nugent, 2011; Sobal et al., 1998). An advantage of this conceptual approach is that an understanding of the drivers of, inputs to, transformations within, interactions between, and outputs at each stage of the system allows more effective guidance of interventions at various stages in the system to achieve desired nutrition and health outcomes.

Within the food and nutrition systems framework (see Figure 1), it is clear that nutritional quality of foods as consumed (the inputs of the consumption stage), in turn, rely on the nutritional quality of outputs from the agricultural production stage (whether at a local or global scale). Whilst there is a large body of literature on methods and indicators for measuring nutritional quality of diets as consumed (see indicators related to the consumption stage in Figure 1), significantly less work has been done on measuring nutritional quality of the outputs of the agricultural production stage. Nutritional quality of agricultural production is rarely measured in practice because agricultural production systems are not designed explicitly to meet the health and nutrition needs of populations; but rather, to maximise yield and economic gains for producers (Bouis & Welch, 2010). It is anticipated that calls to action for agriculture to become more nutrition-sensitive, will not be realised unless a nutritional quality dimension is incorporated into measurement of outputs.

There is on-going tension between the benefits of diverse agricultural production systems and the economies of scale feasible with less diverse systems, for achieving high quality diets (Fanzo, 2017). Greater on-farm production diversity can improve dietary quality of household members. On the other hand, a more market-oriented approach to production (assuming adequate access to markets) can increase income, allowing the household to purchase nutrient-rich foods. However, as others have noted, this debate fails to capture the relationship between production and consumption across scales, (Fanzo, 2017; Remans et al., 2015). Global food production has become increasingly homogenous (Khoury et al., 2014). In Bangladesh, increased supply of fish through rapid expansion of aquaculture has failed to increase nutritional quality of diets. People are eating more fish, but intakes of vital micronutrients from fish have actually decreased, related to reduced diversity and nutritional quality of supply (Bogard et al., 2017). This demonstrates that individual production sub-systems must have an impetus to maximise nutritional quality, irrespective of market orientation.

This study presents a comparative analysis of the merits and limitations of existing indicators that capture some elements of nutritional quality of the outputs of agricultural production sub-systems (individual systems within the production stage of the broader food and nutrition system, Figure 1). First, a brief summary of available indicators, how they are calculated and a discussion of some of the contexts in which they have been previously applied, is provided. Next, a case study of aquaculture production systems in Bangladesh (as an example of an agricultural production sub-system) is presented as the context for application and comparison of selected indicators.

Figure 1: Schematic diagram of the food and nutrition system, including four main stages and indicators relevant to nutritional quality.




Source: Authors, schematic adapted from (Heywood & Lund-Adams, 1991; Sobal et al., 1998). Indicators from (Herforth et al., 2016; Lele et al., 2016)

Note that the schematic is presented linearly, though in reality there are likely to be multiple feedback mechanisms at play throughout the system.

[a] Indicator mentioned only in FAO compendium. [b] Indicator mentioned only in FSIN technical guide. Indicators with no superscript were included in both sources. [c] Indicator identified in published literature elsewhere, but included here as highly relevant for this analysis.

The conclusions drawn from this analysis are used to inform recommendations for inclusion of appropriate indicators in the evaluation of agricultural production sub-systems to maximise their potential to not only feed people, but to nourish them.

## 2 Methods

Two comprehensive collections of indicators have been published recently which are highly relevant for this analysis. The first is a user's guide for 33 types of existing indicators that measure the various dimensions of food and nutrition security published by the Food Security Information Network global initiative, which essentially provide a benchmark for the adequacy of the food and nutrition system (Lele et al., 2016). The second is a compendium of 58 indicators for nutrition-sensitive agriculture published by the Food and Agriculture Organization, which presents a best-practice guide for measuring the impact of agricultural interventions on nutrition (Herforth et al., 2016). An additional indicator (nutritional yield) not captured in the above reviews, but highly relevant to this analysis, was identified in the recent literature and so is included here (DeFries et al., 2015). Indicators from these sources were examined for their relevance in capturing some aspects of food/nutrient availability, access, consumption or utilisation (n=43). Indicators which capture important determinants of nutrition and health outcomes, but are not explicitly relevant to food or nutrients were excluded from this analysis (e.g. indicators of sanitation, income, women's empowerment). Applicable indictors were then categorised according to the applicable food and nutrition system stage (see Figure 1), based on the scale at which data is collected in order to calculate the indicator (e.g. the indicator 'availability of specific foods in markets' is based on data collected at the market level, and so grouped in the distribution stage). Indicators relevant to the agricultural production stage were then further examined; indicators which are only relevant in the context of total food supply and therefore are not useful for decision making around individual production sub-systems (e.g. sub-systems 1.1-1.5, in Figure 1), are listed in Figure 1 for completeness, but are excluded from further analysis (n=4). For example, a common indicator used by the Food and Agriculture Organisation (FAO) as a reflection of nutritional quality of the food supply, is the percentage of dietary energy from non-staple foods, with a high proportion of energy from non-staple foods reflecting a more diverse food supply. However, this indicator does not offer any interpretation of the nutritional quality of outputs from an individual production sub-system, such as a rice production system.

Two groups of indicators were identified that are relevant for further discussion as measures of nutritional quality of the outputs of agricultural production sub-systems; nutritional yield, and measures of functional diversity (including production diversity). A summary of each relevant indicator, including a description, method of calculation, strengths and limitations is included in Table 1.

# 3 Indicators of nutritional quality of agricultural production

## 3.1 Nutritional yield

Nutritional yield is defined as the "number of adults who would be able to obtain 100% of the dietary reference intakes (DRI) of different nutrients for one year from a food item produced annually on one hectare" (DeFries et al., 2015). It is calculated separately for individual nutrients, which could be combined into an index score of selected nutrients of interest in a given context. So far, this indicator has been applied to cereal crop production in three studies, one in India (Defries et al., 2016), one in Senegal (Wood, 2017, forthcoming) and one on the global scale (DeFries et al., 2015). A modified version of this indicator was also included in recent analysis of the contribution of different farm sizes to global food and nutrient production (Herrero et al., 2017).

### 3.1.1 Potential nutrient adequacy

Potential nutrient adequacy builds on nutritional yield by calculating an average nutritional yield weighted by the evenness of nutritional yields in a production system. Scores are scaled from 0-1 so they are not interpreted in the same way as nutrition yields – where scores reflect numbers of people. This new indicator is introduced in a recent analysis of household production systems in Senegal (Wood, 2017, forthcoming).

## 3.2 Functional diversity

Functional diversity indicators stem from ecological sciences in which they are used extensively to assess the degree to which species or varieties in a defined system vary according to specific traits which influence the functioning of the system. Recently, functional diversity indicators have been applied to the field of nutrition in a handful of studies (summarised below), in which the traits of different species or varieties (referred to here from now on as foods), depending on the indicator, are defined by their nutrient composition.

### 8.2.1. Production diversity

Production diversity reflects the number of different foods produced by a defined system (e.g. a plot of land, farm or household). It does not consider specific nutritional traits of the individual foods, though greater diversity in nutritional quality is implied with higher production diversity. A positive relationship between production diversity in a farming system and various nutrition related outcomes have been identified in several studies including; household dietary diversity (Dillon et al., 2015; Jones, 2017; Jones et al., 2014; Koppmair et al., 2017; Sibhatu et al., 2015); household food security (M'Kaibi et al., 2015); dietary diversity of women (Keding et al., 2012; Koppmair et al., 2017; Malapit et al., 2015; Torheim et al., 2004); various measures of child diet quality and feeding practices(Jones, 2014; Koppmair et al., 2017; M'Kaibi et al., 2015; Malapit et al., 2015) and child weight-for-height z-scores (Malapit et al., 2015); though not in all circumstances (Keding et al., 2012; Remans et al., 2011). However, production diversity indicators do not account for variability or similarity in the nutrient profiles of distinct foods. For example, a production system with only a few different foods but with very different nutritional qualities (e.g. a farm producing poultry, maize and spinach) may contribute more to a nutritionally complete diet than a system that includes several foods, all of which are nutritionally similar (e.g. three varieties of maize). Conversely, a farm producing only a single crop e.g. orange sweet potato, may be producing multiple nutritionally distinct food items (e.g. green leafy vegetables and starchy roots), but the production diversity (if counting varieties) would only be considered as one. The counting unit used to reflect production diversity, whether it be species, variety, food, or food group, is therefore critical to appropriate interpretation (Berti, 2015).

### 8.2.2. Shannon diversity and Simpsons index

Shannon diversity (also known as Shannon entropy or the Shannon index) and the Simpson index, are conceptually very similar in that they both build on production diversity by incorporating a measure of the relative abundance of foods produced (though they differ mathematically, see Table 1). For example, they offer a distinction between two farms which both produce three different foods (production diversity of 3); with farm 1) producing equal amounts of foods *a, b* and *c*, in contrast to farm 2) having 80% of production from food *a*, 15% of production from food *b* and 5% from food *c*. Calculation is based on a simple count of the foods produced in addition to a measure of relative abundance, which may be yields in a defined period such as a season or year, or some other measure of abundance such as the unit area of cultivation. Note that how ‘abundance’ is measured is extremely important for how results are interpreted. Shannon diversity and the Simpson index are therefore an improvement on production diversity as they allow for differentiation between farms of the same production diversity with a different distribution of individual foods. Similar to production diversity, Shannon diversity and the Simpsons index do not consider differences in nutrient composition of individual foods. Related to nutrition, Shannon diversity has been used in two recent studies; one presents a regional analysis of global food production and supply diversity (Remans et al., 2014); and the other, in relation to global and regional farm size distributions (Herrero et al, 2017, forthcoming). Related to nutrition, the Simpsons index has been used in a study linking farm level production diversity to household dietary diversity in Malawi (Jones et al., 2014). In this study, the abundance was measured as the area of cultivation of each crop, rather than yields from each crop. It is noted that several other indicators such as the Margalef index and Pielou's evenness index are used in ecology which differ mathematically from Shannon diversity and the Simpson index, but similarly capture elements of diversity and evenness; these are not discussed here to avoid repetition (Khoury et al., 2014; Sibhatu et al., 2015).

### 8.2.3. Nutritional functional diversity

Nutritional functional diversity (NFD) is defined as 'the diversity of nutrients provided by a farm and the complementarity in nutrients among species [foods] on a farm' in relation to the variety of nutrients needed for human health' (Remans et al., 2011). A system with several foods which are nutritionally similar will have a lower NFD than a system with the same number of foods which are more nutritionally distinct. Calculation of this indicator requires determination of all of the foods within a production system, quantification of the nutrient composition of foods, and a series of cross tabulations of the nutrients provided by those foods. These tabulations can then be used to generate a score which reflects the sum of distances between foods, determined by distinctness in nutrient composition; a higher score reflects great nutritional diversity. It does not however, reflect differences in abundance or quantity of each food. This indicator has been applied in three studies; one at the farm level in selected villages in Kenya, Malawi and Uganda (Remans et al., 2011); at the household level in Senegal (Wood, 2017, forthcoming); and at the household level in Malawi, applied to home production, market purchases and overall consumption (Luckett et al., 2015).

### 8.2.4. Modified functional attribute diversity

Modified functional attribute diversity (MFAD) is a measure similar to NFD, which also incorporates a weighting for the number of distinct functional types of foods produced (two foods with the same nutritional value would be considered one functional type) (Remans et al., 2014). Note that MFAD does not consider relative abundance of different foods produced in a system, rather only the *number* of nutritionally distinct foods. This indicator has been used in two global studies; a country and regional analysis of global food production and supply (Remans et al., 2014); and a regional analysis of food production relative to farm sizes (Herrero et al., 2017).

### 8.2.5. Rao's quadratic entropy

Rao's quadratic entropy (Q) provides a measure of the diversity in nutrient composition of foods in a system, weighted by their relative abundance or yields. So far, Q has not been included in published analyses relevant to human nutrition, though, it is included here in response to limitations recognised in a previous study presenting NFD and the need for indicators that incorporate relative abundance (Remans et al., 2011).

## 4 Case study: Fisheries in Bangladesh

Fish is the most important animal-source food in the Bangladeshi diet, both in terms of quantity and frequency of consumption across all population groups (Belton et al., 2014; Bogard et al., 2016). Fish production systems are in transition in Bangladesh, as they are also globally. Capture fisheries production is stagnant, and demand for fish is increasingly being met by growth in aquaculture (fish farming). Aquaculture production in Bangladesh is dominated by pond polyculture systems (usually a selection of 3-5 carp species). These sub-systems might be considered 'diverse' because they produce a number of different fish species, but often these species are nutritionally similar and are generally of lower nutritional quality compared to indigenous species from capture fisheries (Bogard et al., 2015). The result of this transition has been that national fish consumption per person increased by 30% (from 1991 to 2010), but intake of micronutrients from fish did not keep pace, and even declined for some important micronutrients (Bogard et al., 2017). It is worth considering whether inclusion of a measure of nutritional quality in the research and development phases of aquaculture systems would have influenced the combination of species selected for production.

Table 1: Summary of indicators that capture an element of nutritional quality of food production sub-systems.

| Indicator | Description | Method of calculation | Strengths | Limitations |
|---|---|---|---|---|
| Nutritional yield (NY) | Number of adults who would be able to obtain 100% of the dietary reference intakes (DRI) of selected nutrients for one year from a food produced annually on one hectare | $NY_{ij} = \frac{fraction\ of\ DRI_i}{100_{gi}} \times \frac{tonnes_i}{ha/yr} \times \frac{10^4}{365}$<br>i = the selected nutrient of interest<br>j is the selected food item<br>DRI for nutrient i = average recommended daily allowance (RDA) of a female (not pregnant or lactating) and male adult, aged 19-50 years<br>Fraction of DRI for nutrient i = contribution to DRI from 100 g of the food item of interest | Relatively simple to calculate and interpret; accounts for differences in quantities of foods/species produced | Needs to be calculated for each individual nutrient of interest so does not reflect overall nutritional quality (across several nutrients in a single score) |
| Potential nutrient adequacy (PNA) | The magnitude of the fraction of people potentially nourished (average nutritional yield scaled from 0-1 across selected nutrients), weighted by the evenness of nutritional yields across selected nutrients | $PNA = Ave\left(NY_{ij}\right) \times \left(\frac{H}{\ln\left(NY_{ij}\right)}\right)$<br>Ave = average<br>$NY_{ij}$ = nutritional yield for selected nutrients i to j.<br>H = Shannon diversity<br>ln = natural log<br>(both terms scaled from 0-1) | Captures difference in nutrient composition of foods produced and their relative quantity, across multiple nutrients in a single score | Relatively more complex to calculate |
| Production diversity (PD) | Number of foods produced by a given entity such as a farm or household | Simple count of foods, species or food groups in a defined production system | Relatively simple to calculate and interpret | Does not reflect differences in quantities or nutrient composition of different foods produced |
| Shannon diversity (H) | Number of foods produced by a given entity such as a farm or household, weighted by the relative abundance of each food.<br>It quantifies the uncertainty in predicting the type of food randomly selected from a defined population. | $H = \sum_{i=1}^{S} -(P_i \times \ln P_i)$<br>$P_i$ = fraction of the entire population made up of species i<br>S = numbers of foods encountered<br>ln = natural logarithm | Captures differences in quantities* of foods produced (the evenness in production) | Does not reflect differences in nutrient composition of foods produced |
| Simpsons index (SI) | Number of foods produced by a given entity such as a farm or household, weighted by the relative abundance of each food.<br>It quantifies the probability that two foods randomly selected from a | $SI_i = 1 - \sum s_j^2$<br>$S_j$ = fraction of the entire population i made up of food j | Captures differences in quantities* of foods produced (the evenness in production) | Does not reflect differences in nutrient composition of foods produced |

| | | | | |
|---|---|---|---|---|
| | defined population will be the same type. | | | |
| Nutritional functional diversity (NFD) | Diversity of nutrients and complementarity in nutrients among foods produced on a farm relative to nutrient needs for optimal human health | $NFD = \frac{\Delta d + \overline{dG}}{\Delta \lvert d \rvert + dG}$<br>Δd = sum of abundance weighted deviances<br>Δ\|d\| = absolute abundance weighted deviances from the centre of gravity<br>dG=mean distance to centre of gravity | Captures difference in nutrient composition of foods produced across multiple nutrients in a single score | Does not account for differences in quantity of foods produced |
| Modified functional attribute diversity (MFAD) | Diversity of nutrients and complementarity in nutrients among foods produced on a farm relative to nutrient needs for optimal human health | $MFAD = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij}}{N}$<br>n = number of foods<br>d = dissimilarity between each food i and j (as measured by nutrient composition of selected nutrients using a distance algorithm).<br>N = number of functional units, where a functional unit represents the number of food which are nutritionally distinct (i.e. two foods with the same nutrient composition would be considered one functional unit). | Captures difference in nutrient composition of foods produced across multiple nutrients in a single score | Does not account for differences in quantity of foods produced |
| Rao's quadratic entropy (Q) | Diversity of nutrients provided by the system, weighted by the relative abundance of each food | $Q = \sum_{i-1}^{S-1} \sum_{j=i+1}^{S-1} d_{ij}\, p_i p_j$<br>S = total food richness<br>d = dissimilarity between each food i and j (as measured by nutrient composition of selected nutrients using a distance algorithm).<br>$p_i$ = relative abundance of food i | Captures difference in nutrient composition of foods produced and their relative quantity*, across multiple nutrients in a single score | Relatively more complex to calculate |

*Note that this is dependent on how quantity or abundance is measured for calculation. In some cases, this may be actual yields from the system over a defined period such as a season or year. It may also be measured as the area of cultivation, as was done, for example, in calculation of the Simpson index by Jones et al. (2014).

Measurement of nutritional quality (using the indicators described in the previous section) of the outputs of different production sub-systems commonly in use, may provide useful insights into how those sub-systems that offer the greatest potential to nourish the most people could be prioritised in policy and decision-making.

## 4.1 Methods

The nutritional quality of outputs of 18 distinct pond polyculture production sub-systems (see Table 2) was analysed, using selected indicators; nutritional yield, production diversity, Shannon diversity, NFD, MFAD and Q. Nutrient composition of fish species used in calculations was sourced from published literature (Bogard et al., 2015). Nutrients examined here are those of public health concern in the context of Bangladesh based on documented deficiency or inadequate dietary intakes among vulnerable groups; iron, zinc, calcium, vitamin A and vitamin B12 (Arsenault et al., 2013; icddrb et al., 2013). Protein, fat and dietary energy are also examined as fish is an important source of these macronutrients. In calculating nutritional yields, instead of using recommended dietary allowances from the USA Institute of Medicine as per original methodology (DeFries et al., 2015), recommended nutrient intakes (RNI) were used, as they were considered more applicable to the Bangladeshi population (FAO & WHO, 2004). Iron requirements were based on 10% bioavailability. RNIs for zinc were taken from the International Zinc Nutrition Consultative Group, assuming an unrefined cereal-based diet, consistent with the typical Bangladeshi diet (Hotz et al., 2004). The following are average daily RNIs for women and men aged 19-50 years used in calculations: energy, 10,700 kJ; protein, 44 g; fat, 80 g; iron, 21.6 mg; zinc, 14 mg; calcium, 1000 mg; Vitamin A, 550 µg RAE; vitamin B12, 2.4 µg. Functional diversity indicators were calculated using the software FDiversity (version 2008) (Di Rienzo et al., 2008), with guidance from the user manual (Casanoves et al., 2008). Nutritional traits for each production sub-system were defined as the nutrient composition of each species per 100 g raw, edible parts as a proportion of the average adult RNI.

Management of pond polyculture systems in Bangladesh vary widely in terms of stocking densities of different species, inputs, harvesting and several other factors all of which influence yields. Therefore, for the purpose of examining indicators, the total yields of small and large fish from pond polyculture systems used are 204 and 1841 kg/ha/year, respectively, the average yields reported in the literature (Karim et al., 2017). Species included in ‘small’ and ‘large’ fish categories for the various systems are based on production systems described in the literature from Bangladesh (Ali et al., 2016; Alim et al., 2005; Murshed-e-Jahan et al., 2015; Roos, 2001). The average yields are distributed evenly across species within a category included in the system. For example, a polyculture system with one small fish species has the same total yield from small fish (204 kg/ha/year) as the system with four species of small fish (51 kg/ha/year per species, a total of 204 kg/ha/year of small fish). This assumption is made due to lack of more detailed data in the literature on species-specific yields of pond polyculture production systems.

Table 2: Matrix of fish species included in homestead pond aquaculture production sub-systems explored in this study.

| | Production sub-system | Rui (*Labeo rohita*) | Catla (*Catla catla*) | Mrigal (*Cirrhinus mrigala*) | Mirror carp (*Cyprinus carpio*) | Silver carp (*Hypophthalmichthys molitrix*) | Tilapia (*Oreochromis niloticus*) | Mola (*Amblypharyngodon mola*) | Darkina (*Esomus danricus*) | Dhela (*Osteobrama cotio cotio*) | Chapila (*Gudusia chapra*) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Indigenous carp polyculture | X | X | X | | | | | | | |
| 2 | Mixed carp polyculture 1 | X | X | X | X | | | | | | |
| 3 | Mixed carp polyculture 2 | X | X | X | | X | | | | | |
| 4 | Indigenous carp polyculture + Tilapia | X | X | X | | | X | | | | |
| 5 | Mixed carp polyculture 1 + Tilapia | X | X | X | X | | X | | | | |
| 6 | Mixed carp polyculture 2 + Tilapia | X | X | X | | X | X | | | | |
| 7 | Indigenous carp polyculture + Mola | X | X | X | | | | X | | | |
| 8 | Mixed carp polyculture 1 + Mola | X | X | X | X | | | X | | | |
| 9 | Mixed carp polyculture 2 + Mola | X | X | X | | X | | | | | |
| 10 | Indigenous carp polyculture + Tilapia + Mola | X | X | X | | | X | X | | | |
| 11 | Mixed carp polyculture 1 + Tilapia + Mola | X | X | X | X | | X | X | | | |
| 12 | Mixed carp polyculture 2 + Tilapia + Mola | X | X | X | | X | X | X | | | |
| 13 | Indigenous carp polyculture + Mixed SIS | X | X | X | | | | X | X | X | X |
| 14 | Mixed carp polyculture 1 + Mixed SIS | X | X | X | X | | | X | X | X | X |
| 15 | Mixed carp polyculture 2 + Mixed SIS | X | X | X | | X | | X | X | X | X |
| 16 | Indigenous carp polyculture + Tilapia + Mixed SIS | X | X | X | | | X | X | X | X | X |
| 17 | Mixed carp polyculture 1 + Tilapia + Mixed SIS | X | X | X | X | | X | X | X | X | X |
| 18 | Mixed carp polyculture 2 + Tilapia + Mixed SIS | X | X | X | | X | X | X | X | X | X |

SIS, small indigenous fish species.

## 4.2 Indicators of nutritional quality of aquaculture production systems

### 4.2.1 Nutritional yield

The nutritional yield of various nutrients, for selected pond aquaculture systems are shown in Table 3. The highest nutritional yield for each nutrient are all from systems which include SIS (sub-systems 7-18); whereas the lowest nutritional yield for each nutrient are all from large fish systems (sub-systems 1-6). This is driven both by higher overall average yields from systems with SIS, and the higher nutritional value of SIS compared to carp. However not *all* systems with SIS (either Mola, *Amblypharyngodon mola;* or mixed SIS) have higher nutritional yields for fat, iron, calcium and vitamin B12 compared to carp polyculture systems without SIS. Figure 2 clearly shows that there is very little variation in nutritional yields for energy or fat, some variability in the nutritional yields for protein, iron and zinc, and much larger variability in nutritional yields for calcium, vitamin A and vitamin B12. From a decision making perspective, it is likely mainly of interest to focus on nutrients which exhibit greater variability across different systems.

Comparisons between nutritional yields of different systems also elucidate how the inclusion or exclusion of particular species influence nutritional yields of the overall system (Figure 3). For example, compared to the indigenous carp polyculture system (production sub-system 1) inclusion of Mirror carp (*Cyprinus carpio)*, Silver carp (*Hypophthalmichthys molitrix*) and Tilapia (*Oreochromis niloticus*, systems 2, 3 and 4, respectively) – all large fish species, notably reduce nutritional yields for vitamin B12; and inclusion of Mirror carp (*Cyprinus carpio*) and Tilapia (*O. niloticus*, systems 2 and 4 respectively) notably reduce nutritional yields for calcium. This is driven by a smaller proportional contribution to total yield from Mrigal (*C. mrigala*) which has a relatively high vitamin B12 and calcium content. This highlights that increased diversity in the system may not always increase nutritional quality of the system. Addition of Mola (*A. mola*) or mixed SIS (sub-systems 7 and 13, respectively) to the indigenous carp polyculture system (production sub-system 1) results in the largest increase in nutritional yields, particularly of vitamin A, vitamin B12 and calcium.

Prioritising or selecting one sub-system over another for production based on nutritional yields is not straightforward because as there is no single system with higher nutritional yields across all nutrients. This limitation is addressed however, in calculation of PNA. The lowest PNA score was for production sub-system 1 (which is also the least diverse system), whilst the highest PNA score is for production sub-system 12 - mixed carp polyculture with Tilapia (*O. niloticus*) and Mola (*A. mola*).

### 4.2.2 Functional diversity

Functional diversity of selected pond aquaculture systems is shown in Table 3 and Figure 4. Production diversity ranges from 3-9 species, with the most diverse systems being production sub-systems 17 and 18. The Shannon index reflects a combined measure of diversity and evenness in abundance of the different species. For example, systems 2, 3, 4 and 7 all produce four different fish species, but the higher Shannon Index for systems 2, 3 and 4 compared to system 7 indicates that the abundance of the four species in those systems is more evenly distributed.

NFD and MFAD both reflect a similar pattern to production diversity and Shannon diversity. NFD and MFAD are both lowest for the indigenous carp polyculture system (system 1), and highest for the carp polyculture with tilapia and mixed SIS (systems 17 and 18). Adding mixed SIS to the carp polyculture system increases MFAD substantially (system 13, 14 and 15 around three-fold higher than systems 1, 2 and 3 respectively), whilst adding Tilapia to the carp polyculture system only increases MFAD slightly (systems 4, 5 and 6 compared to systems 1, 2 and 3 respectively). This reflects the large diversity in micronutrient content that is added to the production system with mixed SIS. Q exhibits a different trend (see Figure 4e), whereby the carp polyculture systems with Mola (*A. mola*, systems 7-12) have much higher values of Q than carp polyculture systems with mixed SIS (systems 13-18) and carp polyculture systems with large fish only (systems 1-6). This indicates that when abundance (or quantity of individual species) is taken into account, those systems which include Mola (*A. mola*) as the predominant SIS (systems 7-12) are of higher nutritional quality. Interestingly, the sub-system with the highest Q score is also the sub-system with the highest PNA score. From a decision making perspective, in this case the use of production diversity, Shannon index, NFD and MFAD, would each lead to the same conclusion: prioritise production sub-system 18. However, if Q were the indicator of choice, the sub-system for prioritisation would be sub-system 12.

Table 3: Nutritional yields and functional diversity of selected pond aquaculture production sub-systems in Bangladesh.

| | Production system | Nutritional Yield | | | | | | | | | Functional Diversity | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Energy | Protein | Fat | Iron | Zinc | Calcium | Vitamin A | Vitamin B12 | PNA | PD | H | NFD | MFAD | Q |
| 1 | Indigenous carp polyculture | *1.36 | 16.33 | *0.84 | 2.79 | *3.59 | 17.04 | 1.27 | 69.31 | 0.04 | *3 | *1.1 | 0.86 | *0.52 | *5432 |
| 2 | Mixed carp polyculture 1 | 1.39 | *16.11 | 1.01 | 2.63 | 4.34 | 13.17 | 0.99 | 54.38 | 0.09 | 4 | 1.39 | 1.02 | 0.76 | 6888 |
| 3 | Mixed carp polyculture 2 | 1.44 | 16.30 | 1.16 | 4.23 | 3.74 | 22.23 | 0.95 | 54.38 | 0.15 | 4 | 1.39 | 1.45 | 0.79 | 7047 |
| 4 | Indigenous carp polyculture + Tilapia | 1.40 | 16.84 | 0.89 | 2.63 | 3.59 | 13.77 | 1.14 | 55.03 | 0.10 | 4 | 1.39 | 1.00 | 0.72 | 6606 |
| 5 | Mixed carp polyculture 1 + Tilapia | 1.42 | 16.56 | 1.02 | *2.53 | 4.19 | *11.33 | 0.94 | *45.95 | 0.07 | 5 | 1.61 | 1.17 | 0.96 | 6685 |
| 6 | Mixed carp polyculture 2 + Tilapia | 1.46 | 16.71 | 1.14 | 3.81 | 3.71 | 18.58 | *0.91 | *45.95 | 0.13 | 5 | 1.61 | 1.60 | 1.01 | 6971 |
| 7 | Indigenous carp polyculture + Mola | 1.56 | 18.21 | 1.11 | 4.07 | 4.70 | 21.17 | ^23.32 | 85.42 | 0.33 | 4 | 1.31 | 1.45 | 0.95 | 20925 |
| 8 | Mixed carp polyculture 1 + Mola | 1.59 | 17.99 | 1.28 | 3.91 | 5.44 | 17.30 | 23.04 | 70.49 | 0.49 | 5 | 1.57 | 1.62 | 1.2 | 23214 |
| 9 | Mixed carp polyculture 2 + Mola | 1.64 | 18.18 | ^1.44 | 5.51 | 4.85 | 26.36 | 23.00 | 70.49 | 0.56 | 5 | 1.57 | 1.81 | 1.21 | 23230 |
| 10 | Indigenous carp polyculture + Tilapia + Mola | 1.60 | ^18.72 | 1.16 | 3.91 | 4.70 | 17.91 | 23.19 | 71.15 | 0.49 | 5 | 1.57 | 1.60 | 1.18 | 22890 |
| 11 | Mixed carp polyculture 1 + Tilapia + Mola | 1.62 | 18.45 | 1.29 | 3.81 | 5.29 | 15.46 | 23.00 | 62.06 | 0.56 | 6 | 1.77 | 1.77 | 1.42 | 23638 |
| 12 | Mixed carp polyculture 2 + Tilapia + Mola | ^1.66 | 18.60 | 1.41 | 5.09 | 4.82 | 22.71 | 22.97 | 62.06 | ^0.64 | 6 | 1.77 | 1.95 | 1.45 | ^23780 |
| 13 | Indigenous carp polyculture + Mixed SIS | 1.54 | 18.04 | 1.07 | 4.31 | 4.71 | 21.89 | 10.42 | ^85.55 | 0.42 | 7 | 1.45 | 2.42 | 1.92 | 12730 |
| 14 | Mixed carp polyculture 1 + Mixed SIS | 1.57 | 17.82 | 1.24 | 4.15 | ^5.46 | 18.02 | 10.14 | 70.62 | 0.50 | 8 | 1.71 | 2.58 | 2.2 | 15026 |
| 15 | Mixed carp polyculture 2 + Mixed SIS | 1.62 | 18.01 | 1.40 | ^5.75 | 4.86 | ^27.08 | 10.10 | 70.62 | 0.59 | 8 | 1.71 | 2.63 | 2.18 | 14995 |
| 16 | Indigenous carp polyculture + Tilapia + Mixed SIS | 1.58 | 18.55 | 1.12 | 4.15 | 4.71 | 18.63 | 10.29 | 71.27 | 0.51 | 8 | 1.71 | 2.56 | 2.23 | 14712 |
| 17 | Mixed carp polyculture 1 + Tilapia + Mixed SIS | 1.60 | 18.28 | 1.25 | 4.05 | 5.31 | 16.18 | 10.09 | 62.18 | 0.52 | ^9 | ^1.91 | 2.73 | ^2.49 | 15463 |
| 18 | Mixed carp polyculture 2 + Tilapia + Mixed SIS | 1.64 | 18.43 | 1.37 | 5.33 | 4.83 | 23.43 | 10.06 | 62.18 | 0.62 | ^9 | ^1.91 | 2.77 | ^2.49 | 15566 |

PNA, potential nutrient adequacy; PD, production diversity; H; Shannon diversity; NFD, nutritional functional diversity; MFAD, modified functional attribute diversity; Q, Rao's quadratic entropy.

* Lowest value within a column.

^ Highest value within a column.

Note that functional diversity indicators were calculated based on 7 'traits' which are the nutrient composition of species relative to average daily recommended intakes for adults for seven macro- and micronutrients: protein, fat, iron, zinc, calcium, vitamin A and vitamin B12.

Figure 2: Nutritional yields of selected pond aquaculture production sub-systems.

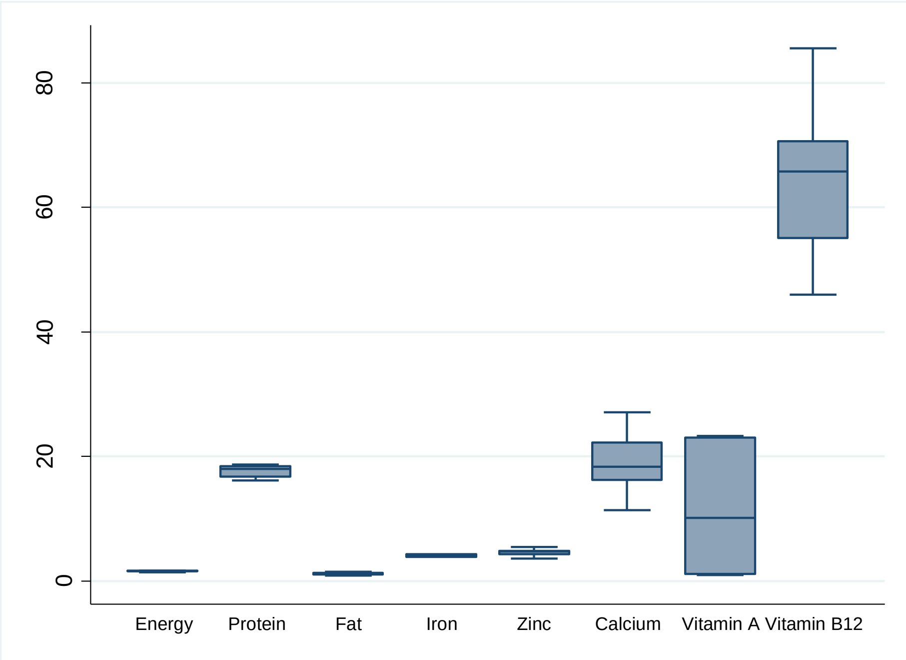
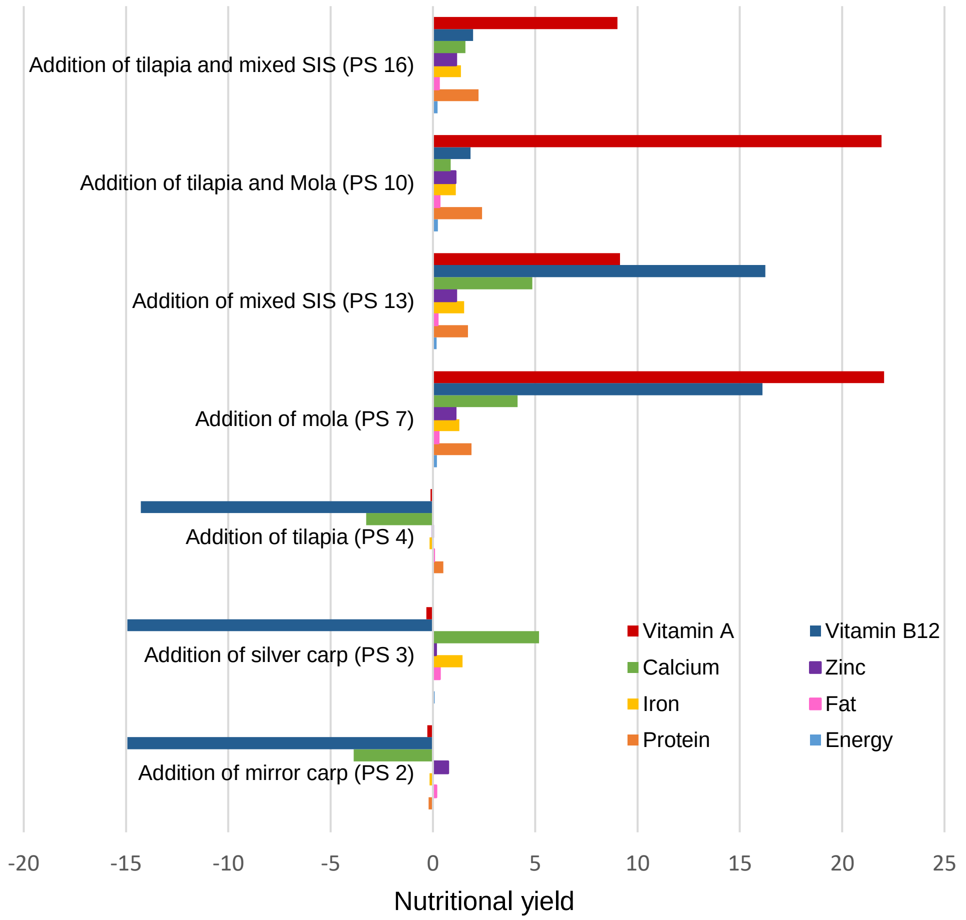
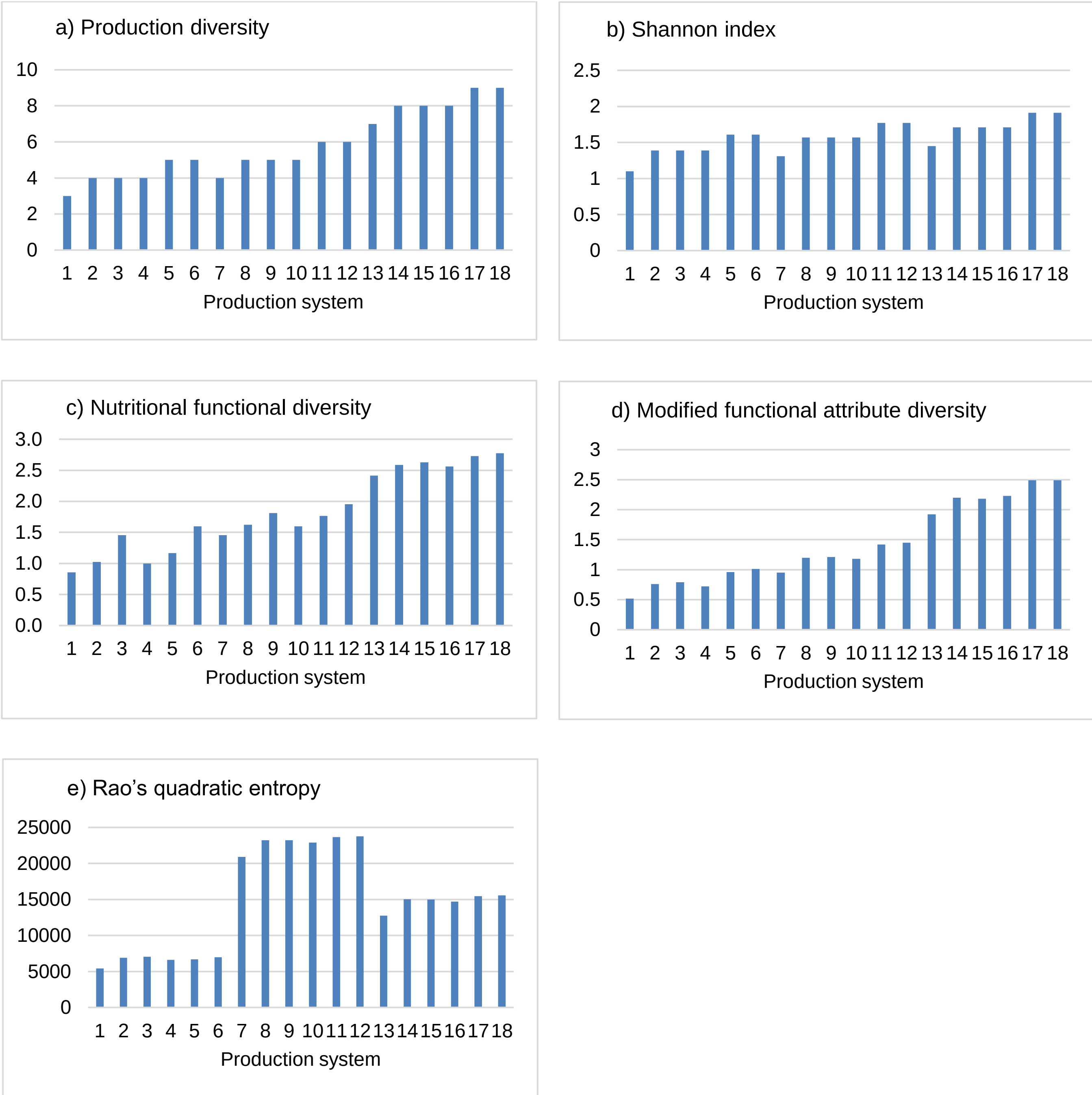



Figure 3: Change in nutritional yield through addition of different species to the indigenous carp polyculture production sub-system (production sub-system 1).




PS, production sub-system. Zero line is the nutritional yield of production sub-system one as reference sub-system.

Figure 4: Nutritional diversity indicators of selected fish production sub-systems (based on seven nutrients; protein, fat, iron, zinc, calcium, vitamin A and vitamin B12).



## 5 Discussion and conclusion

Examination of existing indicators which capture some element of nutritional quality, in reference to the different stages of the food and nutrition system highlight that there are a large number of indicators relevant to the latter stages of the system, and many fewer indicators relevant at the agricultural production stage. By applying relevant indicators to selected aquaculture production sub-systems, it is clear that the different indicators capture quite different aspects of nutritional quality, so using a combination of different indicators is important for comprehensive evaluation. The purpose here was to elucidate indicators which capture the ability of a production sub-system to nourish the most people, and which could potentially be useful for decision-making and prioritising of agricultural production sub-systems. Indicators, therefore, which reflect nutrient composition of species produced, diversity in nutrients produced, and the abundance or quantity of those nutrients, which are simple to calculate and interpret by decision makers is the optimal goal.

Nutritional yields are relatively simple to calculate, and reflect differences in both the nutrient composition of foods produced by different sub-systems, and the quantities in which those foods are produced. One potential disadvantage, depending on the policy context, is that the indicator is calculated for individual nutrients which does not allow for comparison of the nutritional quality of the production sub-system overall. From a policy and decision-making perspective, if production of a single nutrient is to be prioritised then interpretation is simple, for example, in the case study presented here, production system 13 (indigenous carp polyculture with mixed SIS) maximises nutritional yield of vitamin B12. However, if the policy priority is to maximise production of iron, zinc, calcium, vitamin A and vitamin B12, there is no clear 'frontrunner'. This limitation is addressed in the recently proposed PNA, which reflects an average nutritional yield weighted by the evenness in nutritional yields (Wood, 2017, forthcoming). The case study presented here has demonstrated that an important consideration is the degree of variability in nutritional yields for different nutrients, particularly those which are of priority or concern in a given context (e.g. existing micronutrient deficiencies). For example, rather than attempting to optimise nutritional yields across all nutrients, it is likely mainly of interest to focus decision-making on nutrients which exhibit large variability in nutritional yields across different sub-systems (and, therefore, selection of one sub-system over another is likely to have the greatest impact on the potential of the system to nourish people).

An advantage of the various nutritional diversity indicators, is that comparison across different sub-systems is simplified to a single value. The more important question though, is which measure of nutritional diversity best captures the ability of a system to nourish the most people. The case study presented here has shown that sub-systems with the same production diversity can exhibit large variability in other measures of nutritional quality. Therefore, whilst production diversity may provide an indication of nutritional diversity (and the simplest to calculate of all indicators examined here), it fails to capture some important elements. Building on production diversity, Shannon diversity and Simpsons index both incorporate a measure of evenness in abundance of different foods, but neither indicator reflects differences in the macro- or micronutrient content of foods produced in different sub-systems. NFD, MFAD and Q do, though, in different ways and with different interpretations. NFD reflects the distinctness in nutrient composition of species within a system; and MFAD is weighted by the number of nutritionally distinct foods within the sub-system. Therefore, maximising NFD or MFAD may be an appropriate goal for production sub-systems which are the primary source of food and nutrients for a particular group (for example, in settings with limited market access where household members rely on own production for consumption). In contrast, Q is weighted by the abundance or quantity of different foods from the production sub-system. In this sense, maximising Q is likely an appropriate goal, if seeking to maximise the potential of the sub-system to 'nourish' the most people with nutrients of interest.

In reality, there are multiple factors that must be considered when prioritising among alternative production sub-systems. For example, the cost of inputs, labour requirements, environmental impacts, yield and market value of the foods produced. Furthermore, decisions about which foods to produce are ultimately made by farmers, based on their own priorities, knowledge, skills and resources. However, there are a number of levers which can be influenced at a policy level to encourage certain practices for improving the nutritional quality of the outputs of production sub-systems (for example, subsidising cost of agricultural inputs needed for production sub-systems which maximise nutritional quality of outputs). Shifting thinking away from 'feeding people' to 'nourishing people' requires a simple measure of nutritional quality relevant at the production sub-system level which can be drawn on in policy and decision making. The indicators presented in this analysis, particularly nutritional yields, PNA and Q are likely to be of significant value as a means to achieving this goal.

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# 9. Discussion

The broad aim of this research was to understand how fish contributes to nutrition and food security in Bangladesh, how this is changing according to broader trends in aquatic food systems, and how fisheries might be better utilised to reduce malnutrition. The first two points are directly addressed in Chapters 2 and 4-7 (and summarised here in section 9.1 with specific emphasis on the contribution of the thesis to the literature). These findings, in addition to the analysis from Chapter 8, form the basis for discussion of the third point; how fisheries might be better utilised to reduce malnutrition. It is proposed that the answer to this question lies in applying a nutrition-sensitive approach to management of both capture fisheries and aquaculture. What this means in practice is discussed from a programming perspective in section 9.2 and from a policy perspective in section 9.3. The remainder of the discussion describes the strengths and limitations of the thesis (section 9.4), suggestions for future research (section 9.5) and the broader relevance of the thesis findings (section 9.6).

## 9.1. Summary of findings and assessment of contribution to the literature

The contribution of fish to nutrition and food security is best characterised according to the domains of food security; availability, access, utilisation and stability. Considerable emphasis in the existing literature is given to the availability domain. The most comprehensive data on fish availability in Bangladesh is from the Department of Fisheries official statistics, supplemented by additional survey data in the published literature and is summarised in section 2.5. This thesis makes new contributions through presentation of new data and analysis of the role of fish, primarily across the domains of access, utilisation and stability domains, as summarised below.

*Nutritional value of fish*

Chapter 4 provides the basis for understanding the contribution of fish to the utilisation domain of food security, through primary analysis of the nutrient composition of 55 common fish species in Bangladesh. Based on existing literature at the time of the study, this analysis has contributed comprehensive nutrient profiles on 18 species on which there were no prior data, and the juveniles of three species which are commonly consumed, and for which existing data were only on adults. Of the remaining 34 samples, some limited existing nutrient composition data were available, however, this analysis has significantly expanded the range of nutrients reported, particularly on minerals (iodine, selenium, manganese, sulphur, phosphorus and copper), and vitamin B12, vitamin E, vitamin D, folate and the components of vitamin A. No existing data were available on the vitamin B12 content of any fish from Bangladesh, so this is a particularly important contribution. Furthermore, detailed fatty acid profiles of ten species are presented for the first time. This data has since been included in the FAO/INFOODS database on biodiversity (FAO, 2016a), and the FAO/INFOODS global database on fish and shellfish (FAO, 2016b).

This study found that the nutritional value of fish is highly variable across species, particularly in terms of micronutrients. No single species was of resounding superior nutritional quality, across all nutrients, which emphasises the important role of biodiversity in fish consumption for meeting nutritional needs. One important determinant of nutritional value is which parts of the fish are used for the nutrient analyses. In line with the methodology used for food composition tables, ‘raw, edible parts’ (minus cleaning loss and plate waste) of the fish species, taking into consideration cultural norms and practices in Bangladesh, were used for analysis. SIS are often consumed whole, with head and bones, which is in stark contrast to large species, with only the flesh normally consumed. The nutritional consequences of this have been demonstrated in other work which analysed the anatomical parts of fish separately. For example, in Mola (*A. mola*), the eyes and viscera have an extremely high concentration of vitamin A compared to the body tissue (Roos et al., 2002). Bones from fish consumed whole provide a rich source of bioavailable calcium (Hansen et al., 1998; Roos et al., 2003a). It was outside the scope of this study to analyse anatomical parts of individual species, however, the link between overall nutritional value and edible parts is evident in the results presented in Chapter 4. Species that made large contributions to RNIs (>25% of daily RNI) for vulnerable groups across several micronutrients, were all SIS, with the edible parts including head and bones. Large species, of which normally only the flesh is consumed, made generally smaller contributions for fewer micronutrients.

Samples collected for this study also formed the basis of analysis for the measurement of total iron and haem iron in fish, not presented as a chapter in this thesis but published elsewhere (Wheal et al., 2016). Haem iron, found exclusively in ASFs is more bioavailable than non-haem iron, found in both animal and plant foods, and so can make a greater contribution to human physiological needs. The haem iron content of animal flesh food is normally assumed to be 40% of total iron (Monsen et al., 1978). However, other studies have shown that the haem iron content of animal flesh foods varies widely across species (Schönfeldt & Hall, 2011). The emphasis in the existing literature on haem iron content is on terrestrial animals, particularly red meat. In the limited literature on haem iron content in fish, the methods of analysis are highly varied, limiting comparability. Iron (total, haem and non-haem) content of 26 fish samples (mostly SIS) from the study presented in Chapter 4 was measured using improved analytical methods (direct measurement, rather than the more common indirect methods of either inferring from the molecular weight of haematin, or subtracting non-haem iron from total iron). Haem iron content of these samples ranged from 18% to 93% of total iron, and in 18 out of the 26 samples, the haem iron proportion was 50% or higher. Assuming a constant of 40% of total iron as haem iron in fish, the bioavailable iron in these fish samples would be underestimated, on average by 16% (Wheal et al., 2016). These results support earlier findings that assuming a haem iron content of 40% for all fish fails to express the large variation that exists across ASFs, including fish (Carpenter & Clark, 1995; Schönfeldt & Hall, 2011).

*Fish in food-based approaches to address malnutrition*

Chapter 5 offers an opportunity by which the contribution of fish to nutrition and food security could be enhanced through the utilisation domain. From the literature, it is clear that improving nutrition among women of childbearing age, and infants and young children in the first two years of life, offers great benefits in interrupting the intergenerational cycle of malnutrition (Bryce et al., 2008). As described in section 2.2.2, food-based approaches have long been recognised as a key sustainable approach to the alleviation of malnutrition (Thompson & Amoroso, 2011). ASFs are particularly noteworthy as they provide a concentrated source of several highly bioavaiable micronutrients. The focus in existing literature, however, is largely limited to terrestrial ASFs. Chapter 5, therefore, makes a significant contribution to this area of research by providing a concrete example of the potential of a local food-based approach using fish. This chapter demonstrates how large improvements in nutrient intakes among vulnerable groups are possible through adapation of traditional recipes to include fish and other local nutrient-rich foods. Such an approach also offers many other benefits for communities. For example, simple processing methods and use of local ingredients encourage development of local supply chains and associated local economic and social benefits. This approach also has great potential to influence nutrition via the women's empowerment pathway (see Figure T3). For example, engaging rural women's groups in processing of ingredients can increase women's income and skills. Such products can also contribute to promoting traditional food cultures and decrease reliance on imported, costly products which are often the case with supplementation programmes. Whilst theoretical in nature, Chapter 5 highlights a culturally appropriate and feasible opportunity to improve dietary quality, particularly among women and young children. This concept has received considerable interest among the development community in Bangladesh and has since attracted funding for further development and trial distribution (Shiree, 2013), though no project evaluation has been made available. As part of this project, one of the products has received formal approval from the Bangladesh Standards and Testing Institute (the national food safety authority) for small-scale commercial production whilst the second product is still under consideration. Authors of the published mansucript in Chapter 5 have also been contacted by organisers of the Nutrition For Growth global initiative and The World Bank, to investigate options for further research of the proposed products, both in Bangladesh and other countries in South Asia. The products therefore appear to have considerable potential, but require significant further research to evaluate production feasibility and clinical effectiveness for prevention or treatment of malnutrition.

*Contribution of fish to diets*

Chapter 6 significantly advances knowledge on the contribution of fish to the access and utilisation domains, particularly at the intra-household level. As described in the literature review, the contribution of fish to nutrition and food security is undervalued (HLPE, 2014). This is likely due in part, to a lack of data on its contribution to dietary patterns on any significant scale. Food consumption surveys are resource-intensive to conduct, and therefore, often conducted with small sample sizes in defined geographic areas and seasons, limiting generalisability of results. However, a recent large nationally representative survey of rural Bangladesh (comprising 77% of the countries' total population (BBS, 2015)), presented a unique opportunity to conduct a detailed descriptive analysis of the role of fish in diets across different age, gender and wealth groups, as well as geographical variation. This analysis confirmed that fish is by far the most important ASF in diets, across all age, gender and wealth groups, and across all geographic regions in Bangladesh. However, there is considerable variation in consumption across these groups. Mean consumption by the poorest wealth quintile was around half that of the richest. There was similarly large variation in fish consumption between geographic regions, likely reflecting affordability (regions with the lower intakes are also regions with higher poverty rates) and availability of fish (regions with lower intakes are less geographically suited to fish production, either from capture fisheries or aquaculture). Females had a consistently lower average fish consumption compared to males, though the differences were not significant for those aged <15 years, or among the richest households ($P>0.05$). This analysis also highlights the role of dried fish in diets, particularly for the poor. Dried fish accounted for a large proportion of total fish (9-29%) consumed across all age, gender and wealth groups. There was no significant difference in the quantity of dried fish consumed by different wealth groups, though it comprised a larger proportion of total fish among the poor. Dried fish provides a concentrated source of micronutrients and potentially reduces the effects of seasonal availability of fresh fish (due to its longer shelf-life). This reflects an important contribution of fish to the stability domain of nutrition and food security, by providing a nutrient-rich food source at times of potential food shortage. The analysis also demonstrated differences in fish procurement, particularly across wealth groups. Poorer households were more reliant on fishing activities (capture fisheries) whereas richer households were more reliant on aquaculture, highlighting important differences in the contribution of these two fisheries subsectors to livelihoods of different population groups. When considering the source of fish production (either capture fisheries or aquaculture), non-farmed fish make a greater contribution to micronutrient intakes compared with farmed fish in rural Bangladesh. This is likely due to the large diversity of species within the non-farmed fish category, as well as differences in the edible portion of SIS which make up a large proportion of the non-farmed category compared with farmed large fish.

*Temporal changes and links to agricultural policy*

Chapter 7 demonstrates the impact of the current fisheries policy on access and utilisation domains of nutrition and food security over time (thereby reflecting the stability domain). This analysis is an important extension from the existing literature on stability of fish availability, to stability of nutrient availability. This is perhaps the most substantial contribution of the thesis to the broader literature, as it very clearly challenges the dominant rhetoric within agriculture that ‘more is better’. Though similar concerns had been raised in the existing literature on capture fisheries and aquaculture (see for example (Golden et al., 2016)), no such empirical analysis had been conducted. Chapter 7 demonstrates that in terms of dietary patterns, the current approach to capture fisheries and aquaculture management is less than optimal. Fisheries policy in Bangladesh is focused on increasing production and productivity from the aquaculture sector. This has no doubt been successful; fish consumption has increased by 30% from 1991 to 2010 in the face of an expanding population. However increased production and consumption of fish have not improved the nutritional quality of diets, in terms of micronutrient intakes, as was likely assumed would be the case. This demonstrates the need for specific steps in agricultural programmes and policies towards improving nutrition. These findings also confirm the significance of the shift in thinking from ‘food security’ to ‘food and nutrition security’ introduced in section 1.1. It is not enough to have stable availability, access and utilization of food in general; rather, it is essential to have stable availability, access and utilisation of micronutrient-rich foods that meet the needs for human health.

## 9.2. A nutrition-sensitive approach to capture fisheries and aquaculture

This thesis demonstrates that the full potential of fish for reducing malnutrition and improving dietary quality in Bangladesh has not been realised. A nutrition-sensitive approach to management of capture fisheries and aquaculture offers an opportunity to rectify this. Such an approach seeks to maximise the contribution of these sectors to improvements in nutrition. As described in section 2.3.1, there are several pathways through which capture fisheries and aquaculture influence nutrition (see also Figure T5). These pathways mirror those that describe more broadly how agriculture can influence nutrition (see Figure T3 section 2.2.1). There is widespread consensus on how such pathways should be utilised in practice to improve nutrition, summarised recently in a FAO report titled ‘*Synthesis of Guiding Principles on Agriculture Programming for Nutrition’* (2013c). Given that this is a relatively new area of research, this consensus document reflects best-practice principles, in the absence of a strong evidence base (Webb & Kennedy, 2014). These guiding principles are broadly applicable to all agricultural systems, including capture fisheries and aquaculture. Following publication of these guiding principles, an international consultation process, used this guidance document to distil ten key programming principles and five key policy principles for integrating a nutrition-sensitive approach to programmes and policies (see Box 1 below), which form the basis of discussion here (Herforth & Harris, 2014). These policy and programming principles reflect consensus of the international 800+ member Ag2Nut (Agriculture to Nutrition) online community of practice, the UN SCN, the FAO, and workshop participants of the Comprehensive Africa Agriculture Development Programme (CADDP) of the African Union. It therefore represents a broad range of policy makers, researchers and programme implementers from different regions. These policies are also consistent with the approach recommended in other international policy documents, including the Compendium of Actions for Nutrition (United Nations Network for SUN/REACH Secretariat, 2016).

**Box 1: Programming and policy principles of nutrition-sensitive agriculture**

Programming Principles

1. Incorporate explicit nutrition objectives and indicators into design.
2. Assess the local context.
3. Target the vulnerable and improve equity.
4. Collaborate and coordinate with other sectors.
5. Maintain or improve the natural resource base, particularly water resources.
6. Empower women.
7. Facilitate production diversification, and increase production of nutrient-dense crops and livestock.
8. Improve processing, storage, and preservation of nutritious food.
9. Expand market access for vulnerable groups, and expand markets for nutritious foods.
10. Incorporate nutrition promotion and education that builds on local knowledge.

Policy Principles

1. Increase incentives (and decrease disincentives) for availability, access, and consumption of diverse, nutritious, and safe foods.
2. Monitor dietary consumption and access to safe, diverse, and nutritious foods.
3. Include measures that protect and empower the poor and women.
4. Develop capacity to improve nutrition through the food and agriculture sectors.
5. Support multi-sectoral strategies to improve nutrition.

Source: (Herforth & Harris, 2014).

This thesis provides the knowledge required for practical implementation of several of these programming and policy principles related to capture fisheries and aquaculture in Bangladesh and other countries with rich fisheries resources.

In practical terms, a vital step towards reducing malnutrition is increasing access to fish among certain population groups (programming principles 3 and 9). This analysis has demonstrated that non-farmed species, particularly SIS show the greatest potential to improve nutritional quality of diets in Bangladesh. 'Fish' therefore, should not be considered a broad homogenous food group; interventions targeted at vulnerable population groups should prioritise nutrient-rich species including SIS, as well as promoting diversity in species available. A specific recommendation related to the aquaculture sector is therefore to increase production of nutrient-rich fish species, particularly SIS (programming principle 7). Basic technology for including SIS in polyculture systems with carp species already exist. Indeed polyculture systems including the vitamin A-rich species Mola *(A. mola)* has been shown to be a cost-effective strategy for reducing micronutrient malnutrition (Fiedler et al., 2016). However, scaling of this technology requires significant further research on breeding in captivity of these species, and transfer of this technology to private sector hatcheries. This is a necessary step if this carp-SIS polyculture system is to influence availability of these species on a large scale. Related to this, though not addressed specifically in this thesis, are strategies that improve nutrient composition of commonly farmed fish. For example, other studies have shown that the fatty acid content of farmed fish as consumed, is strongly related to the fatty acid content of fish feed (Nichols et al., 2014). This reflects another approach to increasing nutrition-sensitivity of aquaculture systems. Furthermore, a related recommendation is to diversify production systems, not only in terms of species, but also in terms of nutritional diversity. In other words, fish production systems should be designed to produce a range of different fish species which are rich sources of a range of nutrients, particularly micronutrients which are of public health importance in a given context. Therefore, inclusion of a single SIS species in existing carp polyculture systems is not sufficient to achieve this goal, rather a range of mixed SIS should be included in diverse production systems. Implementation of such as intervention (e.g. technology transfer to fish farmers for diversifying production systems) should also incorporate a level of nutrition education, specific to the local context (programming principles 2 and 10), and include specific nutrition objectives in programme design which are monitored and evaluated (programming principle 1). This could, for example, draw on the data presented in Chapter 4, in terms of the nutrition and health benefits of particular fish species. Education and promotion material should also build on local knowledge. For example, indigenous knowledge of consumption of vitamin A-rich Mola *(A. mola)* fish as a cure for night blindness (a clinical manifestation of vitamin A deficiency) has led to the common belief that Mola is “good for your eyes” (Thilsted, 2013).

This thesis has also demonstrated that households of the poorest two wealth quintiles should be targeted, and particularly households in Rangpur and Rajshahi divisions where fish consumption is well below the 60 g/person/day national recommendation (programming principle 3) (BIRDEM, 2013). These vulnerable groups should therefore form the target groups for development programmes that aim to increase availability and access to fish.

The importance of dried fish in dietary patterns, particularly for the poor was demonstrated through the analysis presented in Chapter 6. Until now, very little was known about consumption patterns of dried or fermented fish products. Such products provide a concentrated source of micronutrients, and also have a long shelf life compared to fresh fish, thereby making an important contribution to nutrition and food security, also in periods when access to fresh fish is limited. However, dried and processed fish value chains receive little attention in development programmes or policies. Improving quality and safety of these products, and increasing access to these products by vulnerable groups are likely an effective strategy to improve dietary quality. For example, a locally produced fish-based product in Cambodia has been shown to be an effective ready-to-use therapeutic food for treatment of severe acute malnutrition among infants (UNICEF, 2017). The fish products presented in Chapter 5 offer a practical example of how such products, suited to the context of Bangladesh could be used. Characterisation and improving quality and safety along the dried and processed fish value chains should therefore be a priority area for further research and should be incorporated in applicable programmes (programming principle 8). Chapter 5 also highlights the various ways in which this approach could contribute to women's empowerment (programming principle 6), through, for example, engaging rural women's groups in processing of raw ingredients and even the entire production process.

Of course an essential principle for maintaining and improving the contribution of capture fisheries and aquaculture to nutrition is the maintenance of the natural resource base (programming principle 5). Habitat conservation features in the National Fisheries Policy (Ministry of Fisheries and Livestock, 1998), however, implementation and enforcement remain a problem. There is also a lack of coherence across agricultural sectors. For example, flood control embankments are used for the protection of rice production, yet these embankments restrict fish migration and interrupt breeding cycles, resulting in reductions in fish biomass and biodiversity (Thompson et al., 2002). Capture fisheries are also subject to environmental degradation due to chemical run-off from industry and infrastructure development, including dams and bridges. Capture fisheries and aquaculture programmes, and indeed broader agricultural and non-agricultural programmes must take steps to minimise negative environmental impacts that reduce availability and quality of fish. This requires policy coherence across multiple sectors including but not limited to fisheries, environment, transport, and infrastructure (programming principle 4).

Implications of the thesis findings relevant to nutrition-senstive policy principles are discussed in the following section.

## 9.3. Policy implications of the research

The current international momentum behind improving nutrition (see section 2.1) provides a strong basis for advocating for policy change to improve nutrition outcomes from capture fisheries and aquaculture programmes in Bangladesh. Specific policy recommendations based on the findings of this thesis, relevant to the consensus policy principles (see Box 1) are described here.

As described in Chapter 8, what is produced by farmers is dependent on a number of factors including, for example, yields, labour requirements, costs of inputs and market value of products. Providing incentives (and reduction of disincentives) to produce nutrient-rich foods offers one important policy lever to influence such decisions (policy principle 1). For example, existing agricultural policy in Bangladesh includes subsidised cost of fertilisers, primarily for rice production (Naher et al., 2014). A more nutrition-sensitive approach would prioritise subsidising the cost of inputs required for production systems with the greatest potential to nourish the most people, such as carp polyculture systems including Mola *(A. mola)* or mixed SIS (Chapter 8). Chapter 8 offers a way forward for implementing such an approach by identifying various indicators which could serve as tools for decision makers to prioritise such systems. 'Nutritional yield', 'potential nutrient adequacy' (PNA) and 'Rao's quadratic entropy' (Q) are three indicators that capture the ability of outputs of a production system to 'nourish the most people', and are likely to be of significant value.

The analysis presented in Chapter 6 highlights the value of intra-household data for understanding how dietary patterns differ among age and gender groups, providing insights as to how to target interventions to reach the most vulnerable. Rarely in low and middle-income countries is this kind of data available on a nationally representative scale. Due to popular demand, this particular survey was repeated in 2015-2016, though there are no explicit plans to repeat it at regular intervals going forward. The BBS carries out the HIES surveys at regular intervals (every five years, as is done in many countries), which also provide valuable data on dietary patterns of households, but do not allow for understanding dietary patterns within households. An extension of this survey, to collect regular data on intra-household dietary patterns, perhaps among a sub-set of households, would provide valuable data to monitor changes in dietary patterns among vulnerable groups (policy principle 2).

Key policy principle three of a nutrition-sensitive approach to agriculture highlights the need to protect and empower vulnerable groups, including the poor and women (see Box 1). Such an approach exists in some nutrition and health policy areas in Bangladesh. For example, the National Nutrition Service (NNS) targets supplementary feeding among nutritionally vulnerable groups (pregnant women and young children), and various food provision programmes specifically target the poor (Naher et al., 2014). However, there is significant scope to expand this principle within agriculture, and particularly with the fisheries sector. A recent survey from Bangladesh suggests that women contribute around 22% of the total labour for management of homestead pond aquaculture production systems (Murshed-e-Jahan et al., 2015). However, cultural factors inhibit them from interacting with an almost completely male-dominated extension service. Women are also heavily involved in more distal components of fish value chains, particularly in processing and distribution of dried fish and are exposed to extremely poor working conditions (Belton et al., 2014a). Policies that protect women participating in fish value chains, and encourage opportunities for participation through gender-sensitive skills development are required.

A key strength of the agricultural sector in Bangladesh is the large and decentralised agricultural extension network within both public and private sectors (Naher et al., 2014). Agricultural extension is a term used to describe the workforce of agricultural scientists who have direct and regular contact with farmers and who provide education on improved agricultural practices and in some cases, improve access to inputs such as seeds. Expanding the scope of practice of agricultural extension workers to include an element of nutrition education has been identified as one potential strategy for improving nutrition outcomes of agricultural interventions (contributing to policy principles 4 and 5) (FAO, 2013c). Despite the large extension workforce in Bangladesh offering great potential to reach vulnerable groups, the service is still beset by a lack of operational funds among other concerns (The World Bank, 2005). Therefore, attempts to expand the scope of work of extension agents must be matched by appropriate increases in resources so as not to exert additional pressure on services. There are however, a number of different models of delivery (see for example (Kadiyala et al., 2016)) and a substantial literature base from which lessons can be learnt in improving the capacity of the agricultural extension network (including fisheries and aquaculture) in Bangladesh to improve nutrition (Fanzo et al., 2015; FAO, 2016c).

## 9.4. Strengths and limitations of the research

The strengths of this research lie in its broad scope of analysis from details of the nutritional value of fish, right up to the ‘big-picture’ exploration of temporal trends in national diets and associated policy implications. New primary data on nutrient composition of important fish species are presented, alongside secondary analysis of existing data but from an entirely new perspective. An important strength of this study is the use of large nationally representative survey data (both the BIHS survey – for rural areas, and the HIES surveys). Standard epidemiological methods were applied in analysis, including adjusting for sample weights, cluster design (in the HIES surveys) and controlling for age, sex and geographic location in linear regression models. Results were all generally robust to sensitivity analysis (with minor deviations described in relevant text and tables). Another strength is the use of repeated cross-sectional studies to present temporal trends across three time points. Examination of historical trends over this relatively long time frame (20 years) enabled a reflection on links to policy decisions and how future policies might be oriented to improve health and nutrition outcomes. Finally, the strong quantitative analyses of RQs 1-4 are complemented by the more conceptual approach of RQ 5 (presented in Chapter 8) as a way forward. In this sense, the thesis provides a comprehensive and detailed conceptualisation and analysis of the 'problem' from multiple angles, complemented by pragmatic policy solutions going forward.

Limitations in this research largely pertain to the methodologies used in primary data collection. The BIHS survey forms the basis for analysis in Chapter 6, particularly intra-household food consumption data collected by a single 24-hour recall. Note that a single 24-hour recall is not sufficient to estimate an individual's usual intake of food or nutrients, but when using a representative sample (as is the case here), this method is appropriate to estimate mean intakes of population groups (Gibson, 2005). One limitation of the methodology in data collection, was that all food consumption data was obtained from a single household member respondent – usually an adult female responsible for meal preparation. This may have introduced a form of respondent bias. For example, when an individual is reporting food consumption for all household members, she may be less likely to report differences in dietary patterns between individuals. Particularly in large households, reporting individual consumption patterns for sometimes more than ten household members is likely to be cumbersome for the respondent and may lead to inaccuracies in reporting. The data in this survey were collected over a six month period, so is not seasonally representative (as the HIES is). Furthermore, no information is provided in the survey documentation regarding the prevalence of non-response. However, this can be assumed to be low, given that the survey was conducted face-to-face, that the survey was endorsed by all local government officials, and the culture of Bangladeshi people who are generally very open to participation in such activities.

The HIES surveys form the basis of analysis in Chapter 7, and are based on either repeated 48-hour recalls over a 14 day reference period (2000 and 2010), or repeated 24-hour recalls over a 30 day reference period (1991). Generally, a longer reference period is considered more reliable than shorter reference periods, though the increased interviewer and interviewee time, burden and fatigue associated with the longer reference period may also reduce reliability (Smith et al., 2014). The increase in recall period in later survey years is likely to underestimate consumption (some consumption may be overlooked over a longer recall period) (Smith et al., 2014). Changes in nutrient intakes presented in the analysis are therefore more likely to be smaller than actual temporal changes.

There are also limitations pertaining to the nutrient composition data. Nutrient composition of foods is known to vary due to a great number of factors, including season, stage of the life cycle, local environmental conditions and individual variation. Within-species variation in micronutrient composition was identified in previous analyses (Roos et al., 2003b), so the sampling method of single pooled samples limits representativeness of the results. The effects of this limitation were reduced to an extent by the use of relatively large pooled samples (~ 2000 g per sample which for SIS, depending on the species, represents around 400-2000 individual fish). This does however, remain a limitation of the results and a priority for future analyses. Resource constraints prevented steps that could minimise some of this variation (such as analysing samples across different seasons or sampling from a number of geographic locations). A specific limitation relates to analysis of vitamin A composition. Vitamin A exists in a number of different chemical forms such as β-carotene, dehydroretinol and retinol – all of which have different biological activity levels. In this study, five different components of vitamin A were analysed in fish samples, and combined with appropriate conversion factors were used to estimate the total vitamin A content in retinol activity equivalents. A much less studied chemical form of vitamin A is 3,4-didehydroretinol (also known as vitamin $A_2$), which is only found in fish (and animals that eat fish), and which has been found to have 119-127% of the biological activity of retinol (Riabroy et al., 2014). Unfortunately, it was outside the scope and available resources for this study to analyse vitamin $A_2$ composition of fish, with the implication that the contribution of fish to vitamin A requirements is likely to be under-estimated. Nutrient composition also formed the basis of analysis of nutrient contributions analysed in Chapters 5-8. However, nutrient composition data were not available for all fish species recorded in the surveys, and so substitute data for nutrient composition of similar fish species were obtained from alternative sources. However, this is not likely to have significantly impacted results or interpretation.

One limitation related to the overall aim of assessing the contribution of fish to nutrition and food security, is that this thesis does not explicitly consider access to fish in terms of affordability or fish prices. This is, however, largely covered in detail elsewhere in the literature and discussed in text where relevant (Dey, 2000; Dey et al., 2010; Toufique & Belton, 2014).

A further limitation of the overall approach of this thesis is that it is entirely quantitative in nature. A growing field of research on ‘mixed methods’ highlights the value of integrating qualitative and quantitative research findings in public health (Padgett, 2012). Complementing the quantitative data presented in this thesis with some qualitative data from relevant stakeholders (particularly pertaining to how fisheries might be better utilised to improve malnutrition) may have provided a stronger basis for future research recommendations described in the following section. This was however, considered outside the scope of the thesis.

## 9.5. Suggestions for future research

At a more theoretical level, a truly nutrition-sensitive approach to capture fisheries and aquaculture requires a paradigm shift: the focus of agricultural policy must move beyond maximising quantity, to also maximising nutritional quality. Such a shift is enormously complex and likely to require numerous incremental changes over time. It could be said that this shift has already commenced, given recognition of the importance of nutritional quality in numerous high level international reports and policy documents (see for example (FAO & WHO, 2014, 2015; Global Panel on Agriculture and Food Systems for Nutrition, 2016; IFPRI, 2016; Jones, 2015), suggesting the time is ripe to advance such shifts at more local levels.

It is widely accepted that truly integrating agriculture and nutrition requires that these sectors can communicate in a ‘common language’. An important field of research for enabling such communication, is that of indicators such as those described in Chapter 8 (Masters et al., 2014; Pingali & Ricketts, 2014). Two important areas for further research beyond that presented in Chapter 8 are proposed; stakeholder engagement involving agriculture, nutrition and policy experts (section 9.5.1) and multi-criteria decision analysis (MCDA, section 9.5.2).

### 9.5.1. Stakeholder engagement

Numerous high quality peer-reviewed articles on nutrition-sensitive indicators alone are not likely to lead to wide integration of their use in agricultural programmes and policies. Relevant stakeholders must have ownership over such indicators and they must be adaptable to different contexts. It is therefore recommended that as this field evolves, qualitative research on the relevance and usability of such indicators involving key stakeholders in different contexts (mainly end users including agriculturalists, nutritionists and policy makers) be conducted. Methods such as stakeholder interviews and focus group discussions on barriers and enablers of their use should be utilised.

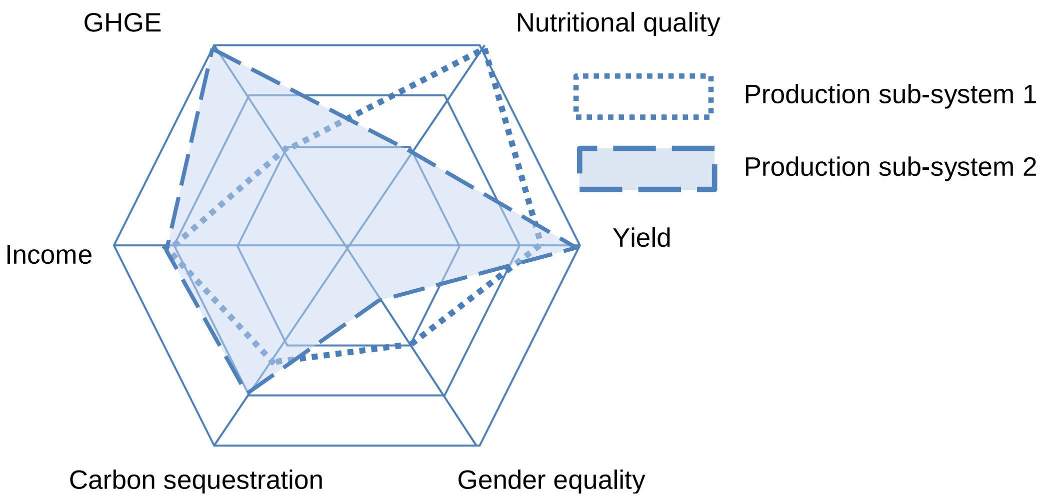
### 9.5.2. Multi-criteria decision analysis

Whilst the various indicators of nutritional quality presented in Chapter 8 show great promise as useful tools to aid in decision making and prioritisation of agricultural production sub-systems, they will not, and should not be the sole basis for decision making and investment in a particular production sub-system. Rather, investment decisions should be made following consideration of all of the relevant outputs of a food production systems including nutritional quality, productivity, economic value, environmental impacts, and social impacts.

However, the importance of each of these factors in decision making will not necessarily be equally distributed, and is highly likely to be context-specific.

One such framework that allows consideration of multiple outcomes simultaneously with weighted importance is MCDA (Baltussen and Niessen, 2006). MCDA is a tool that has been applied to decision making in many other disciplines including agricultural and environmental science, however, it has rarely been applied within the health setting (Baltussen & Niessen, 2006). MCDA requires development of a performance matrix whereby several options or interventions (such as different agricultural production sub-systems) are listed alongside their corresponding scores on a set of selected criteria for comparison (including one or more indicators of nutritional quality). A schematic representation of the weighted scores for several criteria related to two agricultural production sub-systems is shown in Figure T9.

Figure T9: Schematic representation of the use of multi-criteria decision analysis to compare different production sub-systems.




Adapted from (Remans et al., 2011).

It then must be considered whether particular trade-offs are acceptable; that is, the extent to which good performance in one indicator can compensate for poor performance in another. The various methodologies used in application of the MCDA are largely dependent on the context and scale of the options to be considered, the nature of the criteria on which they are to be compared, and the representation and values of stakeholders in the outcomes of the various options, who may or may not have conflicting motivations (e.g. policy makers, farmers, industry, health professionals). MCDA may represent a useful tool for inclusion and consideration of indicators of nutritional quality (such as those presented in Chapter 8), amongst other priorities of a food production system. This represents a valuable area for further research in linking measures of nutritional quality to policy and decision making in practice.

## 9.6. Broader relevance

An important element of this thesis is its framing of the analysis in Bangladesh as a case-study of a broader global issue. Firstly, malnutrition is a global problem, affecting nearly every country in the world, the burden of which is particularly felt in low and middle-income countries (IFPRI, 2016). Secondly, the contribution of fish to diets, nutrition, health and food security around the world is largely undervalued (HLPE, 2014). Thirdly, the transition of a fish supply dominated by species from capture fisheries, towards a supply dominated by farmed species is a global phenomenon (FAO, 2016d). The findings, therefore, are likely to reflect similar trends occurring in many countries around the world, particularly those where fish plays a significant role in dietary patterns, many of which are ‘developing’ countries (Kawarazuka & Béné, 2011). The implications therefore, particularly the need for a nutrition-sensitive approach to capture fisheries and aquaculture are of global relevance. This is particularly the case in many low and middle-income countries where expansion of aquaculture forms a component of the national development agenda.

This analysis has also served to highlight the unique nutrient profiles of indigenous foods, and the large potential of context specific food-based approaches (such as promotion of the local, nutrient-rich food products presented in Chapter 5). Of broader relevance is that this potential is often overlooked, related to lack of data on nutrient composition of indigenous foods, including variation in nutrient content across different species or varieties, particularly in resource-poor settings (de Bruyn et al., 2016). Food-based solutions to dietary problems are often transferred across contexts without sufficient consideration of cultural appropriateness. For example, dairy is considered the most important dietary source of calcium in high-income countries, and it has been increasingly promoted as a solution to calcium deficiency across many low-income regions (Wang & Li, 2008). This is, however, not necessarily a cultural appropriate approach; given the high prevalence of lactose intolerance in many low-income regions, including Asia and the lack of dairy in traditional diets in many regions. In the case of Bangladesh, promotion of consumption of calcium-rich SIS is likely a much more culturally appropriate and sustainable approach. This is of broader relevance to other countries where a lack of data on nutrient composition of local foods may inhibit identification of more culturally appropriate solutions. Investment in profiling nutrient composition of indigenous foods, including different species and varieties should be prioritised in order to aid the identification of context-specific food-based approaches to improve nutrition.

The analysis presented in Chapter 8 on indicators of nutritional quality of agricultural production systems also has broader relevance beyond aquaculture production systems in Bangladesh. The various indicators presented could be useful tools for prioritising and decision making around agricultural production systems generally, particularly in contexts suffering from micronutrient deficiencies. Inclusion of such indicators as standard in monitoring and evaluation of agricultural production systems would be a significant step in shifting away from the focus on yields or quantity, towards valuing nutritional quality of agricultural production.

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## Appendix 1

Fatty acid composition of fish species presented as % of total fatty acids.

| Nutrient[a] | Fatty acid content as % of total fatty acids in raw edible parts of selected fish species | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ilish | Jatka Ilish | Jat Punti | Kajuli, Bashpata | Koi | Modhu Pabda | Parse | Rani, Bou | Thai Pangas | Majhari Thai Pangas |
| Total FA | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Total SFA | 46 | 48 | 31 | 43 | 39 | 38 | 51 | 37 | 42 | 36 |
| Total MUFA | 36 | 32 | 34 | 41 | 46 | 44 | 31 | 37 | 43 | 29 |
| Total PUFA | 19 | 20 | 35 | 17 | 15 | 18 | 18 | 25 | 15 | 36 |
| | | | | | | | | | | |
| C12:0 | 0.1 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | nd | nd |
| C13:0 | nd | nd | nd | nd | nd | 0 | nd | 0 | nd | nd |
| C14:0 | 8.0 | 9 | 1 | 5 | 2 | 2 | 4 | 4 | 3 | 4 |
| C15:0 | 0.3 | 0 | 1 | 1 | 0 | 1 | 2 | 1 | 0 | nd |
| C16:0 | 29.8 | 29 | 18 | 26 | 26 | 24 | 38 | 25 | 29 | 22 |
| C17:0 | 0.2 | 0 | 1 | 1 | 0 | 1 | 1 | 2 | 0 | 2 |
| C18:0 | 6.8 | 8 | 8 | 9 | 8 | 8 | 4 | 1 | 9 | 9 |
| C20:0 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | nd |
| C22:0 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | nd |
| C24:0 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | nd | nd |
| | | | | | | | | | | |
| C14:1 | 0.1 | nd | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |
| C15:1 | nd | nd | 0 | 0 | nd | 0 | 0 | 0 | nd | nd |
| C16:1 | 10.9 | 10 | 3 | 5 | 3 | 5 | 13 | 7 | 1 | 4 |
| C17:1 | 0.1 | nd | 0 | 1 | 0 | 1 | 1 | 1 | 0 | nd |
| C18:1n-6 | nd | nd | nd | nd | 0 | 0 | 0 | 0 | nd | nd |
| C18:1n-7 | 3.6 | 4 | 2 | 2 | 2 | 3 | 3 | 3 | 1 | 3 |
| C18:1n-9 | 19.2 | 16 | 25 | 29 | 39 | 30 | 10 | 19 | 39 | 13 |
| C20:1n-9 | 1.3 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | nd |
| C20:1n-11,13 | nd | nd | 0 | 0 | 0 | 0 | 0 | 1 | 0 | nd |
| C22:1n-9 | 0.1 | nd | nd | nd | 0 | nd | nd | nd | 0 | nd |
| C22:1n-11,13 | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| C24:1 | 0.1 | 0 | nd | nd | 0 | nd | 0 | nd | nd | nd |
| | | | | | | | | | | |
| C18:2n-6 (LA) | 0.6 | 1 | 24 | 3 | 9 | 8 | 2 | 4 | 10 | 6 |
| C18:3n-6 | 0.2 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | nd |
| C20:2n-6 | nd | nd | nd | 0 | nd | 1 | nd | nd | 0 | nd |
| C20:3n-6 | 0.3 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 |
| C20:4n-6 | 0.9 | 1 | 2 | 2 | 0 | 2 | 1 | 2 | 0 | 4 |
| C22:4n-6 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 |
| C22:5n-6 | 0.3 | 0 | nd | nd | nd | nd | 0 | nd | nd | nd |
| Total n-6 PUFA | 2.5 | 3 | 28 | 7 | 11 | 12 | 4 | 8 | 12 | 13 |
| | | | | | | | | | | |
| C18:3n-3 (ALA) | 0.1 | 0 | 2 | 3 | 1 | 1 | 3 | 3 | 1 | 5 |
| C18:4n-3 | 0.6 | 1 | 0 | nd | 0 | nd | 2 | 0 | nd | nd |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C20:3n-3 | nd | nd | nd | 0 | nd | 0 | 0 | 1 | 0 | nd |
| C20:4n-3 | 0.6 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| C20:5n-3 (EPA) | 6.2 | 5 | 1 | 1 | 0 | 1 | 3 | 1 | 0 | 3 |
| C21:5n-3 | nd | nd | nd | nd | nd | nd | nd | nd | 0 | nd |
| C22:5n-3 | 1.4 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 2 |
| C22:6n-3 (DHA) | 1.6 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 4 |
| Total n-3 PUFA | 10.5 | 11 | 5 | 8 | 3 | 4 | 10 | 7 | 1 | 15 |

[a] FA, fatty acid; SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; LA, Linoleic acid; ALA, α-Linolenic acid; EPA, Eicosapentaenoic acid; DHA, Docosahexaenoic acid.
nd, Not detected. Limit of detection for all fatty acids: 6 mg/100 g. Value of 0 indicates some quantity was detected but it rounds to 0% of total FA.
n = 1 pooled sample.